# EXTENDING THE LIFE OF ASPHALT PAVEMENTS

## Michigan DOT Project # OR09086A

# PART II

# Implementation Plan:

# Mitigation Strategies & Demonstration/Pilot Projects

## Products P1 and P3

## May 2011

# Table of Contents

**Section Title** **Page No.**

# LIST OF TABLES

**Table Number** **Page No.**



# LIST OF FIGURES

**Figure Number** **Page No.**

# Implementation Plan:

# Mitigation Strategies and Demonstration/Pilot Projects

## Section 1: Introduction

This report presents the mitigation strategies and demonstration/pilot projects that are recommended to enhance performance and reduce the occurrence of pavements exhibiting accelerated aging or deterioration. The report is grouped into two parts, following the introduction; (1) mitigation strategies and (2) demonstration/pilot projects. The mitigation strategies are those items/features that can be implemented in a reasonable amount of time to extend pavement service life and/or reduce accelerated aging. The demonstration/pilot projects provide additional data to increase the understanding of the mitigation strategy and its effect on construction and performance prior to implementation. The pilot projects also demonstrate the value and effectiveness of the mitigation strategy, where appropriate.

The following summarizes the mitigation strategies and demonstration/pilot projects recommended for enhancing flexible pavement performance. The first three are considered high priority mitigation strategies that can have a significant impact on improving flexible pavement performance without significantly increasing construction costs. Table 1 summarizes some of the details about each mitigation strategy. [Table 1 is located at the end of the Introduction; page 8.] It is recommended that MDOT discuss and debate these mitigation strategies with industry to obtain their support.

1. ***Develop and Enforce a Longitudinal Construction Joint Specification***. All projects with poor performance exhibited excessive longitudinal centerline cracking. This mitigation strategy is being recommended to reduce the length and severity of longitudinal centerline cracking and deterioration (raveling) along the construction joint.

   Nearly all of the DOT individuals interviewed identified the centerline construction joint as being a major concern based on their experience. This helps confirm the observation from the distress data that longitudinal centerline cracking was very prominent on most of the projects with high distress index (DI) values.

   A demonstration project is recommended for this mitigation strategy to confirm the specification values and to obtain industry support.

2. ***Reduce Number of Gyrations to Determine Target Asphalt Content of HMA Mixtures***. All projects with poor performance were found to exhibit longitudinal cracking in the

wheel path and transverse cracking and tears. Excessive longitudinal cracking in or adjacent to the wheel paths and transverse cracks are characteristic of high stiffness-brittle, and/or low strength HMA mixtures, relative to the supporting layers. Reducing the number of gyrations during mixture design can increase the effective asphalt content by volume, which has an effect on mixture durability and resistance to cracking, especially for the lower volume roadways that are thinner and usually have higher deflections.

Multiple agencies have already lowered the number of gyrations for selecting the target asphalt content and job mix formula. Revising the mixture design criteria should improve the mixture's resistance to cracking for both low and high volume roadways; reducing the amount and severity of longitudinal cracks in the wheel path, edge cracks, and transverse cracks.

A pilot project is recommended for this mitigation strategy because any changes to the mixture design procedure and/or criteria will take time to implement. In addition, the pilot projects provide supporting data to confirm the effect on the HMA mixture's volumetric properties that are used for acceptance and payment.

3. ***Biased Inspection and Testing HMA***. Many projects with poor performance exhibited excessive center lane longitudinal cracking. Longitudinal cracking in the center of the lane is not related to the HMA mixture itself or the pavement structure. These cracks are more related to the paving equipment and construction practice.

   It is expected that this cracking is a result of an inadequate amount of mixture being pushed under the paver gear or drive box; sometimes referred to as center lane segregation. An economic and effective method to reduce the occurrence of these longitudinal cracks is to conduct density tests and visual inspection at the center of the paver during the first couple of days of paving and then on an as needed basis as directed by the project engineer. As such, biased inspection and testing is recommended to reduce the length and severity of longitudinal cracks in the center of the lane.

   A few agencies (for example; Washington DOT) already use biased testing to identify areas with temperature differences (sometimes referred to as temperature segregation), while more agencies are considering biased sampling and testing on a routine basis. An infrared camera or sensors can be used to identify areas with a significant loss of temperature during paving.

   A demonstration project is recommended for this mitigation strategy, but only to illustrate use of these procedures for improving construction and performance of HMA pavements.

4. ***Use of Wearing Courses or Surfaces with Enhanced Mixture Properties***. All projects with poor performance were found to exhibit transverse cracks and tears and other forms of cracking and surface deterioration. The Asphalt Institute and other agencies (for example; Colorado and Wisconsin DOT) have sponsored studies related to the use of polymer modified asphalt (PMA) and stone matrix asphalt (SMA) to enhance pavement performance and reduce pavement distress. The MDOT database does not identify those projects where PMA or SMA type engineered mixtures were placed.

   MDOT has allowed the use of gap-graded, neat or unmodified HMA mixtures for the wearing surface. Gap-graded HMA mixtures can exhibit high permeability because of the higher portion of larger aggregate in the aggregate blend. Higher permeability mixtures are more susceptible to accelerated aging and moisture infiltration, which increase surface deterioration of the mixture and reduce its resistance to cracking. The intent of this mitigation strategy is to reduce the amount and severity of various types of cracking (block, fatigue, transverse cracks and tears, etc.) and surface deterioration (raveling).

   No pilot project is suggested for this mitigation strategy because there is a lot of field and laboratory data that document the benefit and reduction in surface distress with the use of PMA and/or SMA mixtures. However, it is recommended that MDOT identify projects with PMA and/or SMA mixtures so that the DI, rut depth, and IRI can be monitored over time in comparison to those with conventional neat HMA mixtures to confirm the increase in service life for life cycle costs analysis.

5. ***Use of a Fundamental HMA Mixture Test.*** It has been reported by multiple researchers that volumetric properties by themselves do not ensure an HMA mixture has the properties required to meet the design requirements (service life). Insufficient data were available to estimate the benefit of using a performance test to identify inferior mixtures and to confirm the job mix formula and target asphalt content based on volumetric properties. The authors, however, recommend its use based on the results from other studies and projects.

   A pilot project is recommended for this mitigation strategy because any changes in the mixture design procedure and/or criteria will take time to implement. Additional data will be needed to confirm the HMA properties used in design and support the volumetric mixture design procedure. This mitigation strategy is a long term effort and a continuation of mitigation strategy #2 – Revised HMA Mixture Design Criteria. The fundamental test used for mixture performance testing can be selected or quantified in accordance with the work completed under mitigation strategy #2.

Table 1. Summary of the Mitigation Strategies

| Mitigation Strategy | Objective or Purpose | Importance | Important Feature | Impact on Construction Cost | Time for Implementation |
|---|---|---|---|---|---|
| Develop, Enforce Longitudinal Construction Specification | Reduce length & severity of centerline cracks & deterioration. | High; impact should be immediate. | None, immediate implementation | None. | 2012 construction season |
| Reduce Gyrations to Estimate Target Asphalt Content & Job Mix Formula | Reduce length & severity of transverse cracks, longitudinal cracks in wheel path & along the edge. | High; impact will take a couple of years | Laboratory experiment is required for implementation | Minor increase in cost. | 2012 for the lab experiment & initial pilot project; 2013 construction season for evaluating performance. |
| Biased Inspection & Testing of HMA | Reduce length & severity of longitudinal center lane cracks. | High; impact should be immediate | Purchase infrared cameras | None. | 2012 construction season |
| Use Wearing Surface with Enhanced Properties; PMA & SMA | Reduce severity of transverse cracks & tears; longitudinal cracks in wheel path & alligator cracks | Moderate; impact will be immediate on higher volume roadways | None, immediate implementation | Increase in cost. | 2012 construction season to implement; performance based tests need to confirm reduction in distress. |
| Use Fundamental Performance Test for Design | Reduces all distresses. | Moderate; impact will take time. | Long term strategy after others are completed | Increase in cost. | Future development & work. |

# *Section 2: Mitigation Strategies*

## *Product P1*

The mitigation strategies recommended are activities or features that can be implemented within one or two years to reduce accelerated aging and deterioration (premature failures) and extend the service life of flexible pavements and HMA overlays. Identification of these mitigation strategies was based on a review of the data included in MDOT's performance database and from discussions with MDOT and industry staff, as well as personnel knowledge of the authors related to flexible pavements materials and construction practices in Michigan.

[This page intentionally left blank.]

# Mitigation Strategy #1:

# Implementation of a Longitudinal Construction Joint Specification

## Introduction

Longitudinal centerline cracking was recorded on 100 percent of the projects exhibiting poor performance. Figure 1 is an example of excessive longitudinal cracking and deterioration along the centerline joint. This cracking and deterioration is directly related to the construction of the centerline joint. Echelon paving is the best strategy to eliminate longitudinal construction joints, but echelon paving is impractical for routine paving of multi-lane roadways; especially for rehabilitation projects for which existing traffic flow must be maintained.

The amount and severity of centerline cracking can be reduced by improving on the construction and rolling of the centerline joint and joint between adjacent lanes in the same direction. Many agencies have already developed and implemented a longitudinal construction joint specification because of the joint's impact on pavement maintenance and performance. It is understood that MDOT drafted a longitudinal construction joint specification in 2009, but that specification has yet to be implemented or included in any pilot study.

Implementation of a longitudinal construction joint specification is considered a high importance mitigation strategy to MDOT and industry in terms of reducing life cycle costs of flexible pavements. This mitigation strategy can reduce the length and severity of longitudinal centerline cracks without increasing construction costs.

## Purpose or Objective of Mitigation Strategy

Proper rolling patterns for compacting a confined and unconfined longitudinal construction joint are available in various HMA construction courses and documents (NHI Course #132032, Hot Mix Asphalt Construction; various NAPA, Asphalt Institute, and FHWA courses). There are different opinions within industry, however, regarding the most effective rolling pattern to achieve higher densities along the centerline joint. The objective of this implementation strategy is two-fold:

1. Provide evidence to MDOT and contractors that the longitudinal construction joint specification will not result in significant penalties.

2. Provide data for confirming the values included in a Percent Within Limits (PWL) type of specification, as well as a contractors quality control plan.

Figure 1. Photograph Showing an Example of Accelerated Deterioration Along a Longitudinal Centerline Joint that was Inadequately Constructed

A demonstration project is recommended to achieve the second objective prior to implementation. MDOT, however, can decide to proceed with the values (percent density level and associated penalty or bonus) originally included in the draft longitudinal construction joint specification. The data from this part of the study would simply be used to confirm those values. It is expected that sufficient data from the demonstration project can be obtained from the 2012 construction season. MDOT is encouraged to proceed with this mitigation strategy.

## Suggested Changes to the Longitudinal Construction Joint Specification

As noted above, MDOT drafted a longitudinal construction joint specification in 2009 but that specification has yet to be implemented or included in any pilot study. The following are suggested changes to that draft specification.

- It is recommended that the specification be included in some demonstration projects during the first construction season of implementation to demonstrate and confirm the "Best Practices and Methods" for rolling longitudinal construction joints to achieve the maximum density along the joint relative to the density achieved near the center of the

HMA mat. In addition, the gradation of the HMA mixture can have a significant effect on the joint density along notched wedge type joints. The surface voids and/or surface texture of the notched wedge can result in low densities that are mix dependent and not a result of the contractor's standard care and workmanship. Demonstration project #1 under Section 3, Demonstration/Pilot Projects, provides details regarding the demonstration projects to be used.

- Longitudinal joints shall be compacted to a target density of 91 percent of the theoretical maximum specific gravity ($G_{mm}$) or 2 percent less than the density obtained within the center of the HMA mat. The theoretical maximum specific gravity used to determine the joint density will be the average of the daily theoretical maximum specific gravity for the material that was placed on either side of the joint. The target density of 91 percent of $G_{mm}$ will be evaluated during the construction season for implementing the longitudinal joint specification, but may be increased to 92 percent in future construction seasons. The longitudinal joints of each lift shall be tested separately – the joints for each lift shall be tested.

- Any area or lot with an average joint density less than 88 percent of $G_{mm}$ will be considered unacceptable.

- If a layer or lift of HMA has joints constructed on both sides of the lift, incentive and disincentive payment for each of those joints will apply to one half of the HMA lift between the joints.

- In areas that include intersections and other areas requiring phasing and traffic traveling over the longitudinal joint before the adjacent lift is placed, the Engineer can waive the requirement for joint density testing.

- When constructing joints in an echelon paving process, the longitudinal joints shall be marked to ensure consistent coring locations.

- Six inch diameter cores shall be taken at the locations designated and marked by the Engineer. The center of the core shall be within 1 inch of the visible joint line, which is marked by the Engineer in designating the core location along the longitudinal joint. The contractor can take additional cores at his own expense.

- A calibrated nuclear or non-nuclear density gauge can be used by the contractor to judge the density and compaction of the longitudinal joint after finish rolling – prior to receiving the test results within four calendar days after the Engineer has taken possession of the cores at the project site. If the test results are considered low, the contractor shall notify the Engineer to accelerate testing of the cores.

## Performance Indicator to be Monitored

It is hypothesized that the length and severity of longitudinal centerline cracks can be reduced by including joint density in the construction specification. Reducing the length and severity of longitudinal centerline cracks will delay the occurrence of a distress index (DI) value requiring some type of rehabilitation and/or preventive maintenance. Thus, density needs to be monitored during construction, and the length of centerline cracks and DI values need to be monitored over time to achieve the objectives of this mitigation strategy. Implementing this mitigation strategy should have no impact on the IRI values and rut depths recorded in the MDOT database.

## Criteria for Project Selection and Number of Projects

The criterion for selecting projects to demonstrate this mitigation strategy is not restrictive. Basically, all projects that have extensive lengths without intersections can be considered. It is suggested that areas with intersections be avoided because of cross over traffic over time. Projects with more than 6 days of paving are also recommended to ensure that lots with different rolling patterns of the longitudinal construction joint can be included in the demonstration.

The sampling matrix for projects included in this mitigation strategy consists of two major factors or tiers which are listed below and shown in Figure 2 – the recommended sampling matrix or experimental factorial.

1. HMA overlay and new construction or reconstruction projects. It is suggested that both rehabilitation (overlays) and new construction type projects be included within the sampling matrix. Type of pavement structure should be kept separate within the sampling matrix, even though pavement type should have no impact on the results from the demonstration projects.

2. Type of longitudinal construction joint. Two major types of longitudinal construction joints should be included in the sampling matrix, because of the need to open the highway to traffic during construction: butt and tapered joints.

    a. Butt joints are more common to HMA overlays with lift thicknesses of 2 inches or less. HMA lifts with thickness greater than 2 inches are usually tapered, because of safety issues in opening the roadway to traffic prior to placing the lift in the adjacent lane. Two types of butt joints have been used to evaluate the performance on longitudinal construction joints; a standard butt joint created by the paver's end plate and a sawed butt joint. The sawed butt joints increases construction costs because of the added equipment and time that is needed for sawing along the HMA mat's edge to remove the edge material. Sawed butt joints are more commonly used for airfield paving projects, where there is more time prior to opening the facility to traffic and heavier loads operate across the joints.

Sawed longitudinal construction joints are typically not used on roadway projects because of the need to open up the roadway to traffic prior to placing the adjacent mat. For this reason, it is recommended that only butt joints created by the paver be included in the demonstration project.

b. Tapered longitudinal construction joints are needed for safety purposes when the HMA lift thickness exceeds 2 inches and the contractor is required to open the lane to traffic prior to placing the adjacent lane. Two types of tapered joints are recommended for use in the sampling matrix or factorial. The first tapered joint is a standard taper, and the second is referred to as the notched edge or wedge joint. The notched wedge joint has a flatter taper (1:12 slope) than the standard tapered joint.

<table>
<tr><th colspan="2">Between Project Parameters</th><th colspan="4">Within Project Parameters</th></tr>
<tr><th rowspan="3">Type of Construction</th><th rowspan="3">Type of Longitudinal Construction Joint</th><th colspan="4">Type of Roller</th></tr>
<tr><th rowspan="2">Pneumatic Rubber-Tired Roller</th><th colspan="3">Steel Wheel Roller; Rolling Patterns dependent on confined or unconfined lift placement.</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td rowspan="3">New or Reconstructed Flexible Pavement, Includes Crush & Shape with HMA Surface</td><td>A-Butt</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B-Standard Taper</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C-Notched Wedge Joint</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">HMA Overlay of Flexible Pavements [Joint type & lift thickness dependent on opening unconfined joint to traffic.]</td><td>A-Butt</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B-Standard Joint</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C-Notched Wedge Joint</td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 2. Suggested Sampling Matrix for Implementing a Longitudinal Construction Joint Specification and Confirming the Specification Values

Three to four projects for each joint type should provide sufficient data and information to confirm the specification values and provide confidence to MDOT and industry on the proper rolling pattern to maximize joint density. The butt joint is probably the more common joint used for new construction, while the notched wedge joint is more common for HMA overlays. Thus, 6 to 8 projects within the 2012 construction season should be sufficient. For the within project parameters, three lots per rolling pattern should be sufficient to evaluate the null hypothesis (rolling pattern has no impact on density of the longitudinal construction joint).

HMA lift thickness is a secondary parameter included in the sampling matrix. The purpose or reason for adding lift thickness to the sampling matrix is to confirm the effect of the tapered joint on the longitudinal construction joint density specification. Most agencies have found that lift thickness is not a factor in defining the density for a longitudinal construction joint.

Two or more lanes being paved in the same direction but at different times can be used to increase the amount of data collected within a particular project. Thus, projects within multiple lanes in the same direction can be given a higher priority to increase the amount of data collected on any one demonstration project. Other parameters that should be varied within a particular project are listed below.

- Type of roller used in the primary or breakdown position. Vibratory rollers and rubber tired pneumatic rollers. Most of the HMA construction courses for rolling an unconfined longitudinal joint are similar. The differences in rolling strategies are related to the use of the steel wheel rollers (static and vibratory modes). Thus, the sampling matrix is structured to determine the rolling pattern that will result in the highest density.

- Type of rolling pattern used for the longitudinal construction joints. Different rolling patterns are recommended for use by different organizations when steel wheel rollers are used in the breakdown or primary position. Three different rolling patterns should be evaluated within the sampling matrix or demonstration for rolling the longitudinal joint. The following are the common ones used and depend on whether the roller operator is compacting an unconfined or confined longitudinal joint.

    - Unconfined Joint: Two locations are recommended for use during the first pass of the steel wheel roller along the joint (static or vibratory modes).

        - The first and preferred location of the first roller pass along the joint – the edge of the steel drum is extended 4 to 6 inches over the edge of the lift.

        - The second location of the first roller pass along the joint – the edge of the steel drum is adjacent to the edge of the lift; in other words, no overhang of the roller over the edge of the lift.

    - Confined Joint: Three locations are recommended for use during the first pass of the steel wheel roller along the longitudinal construction joint (static or vibratory modes dependent on location of roller for the first pass).

- The first and preferred location of the first roller pass along the joint – the roller is operated on the hot side of the joint and overhangs the edge of the lift by 4 to 6 inches (static or vibratory modes).

- The second location of the first roller pass along the joint – the roller is operated on the cold side of the joint for the first pass; only about 6 inches of the roller is operated on the hot side of the mat. This is defined as the cold side pinch method (static mode only for the first pass).

- The third location of the first roller pass along the joint – the roller is operated on the hot side of the joint but the first pass is located about 4 to 6 inches from the longitudinal joint on the hot side. This is referred to as the hot side pinch method. The second pass of the roller is typically over the part not rolled during the first pass (static or vibratory modes for both passes).

Number of lifts placed to evaluate the effect of staggering longitudinal construction joints can be a secondary parameter of the sampling matrix. Recommended practice is to stagger or offset the longitudinal joints between the upper and lower lifts by 12 inches. Staggering longitudinal construction joints is done so that there is no weakened plane (a cold joint) from the top of the pavement to the bottom of the HMA layer. This secondary factor will be difficult to include in the sampling matrix because many of the rehabilitated projects are confined and restricted to existing lane widths for maintaining existing traffic flow. The effect of staggered longitudinal construction joints can be included more easily for new construction or new alignment type projects. Placing a longitudinal construction joint of any lift under or adjacent to the wheel paths of trucks, however, should always be avoided. For this reason, staggering longitudinal construction joints becomes difficult for roadways with confined widths, and thus, was excluded from the demonstration project.

## Assessment of Construction and Pavement Performance: Tests and Data Interpretation

### *Construction Practices and Rolling Patterns*

Two types of field tests are recommended for use in monitoring construction and assessing pavement performance or joint condition at the time of construction. These tests include measuring the density and stiffness of the in place mixture along the joint and within the interior of the HMA mat. The frequency and location of these tests are described in the second part of this document – the pilot projects.

1. Densities can be measured with the nuclear or non-nuclear density gauges, as long as they have been calibrated to cores recovered from the HMA during construction. For this

demonstration project, either of the devices can be used. Cores should also be taken along the edge of the pavement (both along unconfined and confined joints) to confirm the air voids and densities. Densities measured along and adjacent to the joints will be used to confirm the specification values for what can be achieved by the contractor using standard care and workmanship.

2. Stiffness measurements are made with the Portable Seismic Pavement Analyzer (PSPA) in accordance with the procedure outlined in NCHRP project 10-65; *NDT Technology for Quality Assurance of HMA Pavement Construction*.[1] Stiffness values are used as a secondary property for comparing the different features/rolling patterns used to compact the longitudinal construction joints.

Stiffness and density measurements should be taken along the joints and at the same location within the interior of the mat for comparing the measured values. The interior measurements provide the information and data to determine the allowable reduction in density along the unconfined and confined side of the longitudinal joint.

Data from the field stiffness and density tests, along with the cores, are analyzed to determine statistical differences between the different rolling patterns used to compact the longitudinal construction joint. The null hypothesis for this mitigation strategy is that the different rolling patterns for the unconfined and confined longitudinal joints do not have an effect on the density or stiffness measured along the edge of the mat. Sufficient tests should be taken to evaluate the null hypothesis and confirm the values included in the draft longitudinal joint construction specification prepared by MDOT in 2009. It is expected that the null hypothesis will be rejected, and a preferred rolling pattern identified for the longitudinal construction joints.

### *Performance of Longitudinal Construction Joints*

Distress surveys should be completed at periodic intervals to monitor the condition of the joint (centerline cracking length and severity) over time. The project should be divided into lots for acceptance using the MDOT standard procedures and practice. The distress surveys can be completed in accordance with MDOT standard procedures. Each lot should be monitored to determine the impact of rolling pattern on long term performance, as well as type of longitudinal construction joint. These lots can be monitored over a period of at least 5 years to confirm the lower DI values and preferred rolling pattern identified during construction.

[1] *NDT Technology for Quality Assurance of HMA Pavement Construction*, Report Number 626, National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington, DC, January 2009 (Harold L. Von Quintus, Chetana Rao, Robert E. Minchin, Soheil Nazarian, Kenneth Maser, and Brian Prowell).

# Mitigation Strategy #2:

# Implementation of Revised HMA Mixture Design Criteria

## Introduction

Transverse, longitudinal (edge and wheel path), and block cracking are common distresses recorded in the distress index database on those roadway segments with poor performance. In fact, extensive lengths of transverse cracks, longitudinal edge and wheel path cracks were recorded on just about all of the projects classified with poor performance. Conversely, the flexible pavements identified as having good to exceptional performance exhibited significantly less transverse cracks and tears, longitudinal cracks in the wheel path, and block cracking. Longitudinal cracks adjacent to the wheel path cracks and transverse cracks were also noted by some of the MDOT individuals contacted or interviewed as causing premature maintenance.

Pavements with excessive transverse and longitudinal cracking were not restricted to colder climates or MDOT regions, soil type/strength, or traffic level so it was concluded that these cracks are more of a materials issue rather than a climate, traffic, or structural issue. Excessive longitudinal cracks in the wheel path and along the edge and transverse cracks are characteristic of high stiffness, low strength HMA mixtures relative to the supporting layers. Reducing the number of gyrations during mixture design can increase the effective asphalt content by volume, which has a significant effect on mixture durability and its resistance to cracking, especially for lower volume roadways that are thinner and have higher deflections. A mitigation strategy is recommended to minimize the occurrence of material related transverse and longitudinal cracking and is:

- Reducing the number of gyrations for mixture design and revising the HMA mixture design criteria for both higher and lower volume roadways to increase mixture strength and durability; and make the mixture more tolerant to tensile strains.

Multiple agencies have already lowered the number of gyrations for selecting the target asphalt content and job mix formula. Some of these agencies observed that cracking and deterioration of wearing surfaces occurred on a higher percentage on HMA mixtures designed using high levels of $N_{design}$ gyrations.

A pilot project is recommended for this mitigation strategy, because any change in the mixture design procedure and/or criteria will take time to implement. In addition, a pilot project is required to provide data to confirm the effect on the HMA mixture's volumetric properties that are used for acceptance and payment. Simply lowering the number of gyrations without checking the fundamental properties is not recommended because of the potential impact on rutting and other distresses (refer to Mitigation Strategy #5).

Implementation of revised mixture design criteria is considered a high importance strategy to MDOT and industry because it will reduce the number of premature failures and extend the service life of flexible pavements. The strategy may increase construction costs because of higher asphalt contents and potential effects on the aggregate blend or gradation.

## Purpose or Objective of Mitigation Strategy

All projects with poor performance were found to exhibit various forms of longitudinal cracking (wheel path and edge) and transverse cracking. The intent of this mitigation strategy is to reduce the length and severity of longitudinal (wheel path and edge) and transverse cracks and tears.

The hypothesis of this mitigation strategy is that some HMA mixtures are susceptible to fracture because of lower asphalt contents. Lower asphalt contents can reduce the tensile strength of HMA and result in brittle mixtures. Higher laboratory compaction efforts can result in lower effective asphalt contents by volume. Revising the mixture design guidelines and laboratory compaction criteria should improve on the mixture's resistance to cracking for both low and high volume roadways.

## Revised Mixture Design Criteria

MDOT requested specific implementable recommendations regarding the revised gyration levels and aggregate blends for the different conditions and HMA layers. This request goes beyond the scope of work for this project. The intent of this mitigation strategy is to balance a mixture's resistance to distortion, fracture, and surface disintegration. Based on the findings from this study, excessive rutting has all but been eliminated, but at the expense of making some mixtures more brittle and susceptible to fracture which is dependent on the site conditions. To balance between distortion and fracture properties for extending pavement life requires the use of fundamental performance-based properties (refer to Mitigation Strategy #5).

A pilot project is recommended for this mitigation strategy to confirm the effect of changing the mixture design criteria (refer to Pilot Project #3 and Figure 3 in this section). More importantly, revisions for this mitigation strategy are volumetric-based properties. Volumetric properties are important, but their overall effects on the fundamental properties of the HMA mixture can be altered by using different amounts and combination of materials (for example, mineral filler, sand, etc.). Fundamental performance-based property tests are needed to confirm the HMA mixture design will be resistance to fracture and distortion.

The following provides suggested changes to MDOT's current Superpave mixture design criteria or guidelines that can be used as a starting point for evaluating their effectiveness for extending pavement service life.

**NOTE:** IF MDOT DOES NOT PLAN TO USE A FUNDAMENTAL PERFORMANCE-BASED PROPERTY TEST TO CONFIRM THE DIFFERENT GYRATIONS AND HIGHER VMA VALUES, IT IS SUGGESTED THAT THE VALUES IN THE CURRENT MIXTURE DESIGN GUIDELINES CONTINUED TO BE USED.

Number of Gyrations for Selecting Target Asphalt Content:

| Estimated Design Traffic (million ESALs) | Number of Gyrations, $N_{Design}$ at 96% of $G_{mm}$ | Comments |
|---|---|---|
| < 0.1 | 50 | |
| 0.1 to 0.3 | 50 | Some agencies have increased this value to 75. |
| 0.3 to 3.0 | 75 | |
| 3.0 to 10.0 | 75 | For the heavier traffic volumes, some agencies have made this value dependent on climate. The cooler areas are 75, and the hotter areas can be increased to 100. |
| 10.0 to 30.0 | 90 | This value can also be climate dependent; varying from 90 to 100. |
| > 30.0 | 115 | This value can also be climate dependent, varying up to 125 for hot climates. |

Voids in Mineral Aggregate for Selecting or Determining Aggregate Gradation:

| Nominal Maximum Aggregate Size (As Defined by Superpave) | Minimum Voids in Mineral Aggregate, % |
|---|---|
| 1 inch (25 mm) | 12.5 |
| ¾ inch (19 mm) | 13.5 |
| ½ inch (12.5 mm) | 14.5 |
| 3/8 inch (9.5 mm) | 15.5 |

## Performance Indicator to be Monitored

It is hypothesized that the length and severity of longitudinal cracks adjacent to the wheel path and transverse cracks can be reduced by making revisions to the mixture design procedure to increase the mixture's resistance to fracture. Reducing the length and severity of longitudinal and transverse cracks will delay the occurrence of a distress index value requiring some type of rehabilitation and/or preventive maintenance. Thus, the length of longitudinal cracks adjacent to the wheel path and along the edge, transverse cracks, and distress index values need to be monitored to achieve the objective.

Implementing this mitigation strategy may have an impact on the IRI values and rut depths recorded in the MDOT database. As such, other distresses, rut depth, and IRI should be monitored for at least 5 years to confirm the increase in service life (lower DI values, rut depths, and IRI).

## Criteria for Project Selection and Number of Projects

The criterion for selecting projects included within this mitigation strategy is that the project needs to have a sufficient amount of HMA paving so that mixtures can be designed and placed using two different design criteria: the existing mixture design procedure defined as the standard sections and the revised mixture design criteria based on a fewer number of gyrations (lower laboratory compactive effort) defined as the companion sections. The sampling matrix for projects included in this mitigation strategy consists of three multiple factors or tiers which are listed below and summarized in Figure 3.

- Layer type: HMA base layer, intermediate layer, and wearing surface for new construction or reconstruction (including crush and shape with HMA surfaces) and HMA overlays. Layer type is the primary factor, while pavement structure is a secondary factor in the sampling matrix.
- Traffic level: High to low traffic volumes. This primary factor will be used to evaluate the use and impact of number of gyrations on the volumetric and fundamental properties of a particular aggregate blend and aggregate type.
- Aggregate type and blend: Coarse-graded, gap-graded and fine-graded mixtures, and/or small versus large aggregate blends. This factor can be included in the sampling matrix by including pavements with thicker HMA base layers to thinner wearing surfaces. Layer thickness should be compatible with aggregate size because of the minimum lift to nominal aggregate size ratio requirement.

It is recommended that the climate or regional effect on asphalt performance grade selection or determination be kept the same and not be included in the sampling matrix. However, projects should be selected to include different performance grade asphalts that are typically specified and used by MDOT.

For planning purposes, a minimum of 4 overlay projects and 6 new construction projects should be included within this mitigation strategy to determine the appropriate number of gyrations for maximizing performance.

| Between Project Parameters | | Within Project Parameters | | | |
|---|---|---|---|---|---|
| Traffic Level | Aggregate Blend | HMA Layer, if available | Number of Gyrations | | |
| | | | Current Level | Revised Level 1 | Revised Level 2 |
| Low | Coarse-Graded | Base | | | |
| | | Surface | | | |
| | Gap-Graded | Base | NOTE: The gyration levels selected and used should be based on preliminary studies; either conducted by MDOT or other agencies. | | |
| | | Surface | | | |
| | Fine-Graded | Base | | | |
| | | Surface | | | |
| Moderate | Coarse-Graded | Base | | | |
| | | Surface | | | |
| | Gap-Graded | Base | | | |
| | | Surface | | | |
| | Fine-Graded | Base | | | |
| | | Surface | | | |
| High | Coarse-Graded | Base | | | |
| | | Surface | | | |
| | Gap-Graded | Base | | | |
| | | Surface | | | |
| | Fine-Graded | Base | | | |
| | | Surface | | | |

Figure 3. Suggested Sampling Matrix for Implementing Revised HMA Mixture Design Criteria and Lowering the Number of Gyrations for Design

## Assessment of Mixture Design Guidelines and Pavement Performance: Tests and Data Interpretation

Assessment of this mitigation strategy needs to be divided into two parts; one for the laboratory evaluation in determining the target asphalt content and job mix formula, while the second part is the performance evaluation to confirm the reduction in specific longitudinal and transverse cracks, as well as lower distress index values, while not increasing rut depth and IRI – extending the pavement service life.

### *Mixture Tests for Laboratory Evaluation*

The laboratory evaluation is grouped into two subsets.

1. The first subset of test mixtures: all HMA mixtures included in the sampling matrix should be designed with the current mixture design procedure and criteria ($N_{design}$ gyrations). After the target asphalt content and job mix formula have been determined using the existing (or standard) procedure, the fundamental properties should be measured on laboratory prepared specimens at the expected air void level based on the construction specification.

2. The second subset of test mixtures or specimens: the HMA mixture should be compacted using reduced levels of compaction or $N_{design}$ levels. The target asphalt content and job mix formula is determined for the revised compaction levels. The fundamental properties are measured on laboratory prepared specimens at the same expected air void level specified during construction.

Two types of laboratory and field tests are recommended for use in monitoring construction and assessing pavement performance at the time of construction. These tests include the volumetric and fundamental properties of the HMA.

- Volumetric properties include the properties normally measured using the current mixture design process; density, air voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA).

- Fundamental performance properties include dynamic modulus, tensile strength and tensile strain at failure using the indirect tensile test (or a measure of the strain energy required to fracture the specimens), and a repeated load permanent deformation test (flow number test).

The deformation tests should be performed on test specimens that have been short term aged, while the fracture tests should be performed on test specimens that have been long term aged. Short term aging is used to evaluate rutting, while long term aging is used to evaluate transverse and longitudinal cracking and other mixture disintegration type distresses. The fundamental tests are used to determine the effect of changing volumetric properties on the performance properties. The frequency and location of these tests are described in the second part of this document – the pilot projects.

MDOT has already sponsored the use of some fundamental tests to characterize HMA mixtures (You, et al., 2009).[2] The two tests included within that study was the dynamic modulus and flow number (or repeated load permanent deformation) tests. Flow number is an estimate of the mixture's resistance to rutting, while dynamic modulus provides some measure of the mixture's resistance to alligator cracking and rutting.

Rutting was not found to be a major issue in terms of premature failures; few roadway segments were found to have excessive rut depths. Longitudinal and transverse cracks were the more predominant distress for roadway segments with inferior performance. As such, MDOT is encouraged to use a practical fundamental test that measures a mixture's resistance to cracking.

The tensile strength and tensile strain at failure or the strain energy of the mixture can be measured using the indirect tensile test. MDOT is encouraged to use a fracture test for evaluating any change in the mixture design procedure (reducing the number of gyrations for design). Dynamic modulus and flow number (the raw data of plastic strain versus number of load cycles and not the flow number) are still beneficial, especially in determining the HMA mixture inputs to the new Mechanistic-Empirical Pavement Design Guide (MEPDG).

### *Performance of HMA Mixtures Designed Using Different Compaction Levels*

Distress surveys should be completed at periodic intervals to monitor the condition of the flexible pavement or HMA overlay over time. The project should be divided into lots used for acceptance based on MDOT standard procedures and practice. Some of the lots of the project should be designed and placed using current mixture design practice (the standard sections), and the others designed and placed using the revised mixture design guidelines (the companion sections).

The distress surveys should be completed in accordance with MDOT standard procedures. Each lot should be monitored to confirm the impact of HMA design criteria on long term performance.

[2] You, Zhanping, Shu Wei Goh, and Christopher Williams, *Development of Specifications for the Superpave Simple Performance*, Research Report Number RC-1532, Michigan Department of Transportation, Lansing, Michigan, May 2009.

# Mitigation Strategy #3:

# Implementation of Biased Inspection and Testing During Construction

## Introduction

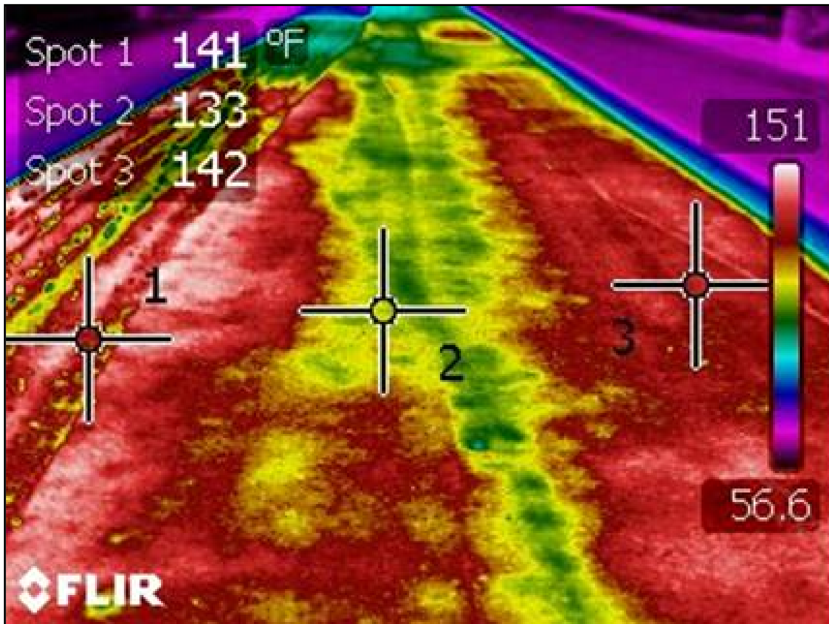
Nearly all projects classified with poor performance exhibited excessive center lane longitudinal cracking. This distress was not identified as a critical issue from the MDOT contacts and interviews, but raveling or mixture disintegration near the center of the lane was identified as an issue. This experience and knowledge helps confirm that a construction defect of segregation or insufficient material at the center of the auger chamber is probably an issue.

Longitudinal cracking in the center of the lane is not related to the HMA mixture itself or the structure. These cracks are more related to the paving equipment and construction practice. It is expected that this cracking is a result of an inadequate amount of mixture being pushed under the paver gear or drive box; sometimes referred to as center lane segregation.

An economic and effective method to reduce the occurrence of these longitudinal cracks is to conduct density tests and visual inspection at the center of the paver during the first couple of days of paving and then on an as needed basis as directed by the project engineer. Biased sampling and testing should identify factors causing center lane cracking during the first day of paving so corrective actions can be taken, if needed. As such, biased sampling and testing is recommended to reduce the length and severity of center lane longitudinal cracks.

A few agencies (for example; Washington DOT) already use biased testing to identify areas with temperature differences (sometimes referred to as temperature segregation). An infrared camera or sensors can be used to identify areas with a significant loss of temperature during paving. Figures 4 and 5 are examples of cold spots that were identified with the infrared camera. Figure 6 is an example showing uniform surface temperatures across the paving lane. Implementation of this mitigation strategy does require the purchase and use of infrared cameras.

No pilot project is recommended for this mitigation strategy to monitor performance. Demonstration construction projects, however, are suggested to illustrate the biased inspection and testing and use of the infrared camera. Implementation of this mitigation strategy should have no impact on construction costs but should extend the service life of flexible pavements. In addition, it should have no impact on the rut depths and IRI values measured by MDOT.




Surface temperatures are measured with the infrared cameras. The infrared images define areas with different surface temperatures at a point in time. If areas with a significant drop in temperature are identified with the infrared camera, other tests or inspection techniques are required to determine the cause of the difference.

These two examples or illustrations from an infrared camera show cold spots along the center of the paver (center lane cold spots). Multiple photos or illustrations can be taken to monitor the change in temperature after paving and/or compaction.

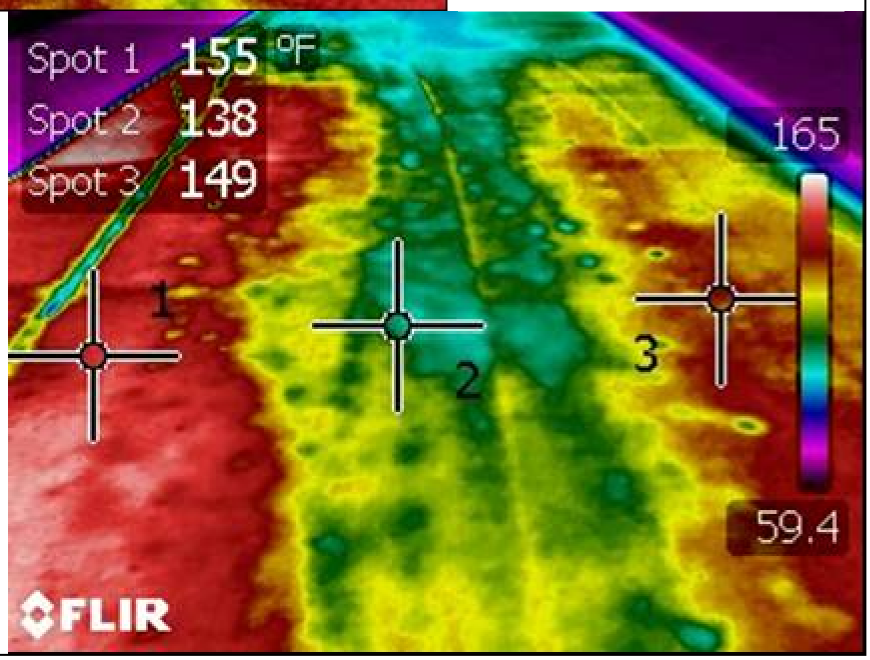
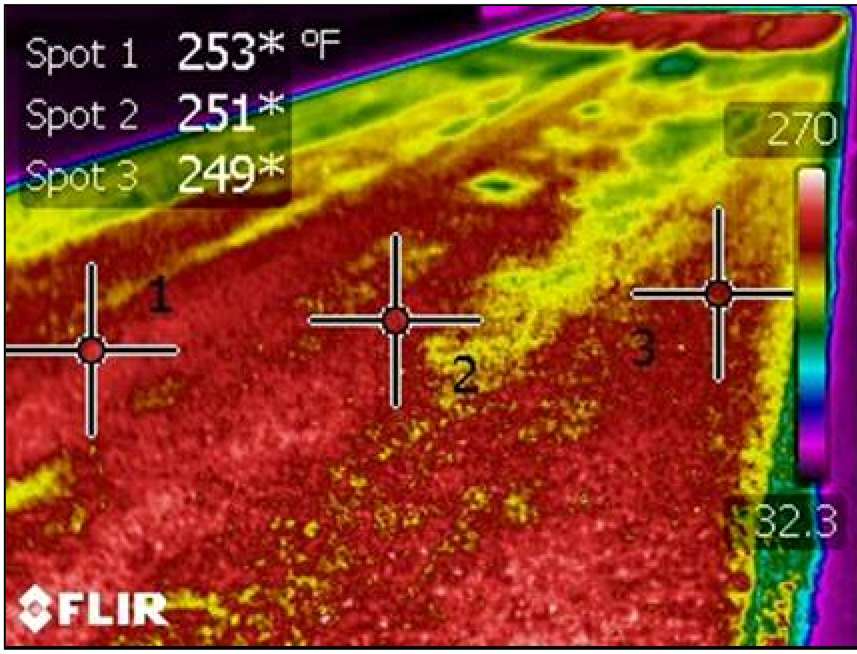
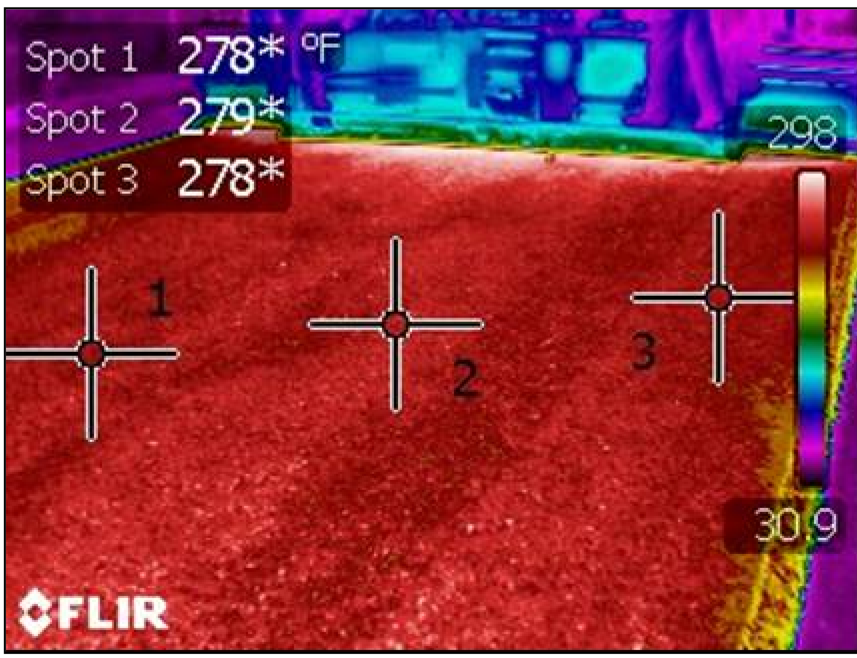



Figure 4. Use of Infrared Camera to Locate Cold Spots or Areas with Low Density; Near Center of Paver (sometimes referred to as temperature segregation)




Infrared photo taken behind the paver prior to compaction and shows truck to truck temperature difference caused by a delay in trucks arriving at the site; the paver had to stop and wait for the next truck.

Figure 5. Use of Infrared Camera to Locate Cold Spots or Areas with Low Density; Delay in Delivery of Mix Where Paver is Sitting for an Extended Period of Time




Infrared photo taken behind the paver showing uniform surface temperatures across the paving lane.

Figure 6. Use of Infrared Camera to Check for Temperature Differences Behind the Paver

## Purpose or Objective of Mitigation Strategy

Longitudinal center lane cracking has been attributed to an insufficient amount of mixture in the center of the paver (directly under the paver's gear box) as a result of worn-out or improperly installed kick-back paddles or aggregate segregation. This condition can be easily identified through visual observations and density tests conducted in a specific area – rather than at random locations. Identifying specific areas with insufficient mixture or segregation and taking corrective action can totally eliminate these longitudinal center lane cracks.

Multiple agencies have purchased infrared cameras to assist in identifying and locating these types of construction defects. Some Michigan contractors have already purchased these cameras as part of their quality control programs.

The objective of this implementation strategy is two-fold:

1. Prepare a set of guidelines that can be used by MDOT staff to locate problem areas at the beginning of paving so that corrective actions can be taken by the contractor. [A draft set of guidelines is included at the end of this subsection.]

2. Demonstrate use of infrared camera to identify construction defects near the center of the auger chamber and in other areas of the mat (refer to Figures 4 and 5).

## Infrared Camera Recommendations and Guidelines

A demonstration project has been recommended to achieve the second objective prior to implementation. The steps and activities recommended for the demonstration project are included in the next Section 3: Demonstration/Pilot Projects – Product P2. MDOT, however, can decide to proceed with implementing this mitigation strategy on a routine basis. It is recommended that MDOT purchase at least one infrared camera for use in the 2012 construction season to demonstrate the effectiveness of biased sampling and testing. In the future, at least one infrared camera per region is recommended.

Many different cameras are available, but FLIR Systems has the following hand-held models that are suitable for application during paving operations.

- T-300 Series Cameras: Models 300, 360, and 400. These cameras range in price from about $10K to $15K. These were the cameras initially used by Washington DOT in the late 1990's to identify cold spots during paving, which had a resolution of 320x256. In the latter 1990's this camera was priced at nearly $50K.

- P-Series Cameras: Models 620 and 640. These cameras range in price from $28K to $40K.

The primary difference between the T-Series and P-Series cameras is the image resolution. The T-Series have a 320x240 resolution, while the P-Series have a 640x480 resolution and higher. Both camera series can be used by an operator riding in a car or truck or walking behind the paver, or they all can be mounted to the back of the paver on a tripod. In addition, they can be hooked to an onboard device for reading the thermal images in real-time. The following lists some of the criteria that should be specified in purchasing the cameras.

- Accuracy and repeatability (+/- 2 percent or 2 degrees Centigrade [3.6 degrees F]).
- Detector resolution or quality of the image collected and stored in the camera for future use.
- Easy to replace battery or charge on an automobile.
- Outputs image in JPEG format (fully radiometric JPEG, which has temperature information).
- Lightweight and ergonomic (less than 2 pounds).
- Mega pixel visual camera with a built-in illuminator lamp (analogous to a flash in a camera).
- Laser pointer built-in.
- Image fusion capabilities.
- Temperature range suitable for HMA behind the paver (all cameras noted above will exceed the range on paving projects).
- Upgrade potential for the camera, including software upgrade potential.
- Post-sale technical support and warranty.

The following is the draft set of guidelines for biased sampling and testing.

> *During the first day of paving, the inspector shall monitor the paving operation and measure the density in specific areas. The infrared camera should be used to identify "cold spots," if present. Cold spots can be the result of longitudinal and truck to truck aggregate segregation, or an insufficient amount of mixture being placed in selected areas – center of the auger chamber (refer to Figures 4 and 5). One area or location to monitor is the mixture placed at the center of the auger chamber and along the outside edges of the slat conveyor (transferring mixture from the paver hopper to the auger chamber).*

*A density reading with a calibrated nuclear or non-nuclear density gauge should be taken at the center of the paver at periodic intervals depending on the length of each sublot during the first day of paving. If the density readings are consistently low, relative to other areas of the mat, paving should be discontinued to determine the reason for the lower density values and corrective action taken.*

*If no defects or "cold spots" with low density readings are found, paving can continue. The infrared camera should be used over the course of the project to identify potential "cold spots" and/or cores taken to confirm that the material has been adequately compacted.*

*If conditions change during the course of the project, biased sampling and testing should be performed at the direction of the project engineer.*

## Performance Indicator to be Monitored

It is hypothesized that the length and severity of longitudinal center lane cracks can be reduced by continuously supplying an adequate amount of mix in the center of the auger chamber and that the HMA has been properly compacted in this area in conformance with the density specification. The location of the test is defined or located using biased techniques, rather than at random at the beginning of the project. Reducing the length and severity of longitudinal center lane cracks will delay the occurrence of a distress index value requiring some type of rehabilitation and/or preventive maintenance. Thus, the length of center lane cracks and distress index values need to be monitored to achieve the objective. Implementing this mitigation strategy should have no impact on the IRI values and rut depths recorded in the MDOT database.

## Criteria for Demonstration Project Selection

The criterion for selecting projects included within this mitigation strategy demonstration is not restrictive. Basically, all projects can be considered. The number of projects depends on the number of available infrared cameras. The sampling matrix for selecting projects included in this mitigation strategy for the 2012 construction season consists of two major factors or tiers which are listed below.

1. Lift thickness: less than 2 inches and greater than 2 inches. Lift thickness has a significant impact on the loss of temperature or time available for compaction. Thin and thicker lifts should be included to demonstrate this strategy.

2. Aggregate blend: gap-graded, coarse-graded, and fine-graded. Gap and coarse-graded mixtures are more susceptible to aggregate segregation and should be included in the demonstration project.

It is suggested that at least one infrared camera be purchased for the 2012 construction season. This camera can be used within a specific region or used on specific projects throughout Michigan.

## Assessment of Construction: Tests and Data Interpretation

Two types of field tests are recommended for use in monitoring construction and assessing the condition of the HMA lift at the time of construction. These tests include density of the in place mixture measured with a nuclear or non-nuclear density gauge and surface temperature differences measured with the use of the infrared camera to locate cold spots. Cores should also be recovered to confirm and/or calibrate the density readings from the nuclear or non-nuclear density gauge.

# Mitigation Strategy #4:

# Implementation of Wearing Courses with Enhanced HMA Mixture Properties

## Introduction

All projects with poor performance were found to exhibit transverse cracks and tears, alligator cracks and longitudinal cracks in the wheel path. Surface deterioration (raveling) was recorded on over 50 percent of these projects. The amount and severity of these cracks and surface deterioration can be reduced by using higher quality wearing surfaces like stone matrix asphalt (SMA) and polymer modified asphalt (PMA) mixtures. MDOT and local contractors have designed gap-graded or uniform-graded, neat (unmodified) HMA mixtures. These mixtures can have lower asphalt contents and high permeability resulting in durability issues; raveling, block cracking (longitudinal and transverse cracks), and alligator cracking with time.

Discussions with contractors, review of field reports, and observations of surface distress suggest that the Type C mixtures specified and placed in the 1980's were susceptible to premature cracking. This condition has changed with some of the revisions made to the HMA specifications in the latter 1990's and early 2000's. However, there are still many projects where excessive cracking has occurred. It is hypothesized that a cause for this premature cracking is a result of the gap-graded, unmodified HMA mixtures that have been specified and used in Michigan, especially for higher volume roadways. Thus, the intent of this strategy is:

- Use of wearing courses with enhanced mixture and asphalt properties to reduce the length of transverse cracks, block cracking, longitudinal cracks in the wheel path and surface deterioration, or to minimize the use of gap-graded aggregate blends (i.e.; mitigation strategy #2).

MDOT has allowed the use of gap-graded or uniform-graded dense HMA mixtures for the wearing surface. Gap-graded HMA mixtures can exhibit high permeability because of the higher portions of larger aggregate in the aggregate blend. Higher permeability mixtures are more susceptible to accelerated aging and moisture infiltration, which increase surface deterioration of the mixture and reduce its resistance to cracking. The intent of this mitigation strategy is to reduce the amount and severity of various types of cracking (block, alligator, transverse cracks and tears, and longitudinal cracks in the wheel path) and surface deterioration.

The Asphalt Institute and other agencies (for example; Colorado and Wisconsin DOT) have sponsored studies related to the use of PMA and SMA mixtures to enhance pavement performance and reduce pavement distress. The MDOT database does not identify those projects where PMA or SMA type engineered mixtures were placed as the wearing surface. No pilot project is suggested for this mitigation strategy because there are a lot of field and laboratory studies that document the benefit and reduction in surface distress with the use of PMA and/or SMA wearing surfaces. It is recommended, however, that MDOT start recording and documenting the projects where these mixtures with enhanced properties have been used to establish performance characteristics that can be quantified and compared to conventional, neat HMA mixtures for the site features, materials, and other conditions encountered in Michigan.

This mitigation strategy is compatible with mitigation strategy #2. In fact, the results from mitigation strategy #2 can be used to determine the fundamental properties for PMA and SMA mixtures, as compared to the existing HMA mixtures produced and placed under the current construction and material specifications. A fundamental performance test should eventually be used to measure the properties of any HMA mixture, but especially those on higher volume roadways (refer to mitigation strategy #5).

## Purpose or Objective of Mitigation Strategy

The objective of this implementation strategy is to provide:

- Documentation and evidence to MDOT and contractors for quantifying the magnitude of the extended service life or reduction in pavement distress with the use of engineered mixtures with enhanced properties (PMA and SMA mixtures).

MDOT is encouraged to proceed with implementing this strategy. Insufficient data, however, exists for quantifying the increase in service life or reduction in distress for conditions encountered and materials used in Michigan. As such, a longer term demonstration project is recommended to achieve the objective during and after implementation of this mitigation strategy. The data from the demonstration project can be used to confirm the expected increase in service life of 3 to 5 years that has been documented and reported by other agencies (Asphalt Institute, Colorado DOT, etc.).

## Performance Indicator to be Monitored

It is hypothesized that the amount and severity of alligator cracks, transverse cracks and tears, longitudinal cracks in the wheel path, and surface deterioration (raveling) can be reduced by specifying the use of PMA and SMA mixtures, especially for higher volume roadways. Reducing the amount and severity of these cracks will delay the occurrence of a distress index value requiring some type of rehabilitation and/or preventive maintenance. Thus, all distresses, rut depths, IRI, and the distress index values need to be monitored to achieve the objective. Implementing this mitigation strategy will have an impact on the IRI values and rut depths recorded in the MDOT database; they should stay the same or be lower.

## Criteria for Project Selection and Number of Projects

The criterion for projects included within this mitigation strategy demonstration is generally restricted to higher volume roadways. No other site feature or factor should restrict the use of these mixtures or mitigation strategy. It is expected that 12 projects will be needed to estimate the reduction in distress and increase in service life, after the performance based tests are used and confirmed from implementation of mitigation strategy #2.

## Assessment of Pavement Performance

Distress surveys should be completed at periodic intervals to monitor the condition of the flexible pavements over time. The distress surveys can be completed in accordance with MDOT standard procedures.

# Mitigation Strategy #5:

# Implementation of a Fundamental HMA Mixture Property Test to Confirm Performance

## Introduction

The last strategy recommended to extend pavement life is to include a fundamental test within the mixture design or confirmation stage. It is expected that industry (contractors, as well as MDOT personnel) may object to this recommendation, and it will take longer to implement. In addition, the strategies previously discussed must first be implemented for this strategy to have any significant impact on extending service life.

It has been reported by multiple researchers that volumetric properties by themselves do not ensure an HMA mixture has the required performance properties to meet the design requirements (service life). A fundamental performance test is recommended to confirm the HMA properties used in structural design and support the volumetric mixture design procedure. This is a long term implementation mitigation strategy. Specifically, this mitigation strategy is compatible with and a confirmation of mitigation strategy #2. This strategy should be implemented after the first three mitigation strategies have been completed. It is also suggested that this strategy be implemented during the implementation and use of the new Mechanistic-Empirical Pavement Design (MEPDG) procedure.

A pilot project is recommended for this mitigation strategy because any changes in the mixture design procedure and/or criteria will take time to implement. This pilot project should be conducted after the other mitigation strategies have been implemented. The reason that the implementation of a fundamental performance test is included as a mitigation strategy is to start the planning process early. In addition, this mitigation strategy should be compatible with the use of the MEPDG for pavement structural design – integrating mixture design, structural design, and quality assurance or construction.

## Purpose or Objective of Mitigation Strategy

The objective of this implementation strategy is to select and use a fundamental performance test for confirming the volumetric properties used during the mixture design stage in selecting the target asphalt content and job mix formula, and to predict the behavior and performance of HMA mixtures. In other words, the objective is to integrate structural design, mixture design, and construction (quality assurance/acceptance).

As noted under mitigation strategy #2, MDOT has already sponsored a study for measuring the dynamic modulus and flow number on different HMA mixtures. This laboratory study will be useful in moving forward with this mitigation strategy. However, MDOT is encouraged to consider and use a mixture's resistance to cracking because nearly all of the roadway segments with poor performance exhibited excessive cracking, rather than excessive rutting. The fundamental properties and test mentioned under mitigation strategy #2 should be considered in supporting t he volumetric mixture design procedure.

## Performance Indicator to be Monitored

All distresses, IRI, rut depths, and distress index values being measured and collected by MDOT for managing the roadway network should be monitored. It is recommended that this performance test be used to assist in calibrating the MEPDG to local conditions and materials.

## Criteria for Project Selection

The criterion for selecting projects included within this mitigation strategy should be compatible with the sampling matrix developed for calibrating the MEPDG to local conditions, site features, and materials. This assumes, of course, that MDOT has future plans to adopt and use the AASHTO DARWin-ME version of the MEPDG software.

## Assessment of Performance: Tests and Data Interpretation

Distress surveys should be completed at periodic intervals to monitor the condition of the flexible pavements and HMA mixtures included within this mitigation strategy. The mixture performance test and interpretation of the test data is dependent on whether this test or tests will be used in conjunction with the MEPDG. Thus, it is suggested that MDOT consider this mitigation strategy as it prepares plans to evaluate and use the MEPDG.

This page intentionally left blank.

# *Section 3: Demonstration/Pilot Projects*

# *Product P2*

This part of the implementation plan provides detailed information for the recommended demonstration and/or pilot and demonstration projects for selected mitigation strategies. Field investigations and testing plans have been prepared for two pilot projects and two demonstration projects. The pilot projects provide additional data to increase an understanding of the mitigation strategy and its impact on construction and performance prior to or during implementation. The demonstration projects illustrate the value and effectiveness of the mitigation strategy that can be immediately implemented. In other words, the demonstration projects provide data to assist in quantifying the benefit.

[This page intentionally left blank.]

# Demonstration Project #1:

# Longitudinal Construction Joint Specification

## Introduction

Excessive lengths and severities of longitudinal centerline cracks are recorded in MDOT's performance database for flexible pavements and HMA overlays with poor performance. The magnitude and severity of the centerline cracks are lower for the pavements and overlays with good to exceptional performance. The implementation of a longitudinal construction joint specification would be beneficial to reduce the length and severity of centerline cracking and lower the distress index.

A draft longitudinal construction joint specification was prepared by MDOT in 2009, but has yet to be implemented.[3] The purpose of the specification is to delay the occurrence of longitudinal centerline cracks for longer periods of time by getting higher densities along the centerline and adjacent lane construction joint. This draft should be implemented immediately. A demonstration project, however, is recommended during implementation of the longitudinal construction joint specification in 2011.

## Objective of Project

1. Provide documentation and evidence to MDOT and industry on rolling a longitudinal construction joint and enforcement of the specification will not result in excessive penalties using standard care and workmanship.
2. Provide data to establish (confirm) the testing guidelines for measuring the density along a longitudinal construction joint that can be used for acceptance. In other words, the testing guidelines should specify the locations of where the density tests/cores will be taken relative to the joint.
3. Provide data to confirm the values and limits included in the Percent Within Limits specification.

## Experimental Hypotheses

- Null hypothesis related to objective #1: Rolling pattern and joint type have no impact or does not affect the density measured along the longitudinal construction joint. It is expected that the null hypothesis will be rejected from the experimental data.

[3] Special Provision for the Acceptance of Longitudinal Joint Density in Hot Mix Asphalt (HMA), 2009.

- The longitudinal construction joint specification to ensure a minimum density level will improve performance and reduce the length and severity of longitudinal centerline cracks. To accept or reject this hypothesis requires that the demonstration projects and individual lots (or sublots) be monitored for at least 5 years. MDOT can decide to base the long term performance decision on the density level itself, because HMA density is one of the most important properties related to long term performance.

## Experimental Factors

The following lists the primary experimental factors included in the sampling matrix (refer to Figure 2 under Mitigation Strategy #2). These factors are grouped into two types: those that are varied between the projects and those that can be varied within a particular project.

- *Type of Construction*: Projects should be selected to include both new construction and HMA overlays. Type construction should not be varied within a particular project, unless the project includes lane widening and rehabilitation.

- *Type of Joint*: Three types of joints should be included in the sampling matrix (refer to Figure 7); (1) butt joint created with the screed end plate, (2) a tapered joint, and (3) the notched wedge joint. Butt joints and the notched wedge joints are more commonly used in Michigan. Butt joints are used during new construction or for HMA lift thickness less than 2 inches. The notched wedge joint is used for safety reasons when the roadway must be opened to traffic and the HMA lift thickness is greater than 2 inches (refer to Figure 8). It is expected that the type of joint will be kept constant within a particular project, and only varied between projects. Type of joints is expected to have an effect on the final density of the joint.

- *Type of Roller in Breakdown Position*: Both steel wheel rollers and rubber tired rollers can be used in the breakdown position. Steel wheel rollers are the ones more commonly used in the breakdown position in Michigan. It is expected that few projects will be identified where the rubber tired pneumatic rollers are used in the breakdown position. Although the type of roller can be varied within a project, it is suggested that the type of roller used in the breakdown position be kept constant within a specific project.

- *Rolling Pattern*: Rolling pattern is dependent on the type of roller that is used in compacting the joint and whether it is an unconfined or confined. The rolling pattern can be varied along a specific project to reduce the number of projects that are required. It is recommended, however, that the same rolling pattern be used within a specific lot for the project so the roller operator is less likely to get confused about which pattern is needed in a particular lot of the project. MDOT should define the lot size for this experiment to reduce the number of projects and amount of HMA for any particular lot. Rolling pattern is expected to have an effect on the final density of the joint.

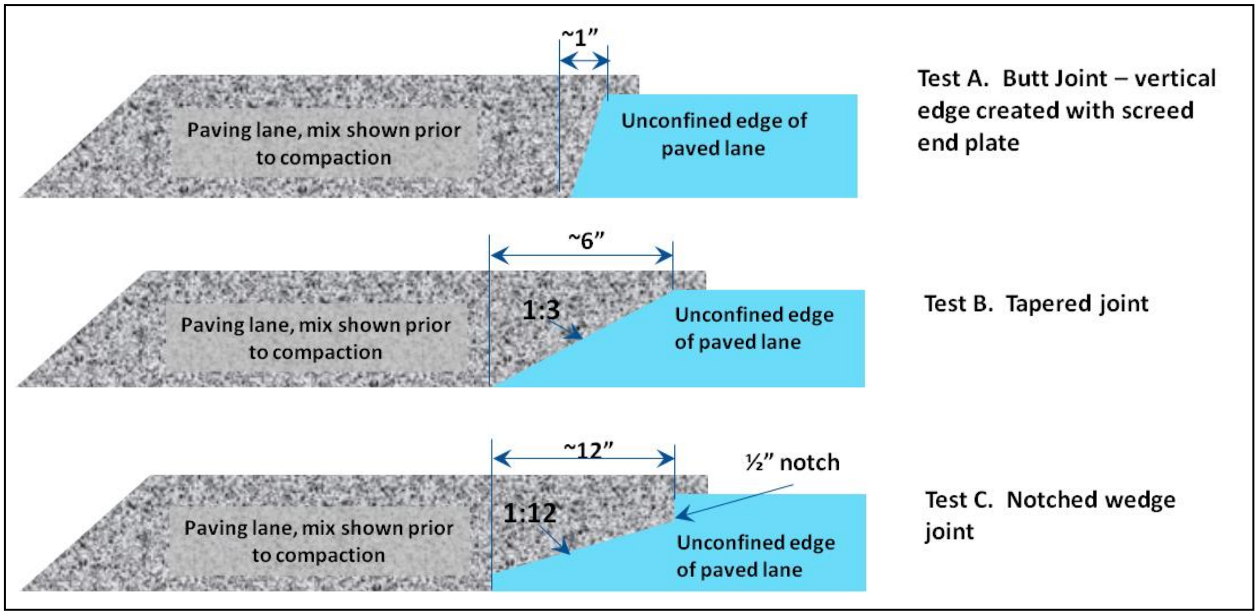



Figure 7. Type of Longitudinal Joints

Figure 8. Notched Wedge Joint (a small steel drum is attached to paver to roll the wedge behind the paver)

The following defines the rolling patterns included in the sampling matrix (refer to Figure 2) for a confined and unconfined joint.

- Steel wheel rollers (static and vibratory modes):
  - Unconfined Joint: Two locations are recommended for use during the first pass of the steel wheel roller along the joint (static or vibratory modes).
    1. The first and preferred location of the first roller pass along the joint – the edge of the steel drum is extended 4 to 6 inches over the edge of the lift.
    2. The second location of the first roller pass along the joint – the edge of the steel drum is adjacent to the edge of the lift; in other words, no overhang of the roller over the edge of the lift.
  - Confined Joint: Three locations are recommended for use during the first pass of the steel wheel roller along the longitudinal construction joint (static or vibratory modes dependent on location of roller for the first pass; refer to Figure 9).
    1. The first and preferred location of the first roller pass along the joint – the roller is operated on the hot side of the joint and overhangs the edge of the lift by 4 to 6 inches (static or vibratory modes).
    2. The second location of the first roller pass along the joint – the roller is operated on the cold side of the joint for the first pass; only about 6 inches of the roller is operated on the hot side of the mat. This is defined as the cold side pinch method (static mode only for the first pass).
    3. The third location of the first roller pass along the joint – the roller is operated on the hot side of the joint but the first pass is located about 4 to 6 inches from the longitudinal joint on the hot side. This is referred to as the hot side pinch method. The second pass of the roller is typically over the part not rolled during the first pass (static or vibratory modes for both passes).
- Rubber tired pneumatic rollers: For both the unconfined and confined joints, the edge of the tire should be located along the edge of the mat – no overhang of the roller. Rubber tired rollers are not commonly used in the breakdown or primary position in Michigan.

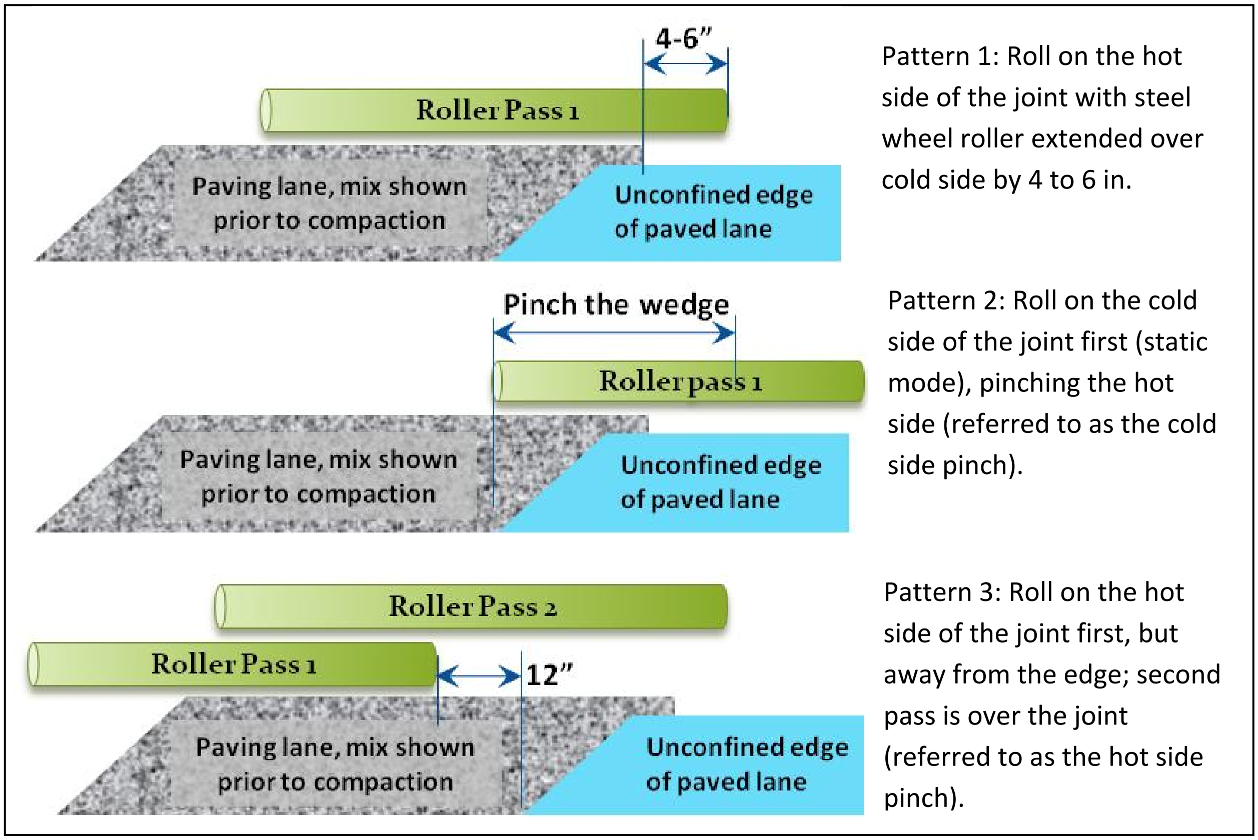



Figure 9. Type of Rolling Patterns for Longitudinal Construction Joint (Steel Wheel Roller)

- *Sealed and Unsealed Joints*: This experimental factor should not have an effect on the final density of the joint, but may have an effect on long term performance. MDOT can decide to exclude this factor from the sampling matrix, because a tack coat should be applied to all cold joints, especially if the joint was opened to traffic prior to placing the adjacent lane. It is recommended that the standard tack coat material specified by MDOT be used, unless MDOT wants to consider other more expensive materials that have been used as an adhesive for longitudinal construction joints. Sealed and unsealed (or glued and unglued) joints should be varied between the lots within the demonstration project. If this factor is included in the experiment, the distress surveys become mandatory to determine the benefit and effectiveness of sealing the joints in comparison to unsealed joints. Distress surveys and performance monitoring will require a minimum of 5 years to determine any systematic difference in centerline cracking and its severity between sealed and unsealed joints.

Other parameters or features that should be recorded during paving, but not included in the experimental matrix, are listed below.

- Overlap of HMA on the cold side of the joint (refer to Figure 10). Excessive overlap of the HMA onto the cold side of the joint can result in inadequate densities along the hot side of the joint because the amount of "roll down" is much less at the joint. No overlap of the HMA onto the cold side of the joint can result in an insufficient amount of mix along the joint. The proper amount of overlap should be 0.5 to 1 times the nominal aggregate diameter.

- Distance between the end of the auger and screed end plate (refer to Figure 11). Excessive distance between the end of the auger and screed end plate (24+ inches) can result in longitudinal segregation near the outside edge of the mat. Longitudinal segregation results in low densities along the joint.

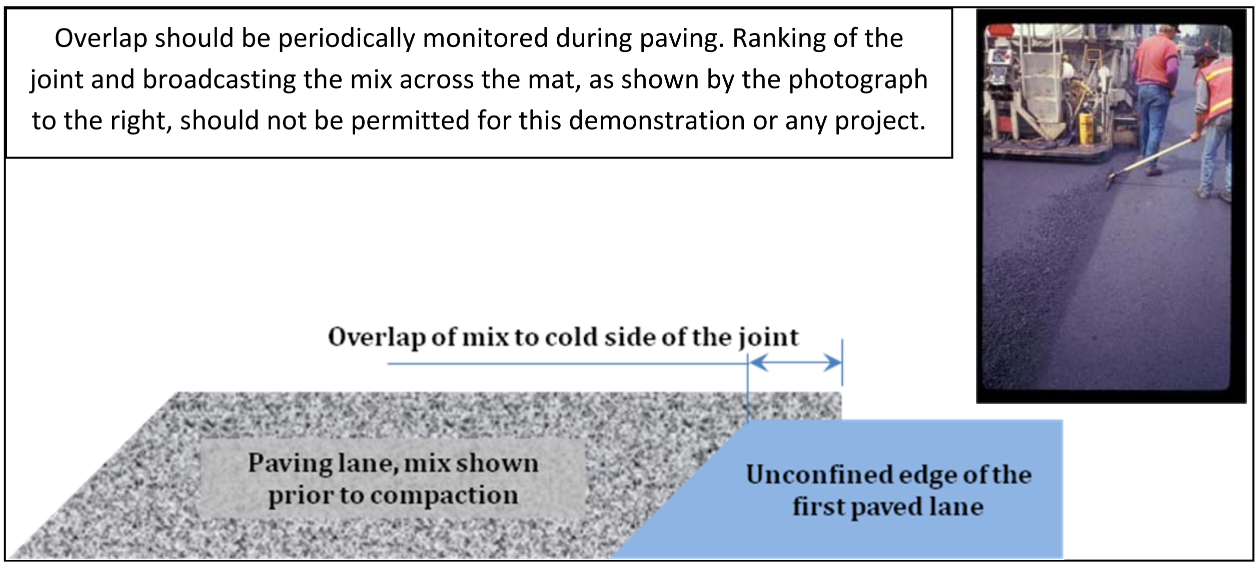



**Figure 10. Overlap of Mixture on Cold Side of Joint**

## Segmentation of Demonstration Project

The layout of the individual test sections (lots) within each demonstration project is presented in Figure 12. The individual test sections or lots represent a different rolling pattern for the type of joint included in an individual project. The sampling matrix for this demonstration project was presented in Figure 2.

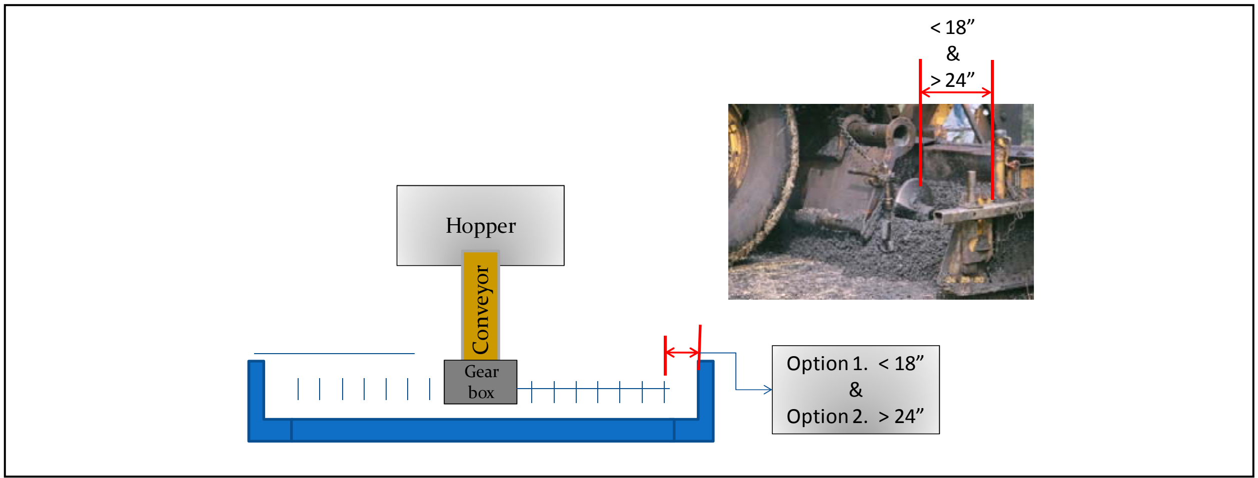
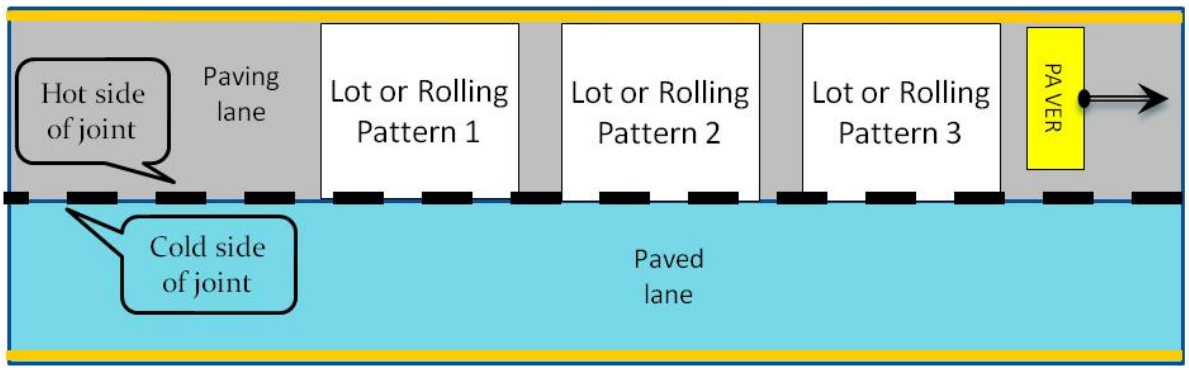



**Figure 11. Distance Between End of Auger and Screed End Plate**



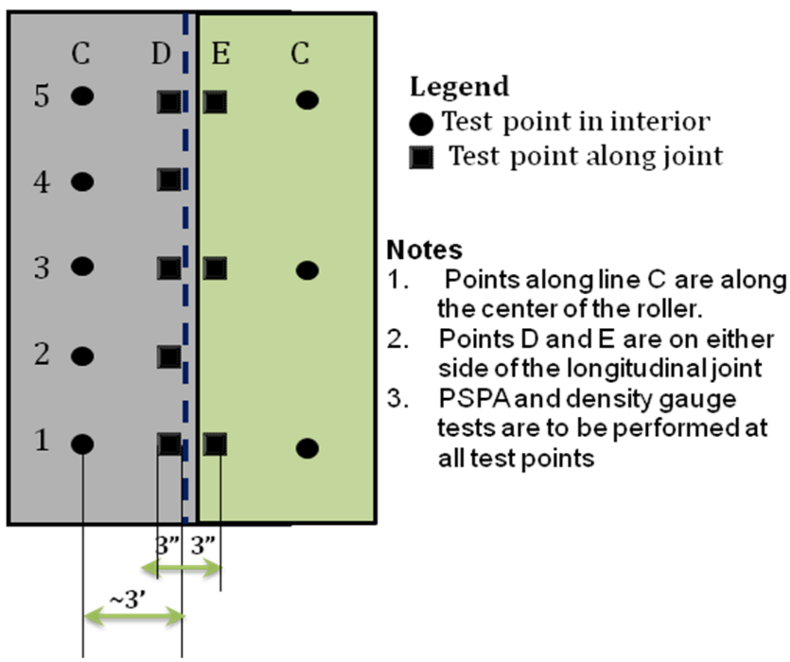

- Projects can be two lane roadways or multiple lanes in the same direction.
- The test sections represent lots within the project that have a specific rolling pattern. A typical lot is defined as a day’s paving, but MDOT can decide to define the lot on another basis for the demonstration projects to reduce the number of days of paving.
- The different rolling patterns used on the demonstration project should be varied along the project length, but be kept constant within a particular lot.
- For the set of rolling patterns, it is recommended that the construction joint be sealed or unsealed so that the experiment is not confounded by other factors.

**Figure 12. Test Section Segments**

## Field Test Plan During Construction

### *Nondestructive Tests*

Two field tests are recommended during construction to evaluate the condition of the joint to accept or reject experimental hypothesis #1: (1) stiffness, measured with the portable seismic pavement analyzer (PSPA); and (2) density, measured with the nuclear or non-nuclear density gauges. Stiffness is not included in the draft longitudinal joint specification, but is included in the field test plan to identify changes in other mixture properties rather than just density. Figure 13 shows the suggested layout of the test points for evaluating the condition of the joint after final rolling, while Table 2 is a summary of the field activities for this demonstration project.




PSPA and density readings with a nuclear or non-nuclear density gauge should be made at 5 locations on the hot side of the joint within the lot for each rolling pattern used to compact the longitudinal joint. Tests at 3 locations on the cold side of the joint should be sufficient. In addition, these tests should be made along the interior of the mat for comparison to the joint readings.

Figure 13. Test Point Location; Determining Specification Values for Joint Density for Each Lot

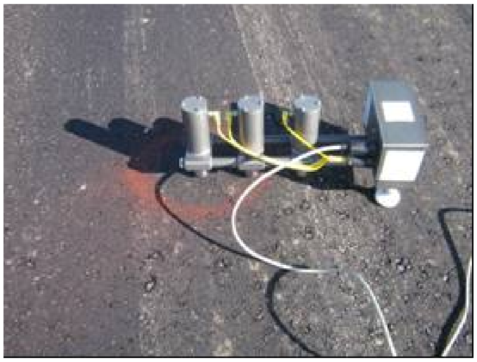
Table 2. Summary of Field Test Plan and Activities

| Field Activity for One Type of Joint | | Comment |
|---|---|---|
| 1 | Locate test sections for the different rolling patterns used during the paving operation. Multiple compaction zones are recommended within the same sublot. | Refer to Figure 13. Areas with the same rolling pattern should be marked for future distress surveys. |
| 2 | Monitor the material being placed along the longitudinal construction joint during placement of adjacent lanes. | The mix previously placed in the adjacent lane should have been monitored in the same manner. |
| 3 | After mix placement and finish rolling, mark the locations for the PSPA tests and density gauge readings along the joint and within the interior of the mat. | Refer to Figure 2. |
| 4 | Take PSPA and density gauge readings in accordance with procedure documented in NCHPR project 10-65. | Three density gauges readings and four PSPA tests should be made at each test point. |
| 5 | Mark locations for the three cores and drill cores. The bulk specific gravity should be measured on each core. | Two cores located along the joint and one within the interior of the mat (lowest and highest density). |

The density gauge and PSPA device can take readings at a rapid rate and will not interrupt the contractor's production rates. At each test location, cluster tests should be performed using both devices. Three readings with the density gauges and three readings with the PSPA should be taken at each test point. The following provides a summary of the tests and location of the devices relative to the longitudinal joint.

- <u>PSPA Test to Estimate the In Place HMA Stiffness:</u>

    1. Place the sensor bar on the pavement surface and parallel to the longitudinal joint and take the first reading.
    2. Rotate sensor bar to that it is perpendicular to the joint, but does not cross the joint.
    3. Move the sensor bar so that the joint is located between the loading point and first sensor on the sensor bar.



- <u>Gauge to Estimate the In Place HMA Density:</u>

    1. Place the density gauge on the pavement surface with the face parallel to the longitudinal joint (center of gauge is about 2 to 3 inches from the joint).
    2. Rotate the gauge so that its face is perpendicular to the joint, but not located over the joint.
    3. Move the gauge so that the middle of its base is located over the longitudinal joint.

The average measurement will be considered representative of the material property at each location, and used to evaluate the reasonableness of the values included in the draft longitudinal construction joint specification (objectives #1 and 3). The individual readings for both devices, however, should be recorded and consistently identified by their specific test location relative to the joint.

### *HMA Cores for Visual Observations and Density Measurements*

A minimum of two cores should be taken within every section (lot) along the joint during construction. One core should be recovered from the interior of the mat. The cores should be located in areas with the highest and lowest density gauge readings. The cores are used to adjust the nuclear or non-nuclear density readings to the core densities. For the tapered or notched wedge joints, a 4 or 6-inch diameter core should be located so that its edge is on the hot side about 1 inch from the joint but material from the taper or wedge at the bottom of the layer is recovered. For butt joints, the edge of the core should be located less than 1 inch from the joint.

## Post Construction Performance Data

Distress surveys are needed to evaluate experimental hypothesis #2. Distress surveys should be performed annually to measure the length and severity of longitudinal centerline cracks and any deterioration along the longitudinal construction joint. The distresses that should be monitored and quantified to confirm experimental hypothesis #2 include:

- Longitudinal cracking and deterioration along the longitudinal joint, grouped by low, medium, and high severity
- Potholes, grouped by number of potholes along joints
- Raveling, grouped by area adjacent to joints

# Demonstration Project #2:

# Biased Inspection and Testing During Construction

## Introduction

Nearly all projects classified with poor performance exhibited excessive center lane longitudinal cracking. It is expected that this cracking is a result of an inadequate amount of mixture being pushed under the paver gear or drive box; sometimes referred to as center lane segregation. An economic and effective method to reduce the occurrence of these longitudinal cracks is to conduct density tests and visual inspection at the center of the paver during the first couple of days of paving and then on an as needed basis as directed by the project engineer.

The infrared camera is a device that can be easily used to identify areas with construction defects that cause center lane longitudinal cracks and deterioration. As such, biased sampling and testing with the use of an infrared camera is recommended to identify factors causing center lane cracking during the first day of paving so corrective actions can be taken, if needed.

A demonstration project is suggested to illustrate the biased inspection and testing and use of the infrared cameras. Implementation of biased inspection and testing activities should have no impact on construction costs but should extend the service life of flexible pavements by eliminating the center lane longitudinal cracks and deterioration.

## Objective of Demonstration Project

1. Prepare/confirm a set of guidelines that can be used by MDOT staff to locate problem areas at the beginning of paving so that corrective actions can be taken by the contractor. The initial guidelines are included in the next section.

2. Demonstrate use of infrared cameras to identify construction defects near the center of the auger chamber and in other areas of the mat (refer to Figures 4 and 5 included in Mitigation Strategy #3).

## Guidelines for Selecting Areas to be Sampled and Tested

The following is a draft set of guidelines that can be initially used for implementing biased inspection and testing activities.

> *During the first day of paving, the inspector shall monitor the paving operation and measure the density in specific areas that are identified as "cold spots." The infrared*

*camera should be used to identify "cold spots," If present. Cold spots can be the result of longitudinal and truck to truck aggregate segregation, or an insufficient amount of mixture being placed in selected areas – center of the auger chamber. One area or location to monitor is the mixture placed at the center of the auger chamber and along the outside edges of the slat conveyor (transferring mixture from the paver hopper to the auger chamber).*

*A density reading with a calibrated nuclear (or non-nuclear) density gauge should be taken at the center of the paver at periodic intervals depending on the length of each sublot during the first day of paving. If the density readings are consistently low, relative to other areas of the mat, paving should be discontinued to determine the reason for the lower density values and corrective action taken.*

*If no defects or "cold spots" with low density readings are found, paving can continue. The infrared camera should be used over the course of the project to identify potential "cold spots" and/or cores taken to confirm that the material has been adequately compacted.*

*If conditions change during the course of the project, biased sampling and testing should be performed at the direction of the project engineer.*

## Construction/Project Features Included in Demonstration

A demonstration project is recommended to achieve the second objective prior to implementation. MDOT, however, can decide to proceed with implementing this strategy on a routine basis. 2012 paving projects selected for this demonstration project should include a range of HMA parameters or properties:

1. Lift thickness: Projects with lift thickness less than 2 inches and greater than 2 inches should be selected for the demonstration. Lift thickness has a significant impact on the loss of temperature or time available for compaction.

2. Aggregate blend: Projects with gap-graded, coarse-graded, and fine-graded aggregate blends should be selected for the demonstration. Gap and coarse-graded mixtures are more susceptible to aggregate segregation and more likely to exhibit greater temperature differences in localized areas for contractors not paying close attention to the paving operation.

## Equipment and Field Test Plan During Construction

Two pieces of equipment are recommended for use in monitoring construction and assessing the condition of the HMA lift at the time of construction: nuclear or non-nuclear density gauges and an infrared camera. The density gauges are used to measure density of the in place mixture after final rolling in multiple locations. The infrared camera is used to locate cold spots behind the paver and after final rolling. Some cores will need to be taken to confirm the density readings.

As understood, MDOT does not have any infrared cameras for monitoring surface temperature differences during paving. It is recommended that at least one infrared camera be purchased for the 2012 construction season to demonstrate the effectiveness of biased sampling and testing. This camera can be used within a specific region or used on specific projects throughout Michigan. In the future, at least one infrared camera per region is recommended.

The following is a listing of the steps or activities suggested to achieve the project objectives.

- Take an infrared image of the HMA surface temperature behind the paver prior to rolling. The images can be saved within the camera for future reference. Images should be taken at different times during the rolling process to determine whether significant temperature differences occur. If the image illustrates uniform temperatures (refer to Figure 6), temperatures will usually stay uniform at a later time; except in areas that are shaded and adjacent to areas that have no shade.

- For projects where the surface temperature is uniform across and along the area paved (no cold spots; refer to Figure 6), the density gauge should be used to randomly measure the density along the center of the paver and outside the edges of the slat conveyor after final rolling. No bias or systematic difference should exist between the density values measured at the center of the paver and those measured in other interior areas of the mat.
    - If no systematic differences in densities are found, paving should continue.
    - If consistently lower densities are found at the center of the paver but those densities are above the specification value, paving can continue, but the inspector should continue to closely monitor the paving operation with the infrared camera and density gauge.
    - If consistently lower densities are found at the center of the paver and those densities are below the specification value, paving should be discontinued to determine the reason for the lower densities and corrective action taken.

- For projects where cold spots are located (refer to Figures 4 and 5), designate or mark the location of the image on the lift and mark the location of the cold spot. Multiple images should be taken as the paver travels down the roadway to confirm multiple locations of the cold spots. After final rolling, the density gauge should be used to take readings in the cold spots and in areas outside the cold spot.

- If the densities are found to be consistently lower and outside the specification value, paving should be discontinued until the cause of the cold spots are determined and corrective action taken to eliminate the cold spots.

- If the densities are found to be consistently lower in the cold spot, but exceed the specification value, paving can continue. The inspector should continue to closely monitor the paving operation with the infrared camera and density gauge.

- Cores should be taken in selected areas to adjust the nuclear or non-nuclear density readings. These cores are used to calibrate the density gauge.

- Once adequate density levels have been confirmed, the inspector should use the infrared camera periodically (or at random) to ensure that the surface temperatures of the lift are remaining uniform. If any cold spots are located during construction (longitudinal or truck-to-truck temperature differences; refer to Figures 4 and 5), densities should be taken within those areas to confirm that the density exceeds the specification value.

# Pilot Project #3:

# Revised HMA Mixture Design Criteria

## Introduction

Extensive lengths of transverse cracks, alligator cracks, longitudinal edge and wheel path cracks, block cracking, and raveling were recorded on just about all of roadway segments exhibiting poor performance. Conversely, segments with exceptional performance exhibited significantly less transverse cracks and tears, and minor lengths of longitudinal cracks, alligator cracks, block cracking, and raveling.

The roadway segments with excessive cracking were not restricted to colder climates or MDOT regions, soil type/strength, or traffic level so it was concluded that these cracks are more of a materials issue rather than a climate, traffic, or structural issue. Excessive alligator cracks, longitudinal cracks in the wheel path and along the edge, and transverse cracks are characteristic of high stiffness, low strength HMA mixtures relative to the supporting layers. Higher laboratory compactive efforts (higher $N_{design}$ values) will result in lower effective asphalt contents by volume. Reducing the number of gyrations during mixture design will increase the effective asphalt content by volume, which has an effect on mixture durability and its resistance to cracking, especially for lower volume roadways that are thinner or pavements built over weak soils – both of which have higher deflections.

The hypothesis is that some HMA mixtures are susceptible to fracture because of lower asphalt contents. Lower asphalt contents can reduce the tensile strength of HMA and result in brittle mixtures. Higher laboratory compaction efforts can result in lower effective asphalt contents by volume. More importantly, MDOT and industry have designed gap-graded for uniform-graded unmodified HMA mixtures on numerous projects, especially for the wearing surface. Gap-graded, unmodified HMA mixtures can exhibit higher permeability because of higher portions of larger (coarser) aggregate in the aggregate blend. Low asphalt content mixtures with high permeability are more susceptible to accelerated aging and moisture infiltration, which increases surface deterioration and reduces the mixture's resistance to cracking. Revising the mixture design guidelines and laboratory compaction criteria should improve on the mixture's resistance to cracking for both low and high volume roadways.

A pilot project is needed before making any revisions to the current HMA mixture design procedure. This pilot project will provide data to determine the effect of lowering the number of gyrations on the volumetric properties that are used for acceptance and payment. Simply lowering the number of gyrations is not recommended because of the potential impact on rutting and other distresses. The pilot project will also provide data to compare the fundamental properties between different aggregate blends (gap-graded versus coarse and fine-graded mixtures).

## Objective of Pilot Project

1. Provide experimental data to determine whether lowering the number of gyrations for mixture design to determine the target asphalt content based on volumetric properties will increase the mixture's resistance to fracture, while maintaining its resistance to rutting.
2. Evaluate the fundamental properties (related to performance) of gap-graded, unmodified HMA mixtures, in comparison to coarse-graded and fine-graded neat mixtures and/or mixtures with enhanced fundamental properties. Mixtures with enhanced fundamental performance properties are included in Pilot Project #4.

## Experimental Hypotheses

1. Reducing the number of gyrations for mixture design and increasing the minimum VMA will increase the effective asphalt content by volume, increasing the mixture's resistance to fracture and disintegration, and make the mixture more tolerant to tensile strains.

## Experimental Factors

The following lists the experimental factors included in the sampling matrix (refer to Figure 3 under Mitigation Strategy #3).

- Layer type: HMA base layer and wearing surface for new construction or reconstruction (including crush and shape with bituminous surfaces) and HMA overlays. Layer type is the primary factor, while pavement structure is a secondary factor in the sampling matrix. Projects should be selected that include both new construction and HMA overlays.

- Traffic level: High to low traffic volumes. This experimental factor will be used to evaluate the use and impact of number of gyrations on the volumetric and fundamental properties of a particular aggregate blend and aggregate type related to durability versus load resistance properties. At present, $N_{design}$ is dependent on traffic level. Other parameters that are related to mixture flexibility maybe as important. In other words, mixtures may need to be more flexible or more strain tolerant for pavements with higher deflections, independent of traffic level.

- Aggregate type and blend: Coarse-graded, gap-graded and fine-graded mixtures, and/or small versus large aggregate blends. Aggregate blend is the primary factor included in the sampling matrix, because of its effect on the asphalt content demand based purely on surface area, as well as on the mixture's resistance to cracking and rutting. Nominal aggregate size is a secondary parameter and is included in the sampling matrix through lift thickness; thicker HMA base layers to thinner wearing surfaces. Layer thickness should be compatible with aggregate size because of the minimum lift to nominal aggregate size ratio requirement.

- Number of Design Gyrations: The number of gyrations included in the Michigan mixture design procedure represents the baseline condition (Asphalt Institute SP-2 Mixture Design Manual). It is suggested that two other levels be used to determine the effect on the volumetric and fundamental properties of the mix at the target asphalt content. The gyration levels selected and used can be based on preliminary studies; either conducted by MDOT or other agencies that have already lowered $N_{design}$.

It is recommended that the climate or regional effect on asphalt performance grade selection be kept the same and not included in the sampling matrix. However, projects should be selected to include different performance grade asphalts that are typically specified and used by MDOT.

## Laboratory Test Plan

The laboratory test plan represents a large testing effort, which is summarized in this section. A total of 8 test specimens are required for each gyratory level or 24 test specimens for three levels of gyration for each mixture. It is expected that the number of specimens can be reduced to optimize the sampling matrix for the different sets of test specimens. The following summarizes the testing plan and sampling matrix (refer to Figure 3).

The laboratory evaluation is grouped into two subsets.

1. The first subset of test specimens: all HMA mixtures included in the sampling matrix should be designed with the current mixture design procedure and criteria ($N_{design}$ gyrations). After the target asphalt content and job mix formula have been determined using existing procedures, the fundamental properties should be measured on laboratory prepared specimens at the expected air void level based on the construction specification.

2. The second subset of test specimens: the HMA mixture should be compacted using reduced levels of compaction or $N_{design}$ levels. The target asphalt content and job mix formula is determined for the revised compaction level. The fundamental properties are measured on laboratory prepared specimens at the same expected air void level specified during construction.

Two types of laboratory and field tests are recommended for use in monitoring construction and assessing pavement performance at the time of construction. These tests include volumetric and fundamental properties of the HMA.

- Volumetric properties include those properties normally measured using the current mixture design process; density, air voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA). The volumetric properties are used to determine the target asphalt content in accordance with Michigan's existing procedures – current mix design methodology for selecting the target asphalt content.

- Fundamental performance properties include dynamic modulus, tensile strength and tensile strain at failure using the indirect tensile test (or a measure of the strain energy required to fracture the specimens), and a repeated load permanent deformation test. The fundamental properties are measured on laboratory compacted specimens to the expected in place air void level and compared to the number of gyrations used to determine the target asphalt content and job mix formula.

    - Dynamic modulus tests should be performed in accordance with AASHTO T 79 (*Determining the Dynamic Modulus and Flow Number for HMA using the Asphalt Mixture Performance Tester*) for preparing a master curve relationship (AASHTO PP 61 or PP 62). Replicate test specimens should be sufficient for each mixture.

    - Indirect tensile strength tests should be performed in accordance with AASHTO standards for determining the indirect tensile strength and tensile strain at failure or the strain energy. Triplicate test specimens are needed for this test because the strain measurements are variable. The test temperature is the equivalent temperature for fatigue.

    - Repeated load permanent deformation tests should be performed in accordance with AASHTO T 79 for determining the flow number, with the exception that confined tests are needed (the confining pressure is 10 psi and the applied deviator stress is 70 psi). The other difference is that the slope and intercept of the plastic strain versus number of load cycles need to be determined and reported in addition to flow number. The test temperature is the equivalent temperature for rutting. Triplicate test specimens are needed for this test because of the variability in the test results.

The deformation tests should be performed on test specimens that have been short term aged, while the fracture tests should be performed on test specimens that have been long term aged. Short term aging is used to evaluate rutting, while long term aging is used to evaluate transverse and longitudinal cracking and other mixture disintegration type distresses. The fundamental tests are used to determine the effect of changing volumetric properties on the performance properties.

As noted previously, MDOT has already sponsored the use of some fundamental tests to characterize HMA mixtures (You, et al., 2009). The two tests included within that study was the dynamic modulus and flow number (or repeated load permanent deformation) tests. Flow number is an estimate of the mixture's resistance to rutting, while dynamic modulus provides some measure of the mixture's resistance to alligator cracking and rutting.

Rutting was not found to be an issue in terms of premature failures; few roadway segments were found to have excessive rut depths. Longitudinal and transverse cracks were the more predominant distress for roadway segments with inferior performance. As such, MDOT is encouraged to use a practical fundamental test that measures a mixture's resistance to cracking.

The tensile strength and tensile strain at failure or the strain energy of the mixture can be measured using the indirect tensile test. MDOT is encouraged to use a fracture test for evaluating any change in the mixture design procedure (reducing the number of gyrations for design). Dynamic modulus and flow number (the raw data of plastic strain versus number of load cycles and not the flow number) are still beneficial, especially in determining the HMA mixture inputs to the new Mechanistic-Empirical Pavement Design Guide (MEPDG).

## Performance Assessment of Revised HMA Mixture Design Guidelines

Distress surveys should be completed at periodic intervals to monitor the condition of the flexible pavement or HMA overlay over time. The project should be divided into lots used for acceptance based on MDOT standard procedures and practice. Some of the lots of the project should be designed and placed using current mixture design practice (the standard sections), and the others designed and placed using the revised mixture design guidelines (the companion sections).

The distress surveys should be completed in accordance with the standard procedures being used by MDOT. Each lot should be monitored to determine the impact of HMA mixtures on long term performance.

To maximize the benefit from this pilot project, it is recommended that these sections be identified and well documented for future use in calibrating the MEPDG to Michigan local conditions and materials.

# Pilot Project #4:

# Wearing Courses with Enhanced HMA Mixture Properties

## Introduction

All projects with poor performance were found to exhibit transverse cracks and tears, alligator cracks, longitudinal cracks in the wheel path, and surface deterioration (raveling). The amount and severity of these cracks and raveling can be reduced by using higher quality wearing surfaces; such as stone matrix asphalt (SMA) and polymer modified asphalt (PMA). MDOT and local contractors have designed and used gap-graded, unmodified HMA mixtures. These mixtures can have lower asphalt contents and high permeability resulting in durability issues; raveling, block cracking (longitudinal and transverse cracks), and alligator cracking with time.

It is hypothesized that a cause for this premature cracking is a result of the gap-graded unmodified HMA mixtures that have been specified and used in Michigan, especially for higher volume roadways. Thus, use of wearing courses with enhanced mixture and asphalt properties is expected to reduce the amount of transverse, block cracking, and longitudinal cracking in the wheel path.

As noted previously, MDOT has allowed the use of gap-graded dense HMA mixtures for the wearing surface. Gap-graded HMA mixtures can exhibit high permeability because of the higher portions of larger aggregate in the aggregate blend. Higher permeability mixtures are more susceptible to accelerated aging and moisture infiltration, which increase surface deterioration of the mixture and reduce its resistance to cracking. The intent of this pilot project is to reduce the amount and severity of various types of cracking (block, alligator, transverse cracks and tears, and longitudinal cracks in the wheel path) and surface deterioration by using HMA mixtures with enhanced properties (PMA and SMA).

There is a lot of support that documents the benefit and reduction in surface distress with the use of PMA and/or SMA mixtures to be used as the wearing surface. The MDOT database, however, does not identify those projects were PMA or SMA type engineered mixtures were placed as the wearing surface. It is recommended that MDOT start recording and documenting the projects where these mixtures with enhanced properties have been used to establish performance characteristics that can be quantified and compared to conventional, neat HMA mixtures for the site features, materials, and other conditions encountered in Michigan.

It is recommended that MDOT proceed with the use of SMA and PMA wearing surfaces on the higher volume roadways, but only after the two demonstration projects have been completed.

This pilot project is compatible with pilot project #3 (Mitigation Strategy #2). In fact, the results from pilot project #3 can be used to determine the fundamental properties for PMA and SMA mixtures, as compared to the existing HMA mixtures produced and placed under the current construction and material specifications. A fundamental performance test should eventually be used to measure the properties of any HMA mixture, but especially those on higher volume roadways (refer to mitigation strategy #5).

## Objective of Pilot Project

The objectives of this pilot project are to:

1. Collect performance data on roadway segments with PMA and SMA wearing surfaces for quantifying the magnitude of the extended service life or reduction is pavement distress.

2. Revise the MDOT performance database to designate and record the mixtures with enhanced surface properties.

It is recommended that MDOT proceed with implementing Mitigation Strategy #4, but there is insufficient data for quantifying the increase in service life or reduction in distress for conditions encountered and materials used in Michigan. This longer term pilot project has been recommended to achieve this objective. The data from the pilot project will be used to confirm the expected increase in service life of 3 to 5 years based on studies sponsored by other agencies (Asphalt Institute, Colorado DOT, etc.).

## Performance Assessment of PMA and SMA Mixtures

Distress surveys should be completed at periodic intervals to monitor the condition of the flexible pavements over time. The distress surveys can be completed in accordance with MDOT standard procedures. It is recommended that the following distresses be monitored and quantified during the field distress surveys:

- Smoothness in terms of International Roughness Index (IRI)
- Rutting in the wheel path
- Alligator cracking grouped by low, medium, and high severity
- Block cracking grouped by low, medium, and high severity
- Longitudinal cracking in the interior of the lane, grouped by low, medium, and high severity
- Longitudinal cracking along the longitudinal joint, grouped by low, medium, and high severity
- Potholes, grouped by number of potholes in the interior and along joints
- Raveling, grouped by area in the interior and adjacent to joints

This pilot project will require a minimum of 10 years to complete to collect data within Michigan for confirming the increase in service life with the use of wearing surface with enhanced mixture properties. This increase in service life, however, can be estimated in a much shorter time period by measuring the fundamental performance properties of the mixtures used on selected project.

To decrease the amount of time for confirming the increase in service life, the procedure used by the Asphalt Institute in combination with the measured mixture properties under Pilot Project #3 is recommended.