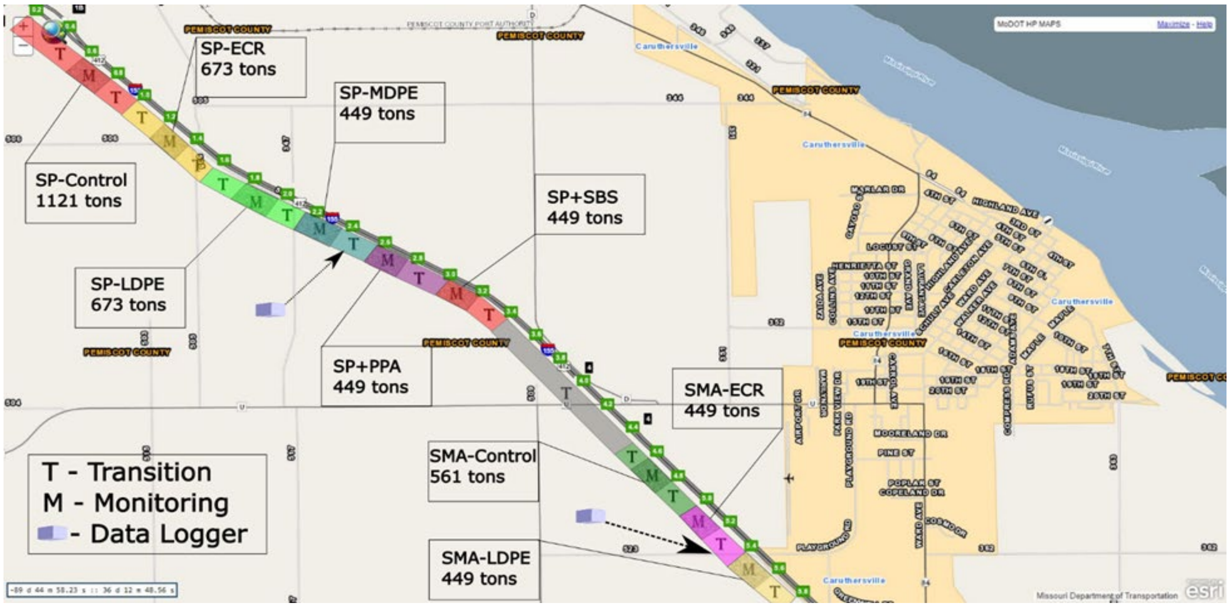
# Implementation of Balanced Mixture Design in Missouri Test Sections with Modifiers

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**16. Abstract**

The overarching goal of this study was to advance the deployment of innovative pavement technologies prevalent in the state of Missouri. In this study, the focus was on evaluating recycled polymers for use in asphalt mixtures and Balanced Mixture Design (BMD) implementation. Nine test sections were constructed on I-155 near Hayti, MO. Six sections were constructed with Superpave dense graded mixtures and the other three with Stone Matrix Asphalt (SMA) mixtures. These sections were modified with recycled polymers such as ground tire rubber and different kinds of waste plastics, and with virgin polymers such as Styrene-Butadiene-Styrene (SBS) and Polyphosphoric Acid (PPA). A Joint Special Provision (JSP) was utilized for this project, which recommended the BMD thresholds for CT-Index to be 45.0 for dense-graded mixtures and 160.0 for SMA mixtures. The Hamburg rutting criteria was 12.5 mm at 15,000 passes. Additionally, an elevated BMD criteria of CT-Index = 80.0 was imposed for two of the six dense graded mixtures. The team conducted cracking, rutting, as well as moisture damage tests on the specimens produced in the lab and in the plant. All the results indicate that the mixtures incorporating recycled polymers perform equivalently or better than the virgin polymer mixtures. In the future, the research team will continue to evaluate the long-term performance of these sections with periodic field visits, with an aim of correlating field observations to laboratory results. This will help finetune the BMD thresholds, leading to more optimized mixture designs. Furthermore, the long-term performance of the recycled polymer sections will inform the development of specifications to facilitate the adoption of recycled polymers in lieu of virgin polymers.

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**Final Report**

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## Disclaimer

The findings and conclusions of this study are those of the research team, and do not necessarily reflect the views and opinions of the Missouri Department of Transportation.

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# Executive Summary

The overarching goal of this study was to advance the deployment of innovative pavement technologies being investigated in the state of Missouri. In the recent past, the Missouri Department of Transportation (MoDOT) has investigated the use of recycled polymers in their Superpave and SMA mixtures. Recycled polymers such as ground tire rubber and waste plastics have been the primary focus of this effort. The increasing adoption of Balanced Mix Design (BMD) methodology has helped in the establishment of a framework wherein the contractors can facilitate material innovation through the adoption of these recycled polymers. To that end, MoDOT has supported the construction of several asphalt test sections to evaluate the field performance of recycled polymer modified asphalt mixtures designed with BMD methodology. For example, in 2021 MoDOT constructed four test sections on Route 740 (Stadium Blvd.) in Columbia, MO as a pilot implementation of BMD methodology and acceptance criteria, and as a demonstration for the use of recycled polymers in asphalt mixtures. This study also covers a similar demonstration project on I-155 near Hayti, MO, in the bootheel of Missouri. It builds on the Stadium Blvd. project by evaluating more variables such as different modifiers, mixture types, and traffic.

In 2023, to further the research begun on Stadium Blvd., MoDOT identified an approximately six mile stretch along I-155 to lay out nine mixtures. The mixtures included recycled (ground tire rubber (GTR) and waste plastic (WP)) and virgin (SBS and Polyphosphoric Acid (PPA)) polymers incorporated in dense graded and SMA mixtures. For the GTR section, an Engineered Crumb Rubber product was used, similar to the product used in Stadium Blvd. For waste plastics, a pelletized low-density Polyethylene (PE) product and a shredded/flaked mixed-density PE product were used in construction. The research team used the BMD requirements outlined in a MoDOT Joint Special Provision (JSP) specific to this project. The dense-graded mixtures had a minimum CT-Index threshold of 45 and an elevated BMD CT-Index requirement of 80. For SMA mixtures, the CT-Index requirement was 160. The maximum rut depth requirement, utilizing the Hamburg Wheel Track Test (HWTT), for all mixes was 12.5 mm at 15,000 passes. The research team from the Mizzou Asphalt Pavement and Innovation Lab (MAPIL) tested Lab Mixed Lab Compacted (LMLC), Plant Mixed Plant Compacted (PMPC), and Plant Mixed Lab Compacted (PMLC) mixtures. The research team designed and produced the LMLC mixtures in their lab and also produced PMPC mixtures in the field with their mobile asphalt testing laboratory. Additionally, the research team produced PMLC mixtures by reheating the mixtures sampled from the field and compacting them in the MAPIL laboratory.

The team conducted a variety of tests on the mixtures to determine their performance. The cracking tests included IDEAL Cracking Test (IDEAL-CT) and Disk-Shaped Compact Tension (DC(T)), the rutting tests included HWTT and IDEAL Rutting Test (IDEAL-RT), and moisture damage tests included Tensile Strength Ration (TSR) and the Stripping Inflection Point (SIP) parameter derived from the HWTT. The IDEAL-CT results showed good cracking resistance for all the mixtures. All PMPC mixtures except two showed an increase in CT-Index compared to LMLC mixtures. The two exceptions were measured to have statistically similar CT-Index values to their LMLC counterparts. The recycled polymer modified mixture performance was on par or better than the virgin polymer mixture performance. Similar conclusions were drawn from the DC(T) fracture energy results of the PMLC mixtures. In terms of HWTT rutting, all the

mixtures were exceptional. The PMPC mixtures had greater rutting compared to the LMLC mixtures, and the PMLC mixtures showed the least rutting, indicating different aging levels between the LMLC, PMPC, and PMLC mixtures. Once again, the recycled polymer mixtures performed similarly or better than the virgin polymer mixtures. The IDEAL-RT test results showed that generally SMAs have a lower RT-Index than dense graded mixtures. Traditionally, the SMAs exhibit better rutting resistance than dense graded mixtures and, thus, were expected to have a much higher RT-Index, indicating better rutting resistance. This finding necessitates an in-depth evaluation of the failure mechanism prevalent in the IDEAL-RT test and its ability to correlate to field observations. Finally, the PMLC Superpave mixtures were evaluated for moisture damage. The SIP parameter showed that none of the mixtures were prone to stripping. TSR results highlighted one mixture that was a borderline failure (TSR = 79.1), but all the other mixtures had a high TSR, above 90. Overall, the Superpave mixtures were resistant to moisture damage.

The research team will continue to evaluate the long-term performance of these test sections through periodic field visits, with the aim of correlating field observations to laboratory results. This will help finetune the BMD thresholds and improve the mixture designs. Further, these sections will also be evaluated as part of a national study on the mitigation of reflective cracking by various additives in asphalt mixture in partnership with the National Road Research Alliance including researchers from the National Center of Asphalt Technology and the University of New Hampshire. Finally, the long-term performance of the recycled polymer sections will inform the development of specifications to facilitate the adoption of recycled polymers in lieu of virgin polymers.

# Chapter 1: Introduction

## 1.1 Background and Motivation

MoDOT is in the process of fully implementing Balanced Mixture Design (BMD) methodology in its asphalt materials and construction specifications. In the past few years MoDOT has evaluated various performance tests and undertaken extensive benchmarking of existing mixtures to establish preliminary test thresholds based on mix type and application for quality acceptance. During the same timeframe, MoDOT also began investigating the use of recycled polymers such as ground tire rubber (GTR) and post-consumer recycled plastics (PCR-P) in asphalt mixtures, primarily to substitute virgin polymers in asphalt mixture. To that end, in 2021, MoDOT constructed four test sections on Route 740 (Stadium Blvd.) in Columbia, MO as a pilot implementation of BMD methodology and acceptance criteria, and as a demonstration for the use of GTR and PCR-P in asphalt mixtures (Rath et al., 2022). MoDOT worked with University of Missouri researchers to design the mixtures with the recycled polymers and to conduct long-term field evaluation of the sections. The field evaluation has shown encouraging results highlighting the benefits of using recycled-polymer-modified asphalt mixtures designed with BMD methodology. However, the test sections were limited in scope with regards to traffic level, mix type, and recycled plastic type and were based on old BMD thresholds. As MoDOT looks forward, to not only fully implementing BMD into construction specifications but also to bringing in specifications that allow for the use of recycled polymers in lieu of virgin polymers in asphalt mixtures, a need was identified to build more demonstration projects that could explore more than one mix variable.

To that end, MoDOT identified an approximately six mile stretch on I-155, located in Hayti, MO, where the use of recycled polymers incorporated in asphalt mixtures following the BMD methodology could be demonstrated. The modifications included using ground tire rubber (GTR), post-consumer recycled plastics (PCR-P), styrene-butadiene-styrene (SBS), and polyphosphoric acid (PPA). The experimental sections include both dense-graded and Stone Matrix Asphalt (SMA) mixture types. These mixtures were designed based on the new BMD test thresholds that were part of the Job Special Provision (JSP) for this project. The dense-graded mixtures had a minimum CT-Index threshold of 45 and an elevated BMD CT-Index requirement of 80. For SMA mixtures, the CT-Index requirement was 160. The maximum rut depth requirement for all mixes was 12.5 mm at 15,000 passes, utilizing the HWTT. The existing asphalt layer was milled and overlaid with a 2” thick asphalt surface layer. The underlying concrete was repaired, as needed.

The following sections highlight the research questions investigated in this study and the organization of the report.

## 1.2 Objectives

As highlighted in the prior section, MoDOT constructed a demonstration project in Columbia, MO to showcase the constructability and evaluate the performance of recycled polymers in asphalt mixtures, primarily focusing on ground tire rubber and waste plastics. To advance the deploy-ability of these new material technologies and the balanced mixture design methodology, this project focused on the following research objectives:

a. Investigate the effects of recycled polymers on a wider number of variables associated with asphalt pavements, namely, (i) mix types, (ii) BMD thresholds, (iii) traffic.

b. Compare aspects of asphalt mixtures with respect to the use of virgin and recycled polymers.

c. Compare the constructability of different asphalt mixtures, particularly when using different types of waste plastics.

In addition, these sections are also part of a national study on the mitigation of reflective cracking, in partnership with the National Road Research Alliance, sponsored by the Minnesota DOT. As stated earlier, these sections are constructed as 2" thick asphalt overlay on existing concrete pavement, which makes them excellent candidates to study the effect of the additives on the mitigation of reflective cracking. This report does not include the reflective cracking study within its scope.

## 1.3 Report Organization

Based on the highlighted research questions, the report is organized as follows:

**Chapter two** describes the planned lay out of the research sections and the adjustments to the plan during construction.

**Chapter three** provides details regarding the material sampling and mixture modification process. Two mixes were designed by the contractor, a dense graded and a stone matrix asphalt. Each of the Missouri Asphalt Pavement and Innovation Lab (MAPIL) modified mixes were based on the contractor's designs. Mixture modification methodology and lab mixing procedures are explained in this chapter.

**Chapter four** provides the testing and analysis methods used by the MAPIL during the design phase of the project. Additional tests were added to the testing suite performed after paving and are described here as well.

**Chapter five** provides laboratory testing results for the lab produced and plant produced mixtures. The plant produced mix was compacted both at the plant on the day of production and also sampled into pails and transported back to MAPIL, reheated and compacted.

**Chapter six** provides summary and conclusions of this research investigation. Future research recommendations are also provided.

# Chapter 2: Construction of Test Sections

## 2.1 Planning Phase

In the planning phase, as mentioned earlier, MoDOT identified an approximately six mile stretch along I-155 to lay out nine mixtures. Table 2-1 shows the planned mixtures and other pertinent details including mile markers (location) and description of the mixes. Each section was planned with transition sections preceding and following a 0.2-mile monitoring stretch. It is well-known that mixture properties need time (and thus tonnage) to restabilize after mix proportion adjustments are made. Thus, the transition sections were included in the plan to allow researchers to avoid the areas of material property gradients when conducting long-term field performance monitoring. It is important to note that the transition sections are not expected to perform poorly in the field but are simply not representative of the particular mixture formulation under evaluation. Figure 2.1 shows the layout of nine separate modified mix designs that were planned to be constructed during this project, along with monitoring and transition sections - marked by the letters M and T, respectively. It is also noteworthy that this project was not fitted with data loggers as was initially planned based on the schematic presented in Figure 2.1.

**Table 2-1. Details of the Missouri I-155 sections to be constructed on I-155 in Hayti, MO**

| Section ID/Name** (Abbreviation on Signs) | Transition/ Monitoring Log Mile Locations (Transition Areas) | Test Section Location[I] | General Description |
|---|---|---|---|
| Control<br>SP125CLP<br>(SP-Control) | 0.0 to 1.0<br>(0.0-0.75) | Mile Marker 0.6 to 0.8 | Control Section<br>2" SP125CLP w/ PG 64-22H w/ 25 - 30% maximum virgin effective binder replacement using RAP |
| Engineered Crumb Rubber<br>(SP-ECR) | 1.0 to 1.6<br>(0.96–1.34) | Mile Marker 1.2 to 1.4 | Modify control mix with ElastikoTM Engineered Crumb Tire Rubber – Target Range of 5 – 10 % by weight of virgin asphalt binder |
| Waste Plastic/PCR –<br>Low Density Polyethylene<br>(SP-LDPE) | 1.6 to 2.2<br>(1.56–1.94) | Mile Marker 1.8 to 2.0 | Modify control mix with Waste Plastic (PE Rich) – Target Range of 0.25 – 1 % by weight of asphalt mixture |
| Waste Plastic/PCR –<br>Mixed Polyethylene<br>(SP-MDPE) | 2.2 to 2.6<br>(2.16–2.34) | Mile Marker 2.2 to 2.4 | Modify control mix with Waste Plastic (PE Mixed) – Target Range of 0.25 – 1 % by weight of asphalt mixture |
| Elevated BMD w/ PPA or alternate method<br>(SP-PPA) | 2.6 to 3.0<br>(2.56–2.74) | Mile Marker 2.6 to 2.8 | Modify control mix to meet elevated CT-Index requirement with Polyphosphoric Acid (PPA) |
| Elevated BMD w/ SBS<br>(SP-SBS) | 3.0 to 3.4<br>(2.96–3.14) | Mile Marker 3.0 to 3.2 | Modify control mix to meet elevated CT-Index requirement with Styrene-butadiene-styrene (SBS) polymer |

| | | | |
|---|---|---|---|
| Control mix OR<br><br>Extra Transition Area for Mix Preparation | 3.4 to 4.5<br><br>(3.36– 4.74) | N/A | This location contains bridge and interchange and would not be feasible for a monitoring area location. |
| SMA Control<br><br>SP125BSM<br><br>(SMA-Control) | 4.5 to 5.0<br><br>(As needed) | Mile Marker 4.6 to 4.8 | Control Section<br><br>2” SP125BSM w/ PG 64-22H w/ 20 - 30 % maximum virgin effective binder replacement using RAP |
| SMA -<br><br>Engineered Crumb Rubber<br><br>(SMA-ECR) | 5.0 to 5.4<br><br>(4.96–5.14) | Mile Marker 5.0 to 5.2 | Modify SMA control mix with Elastiko$^{TM}$ Engineered Crumb Rubber –<br><br>Target Range of 15 – 20 % by weight of virgin asphalt binder |
| SMA -<br><br>Waste Plastic/PCR –<br><br>(SMA-LDPE) | 5.4 to 5.8<br><br>(5.36–5.54) | Mile Marker 5.4 to 5.6 | Modify SMA control mix with Waste Plastic/PCR (LDPE-PE Rich) – Target Range of 0.25 – 1 % by weight of asphalt mixture |

** Note:  The contractor may reorder the construction of test sections; except all SMA test sections shall be constructed from Log Mile 4.5 to 5.8.

[Ɨ] The actual log mile does not match the log mile of the mile marker posts.

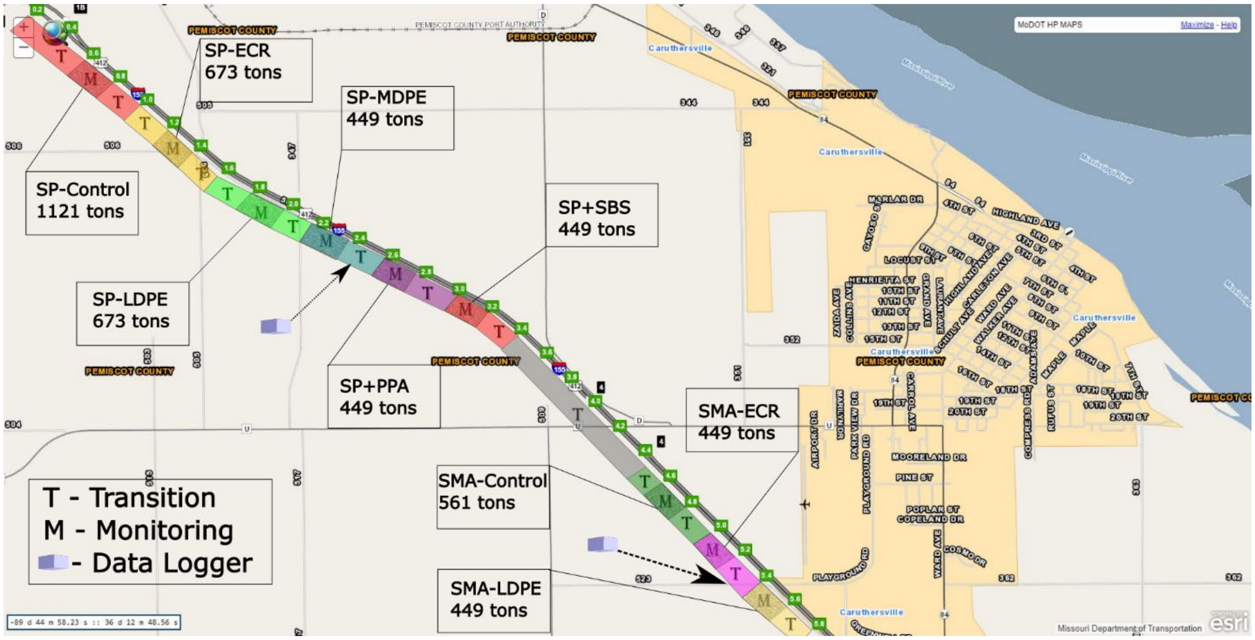



**Figure 2.1. Planned layout of the demonstration sections with estimated tonnage**

## 2.2 Construction Phase

During the construction phase, practical considerations led to the re-shuffling of the location of the mixtures. Figure 2.2 shows the actual location of the monitoring and transition sections that were constructed. Most notably, the Superpave control section (SP-Control) was supposed to be the mixture with a PG64H-22 binder, but it was replaced with a Mixed Density PE-modified mixture with a stiffer PG64-22 binder due to reasons discussed in the later sections.

As seen in the Figure 2.2, the LDPE and ECR sections had significantly longer transition sections. During the construction of the LDPE section, the crew noticed a few rich spots on the pavement which led to examination of the feeder system. It was determined that the feeder system had a couple of power surges wherein the feed rates were inconsistent but within tolerable limits. This led to the extension of the transition section preceding the monitoring stretch for the LDPE mixture to accurately dial-in the mixture.

The ECR section also has a significantly longer transition section but due to different reason. On the day of construction, the plant had a faulty air compressor which led the plant to shut down. This resulted in the ECR section being constructed the next day and a longer-than-planned transition section.

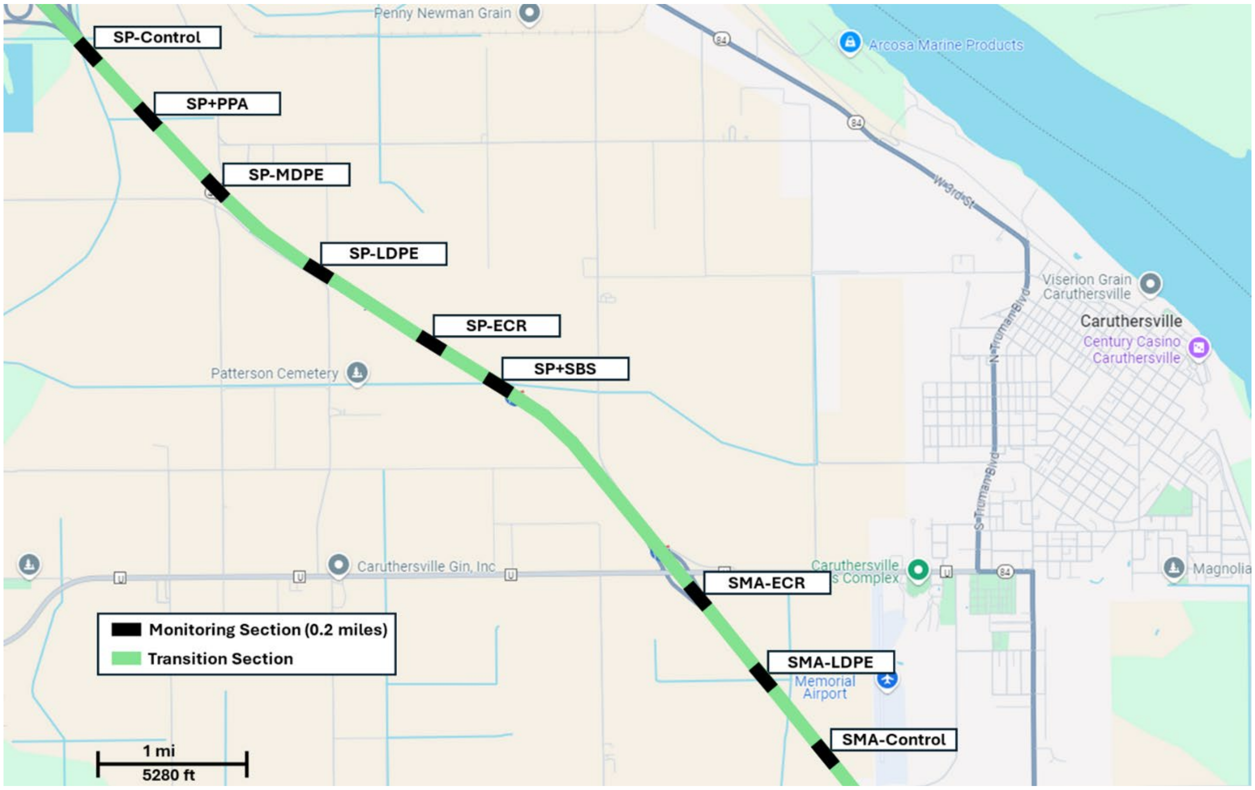



**Figure 2.2. On-field layout of the demonstration sections with marked monitoring and transition sections**

# Chapter 3: Material Sampling and Mixture Modifications

## 3.1 Overview

This study was conducted in three phases. In Phase I, the MAPIL research team consulted with Delta Companies to procure materials, and then replicated Delta's unmodified designs in the university laboratory. After matching Delta's unmodified designs, MAPIL added modifiers and created the new mix designs. The new mixtures were required to pass the IDEAL-CT test (ASTM D8225) and the Hamburg Wheel Tracking Test (HWTT) (AASHTO T 324) (AASHTO, 2017; ASTM D8825-19, 2019). In Phase II the plant produced mixes were also tested, utilizing the IDEAL-CT test and HWTT. Additional performance tests were performed for further insight into the performance differences between the various modifiers and mix gradations.

## 3.2 Material Procurement

MAPIL and MoDOT held several meetings with the paving contractor's quality control manager to discuss the traffic requirements and research goals of the new test sections. The quality control manager assisted in the procurement of the aggregates and binders. The paving contractor set up a portable asphalt plant near the intersection of Rt. 84 and I-155 in Hayti, MO. Aggregates were sampled from this plant on October 24, 2022.

The dense graded mix is comprised of five stockpiles. Two stockpiles are trap rock, two are limestone/dolomite and the last is a RAP stockpile. The dense graded design's gradation is 30% RAP for an Asphalt Binder Replacement (ABR) of about 25%. The dense graded mixture has a total binder content of 5.1%. The virgin binder is a PG64H-22 dosed with 0.3% of a liquid antistrip. The SMA was built from the same two trap rock stockpiles, another three stockpiles are from a limestone source, and a lime is used as mineral filler, resulting in a total of six stockpiles. Cellulose fibers are added to the SMA mixtures at 0.3% weight of mix. The binder in the SMA is PG64V-22 and is 5.8% of the mix. The aggregate gradation of both of the mixture types are shown in Figure 3.1.

Asphalt cement was supplied by the contractor's asphalt supplier. Five five-gallon pails of PG64H-22 were drawn from the asphalt plant's tank. Additionally, the MAPIL was supplied with five five-gallon pails of each PG64-22 and PG58-28. The PG64V-22 was supplied by the contractor's Quality Control (QC) manager. The PG70-22 binder was shipped from a second binder terminal that routinely supplies binder to the Delta companies asphalt plant in Hayti, MO.

The recycled asphalt additives were purchased and shipped to the asphalt plant from the respective additive manufacturers. Figure 3.2 shows the various additives used in the study. The Engineered Crumb Rubber (ECR) is a ground tire rubber product produced by Asphalt Plus LLC., in Chicago, IL. It is made from recycled scrap tires and is engineered to give the modified asphalt mixture better handling properties compared to the non-engineered ground tire rubber. The low-density polyethylene (LDPE) is produced by NaturaPCR in Houston, TX. This product is a post-consumer film that has been melted and then extruded into a pellet form that is easy to handle. The mixed density polyethylene (MDPE) is produced by Driven Plastics in Pueblo, CO.

It is a mixed source, post-consumer plastic which is conglomerated and then shredded to a size compatible with the pneumatic feeder system.

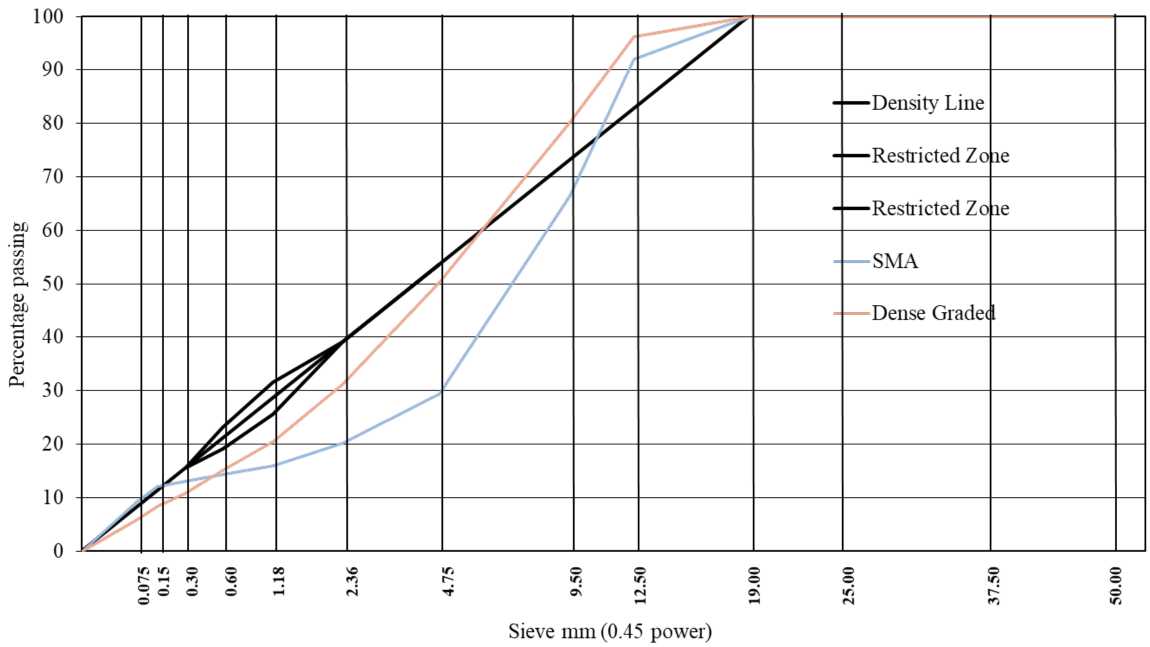



**Figure 3.1. Aggregate gradations for all mixtures**

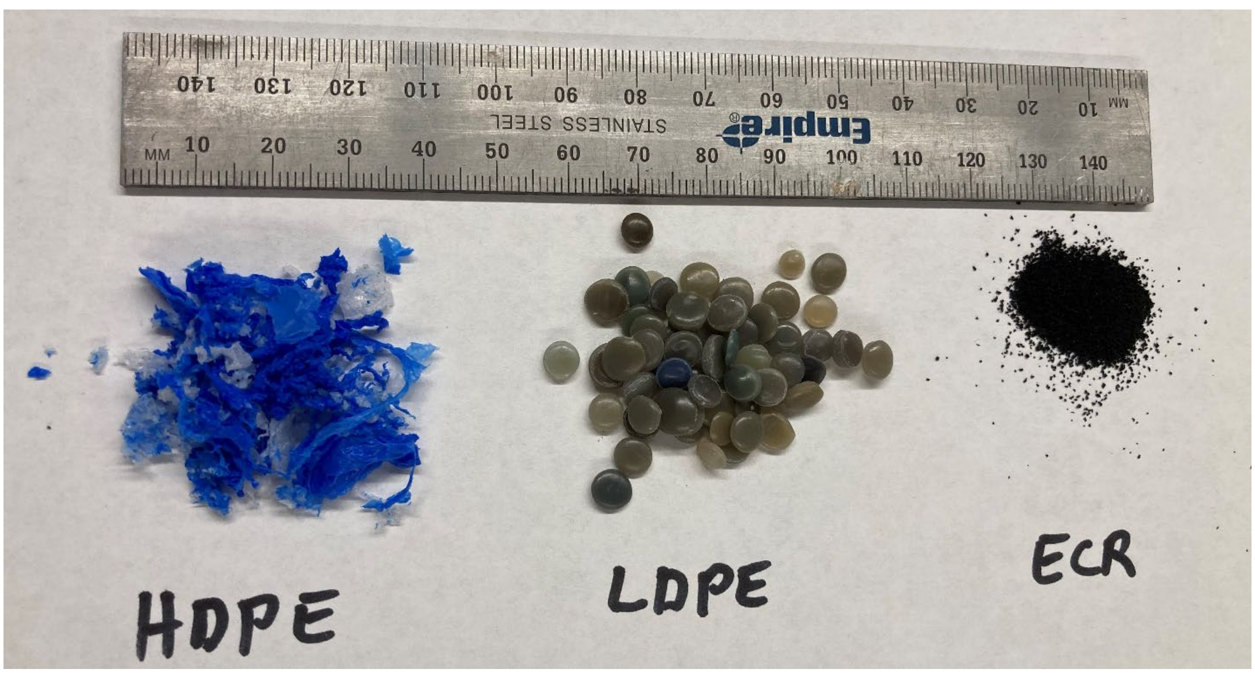



**Figure 3.2. Image showing the different recycled polymers used in this study**

## 3.3 Laboratory Mixing and Mixture Modification

The MAPIL team reproduced the dense graded and the SMA mixtures according to the Job Mix Formula (JMF) provided by the contractor. Their reproduction was considered successful when volumetric properties were within MODOT tolerances of the JMF values, as indicated in Table 3-1 and Table 3-2. Mixtures were produced in the MAPIL lab with a bucket mixer. The mixing temperature was 165 ºC (329 ºF) and the aging and compaction temperature was set at 155 ºC (311 ºF). The short-term oven aging protocol for the mixtures was two hours at compaction temperature with stirring/remixing performed with a large metal spoon at one-hour intervals.

Virgin aggregates and binder were heated to 165 ºC. Approximately 45 minutes prior to mixing, the RAP was added to the virgin aggregates in the oven set at 165 ºC. Once the binder and aggregates reached the adequate temperature, the binder was measured into the bucket and they were mixed for two minutes.

**Table 3-1. Volumetric results for the reproduced dense graded mixture**

| Mixture Property | Design Target | Production Tolerance | Values from JMF | Designed at MAPIL |
|---|---|---|---|---|
| Va | 4.0 | +/- 1.0 | 4.0 | 4.2 |
| VMA | >14.0 | -0.5 to +2.0 | 14.6 | 14.7 |
| VFA | 65-75 | NA | 73 | 72 |

**Table 2-2. Volumetric results for the reproduced SMA mixture**

| Mixture Property | Design Target | Production Tolerance | Values from JMF | Designed at MAPIL |
|---|---|---|---|---|
| Va | 4.0 | +/- 1.0 | 4.0 | 4.1 |
| VMA | >17.0 | -0.5 to +2.0 | 16.8 | 17.3 |
| VFA | >75 | NA | 76.2 | 76.2 |

After matching the contractor's mixture designs in the MAPIL lab, work began on how to add the recycled polymers into the mix designs. Aggregate gradations were unaltered by the modification, but the proportion of the total mix was adjusted to allow for the recycled polymer content. The mixture modifiers were incorporated at 0.4-0.5% of the weight of the total mixture. This modification level was adopted based on previous experiences. The laboratory mixing procedures were modified slightly when recycled polymers were added to the mixtures, as follows:

Waste Plastics (WP): This project included waste plastics in two forms - pellets and shreds, as shown in Figure 3.2. Irrespective of the form, the waste plastics were added into the heated aggregates about 15 minutes prior to mixing. Preheating the plastics allowed them to soften and facilitated proper mixing. The modified mixes were first checked for air voids at design gyrations. It has been observed that the incorporation of waste plastics aids the mixtures in compaction. Thus, the amount of virgin binder was reduced in order to maintain 4.0% air voids at the same design gyrations for the mixtures with waste plastics.

Engineered Crumb Rubber (ECR): In the laboratory, the rubber is high sheared into the binder for 30 minutes at 163 ºC (325 ºF) just prior to mixing. This "partial wet process" was adopted as a way to simulate the appropriate conditions and mixing energy generated in the continuous flow asphalt plant, with the standard mixing bucket. The ECR was computed at 10% of the virgin binder, which was about 0.4% of the total weight of the mixture. After high shearing the ECR into the binder, it is added to the aggregate and mixed in the bucket mixer for two minutes to produce the mixture. In addition, 0.2% supplemental binder was added by weight to the total mixture to compensate for the binder absorbed by the rubber particles and to coat the additional fines added to the mixtures from the rubber particles. Due to the additional binder the air voids at design gyrations are lower for ECR mixtures.

The balanced mix design goals were provided by MODOT in the JSP (Joint Special Provisions) for the paving project. In this project there were three BMD acceptance criteria set. All three BMD levels required a HWTT rut depth of less than 12.5mm at 15,000 passes. The lowest BMD CT-Index criteria was for the dense graded mixtures. They had to have a CT-Index of at least 45. A second category of dense graded mixtures called "elevated BMD", including polyphosphoric acid (PPA) and SBS mixtures, needed to have or exceed a CT-Index of 80. The highest BMD CT-Index criteria was for the SMA mixtures. They were required to have a CT-Index of 160 or higher.

After meeting the BMD thresholds, final modified mixture volumetrics were measured. Not all modified mixtures met the volumetric requirements imposed on typical SP125 mix designs. This was permitted by the JSP.

## 3.4 Final Mixture Designs

The research team began the mixture design process by reproducing the contractor-design SP-control mixture, as designated in Table 2-1. This mixture was originally supposed to use PG64-22H binder, modified with PPA. When the mixture was tested, it satisfied the elevated BMD requirements for the SP-PPA mixture. Research team conversations with MODOT yielded the decision to use a mixture that would test closer to the lower BMD cracking threshold of 45. To that end, a mixture was made with the neat PG64-22 binder modified with 0.5% weight of mix of the MDPE shredded plastic. More details, along with the CT-Index results are discussed in the next chapter.

The remainder of the mixtures followed a predictable trend, and the researchers were able to skip an iteration or two to reach acceptable BMD results in later mixtures. Generally, the PG64-22 neat binder is too stiff for direct use with the selected additives and will produce relatively low CT-Index values in the IDEAL cracking test. Also, in the waste plastic mixtures the binder content was usually decreased by 0.3%. Mixture iterations involved the use of progressively softer binder grades until the measured CT-Index values were acceptable. This was followed by adjustment of the binder content to reach 4.0% air voids when compacting at the specified number of gyrations in the Superpave compactor. Fortunately, none of the mixture designs that the researchers worked on showed any rutting or moisture susceptibility issues.

Testing of the trial mixes was limited to volumetric and the required BMD tests, which were the IDEAL-CT and the HWTT. The time between sampling aggregates and paving dates was insufficient to perform the required tests on all the mixture iterations. In order to maximize efficiency, the CT-Index was obtained first in each iteration and if the mixture failed, then the mixture iteration was rejected with no further testing. This report only focusses on the final mixture iterations for brevity. It is worth noting that the research team was unable to reproduce the SMA-control in the lab prior to paving and relied on the BMD testing completed by the contractor. Those results are reported herein.

The final mixture designs and other pertinent details are presented in Table 3-3. One of the goals of the researchers was to minimize the number of binders needed for paving all the mixtures. The plant only had two binder tanks available. Therefore, it was attempted to have all the designs with recycled polymers use the same binder grade. The was also done for the SMA's with additives.

The volumetric properties of the final mixture designs are shown in Table 3-4. The performance results are discussed in Chapter 4.

**Table 3-3. Final mixture designs placed in the test sections**

| Mixture Name | Binder Grade | Virgin Binder (%) | Antistrip (%) | Fiber (%) | Recycle Type | Recycle Content (%) |
|---|---|---|---|---|---|---|
| SP-Control | 64-22 | 3.8 | 0.3 | 0 | MDPE | 0.5 bwom* |
| SP-ECR | 58-22 | 4.0 | 0.3 | 0 | ECR | 10 bwob** |
| SP-LDPE | 58-22 | 3.5 | 0.3 | 0 | LDPE | 0.5 bwom |
| SP-MDPE | 58-22 | 3.5 | 0.3 | 0 | MDPE | 0.5 bwom |
| SP-PPA | 64H-22 | 3.8 | 0.3 | 0 | NA | NA |
| SP-SBS | 70-22 | 3.9 | 0.5 | 0 | NA | NA |
| SMA-Control | 64V-22 | 5.8 | 0 | 0.3 | NA | NA |
| SMA-ECR | 64-22 | 6.0 | 0 | 0.3 | ECR | 10 bwob |
| SMA-LDPE | 64-22 | 6.0 | 0 | 0.3 | LDPE | 0.5 bwom |

*bwom = by weight of mixture, **bwob = by weight of binder
Note: ECR was added by weight of virgin binder

**Table 3-4. Final mixture design volumetrics**

| Mixture Name | Gmm | VTM | VMA | VFA | DP |
|---|---|---|---|---|---|
| SP-CTRL | 2.473 | 3.5 | 13.7 | 74.7 | 1.4 |
| SP-ECR | 2.470 | 2.6 | 13.7 | 80.8 | 1.3 |
| SP-LDPE | 2.479 | 4.1 | 13.9 | 71.2 | 1.4 |
| SP-MDPE | 2.474 | 3.9 | 14.0 | 72.2 | 1.4 |
| SP-PPA | 2.491 | 4.2 | 14.7 | 71.6 | 1.3 |
| SP-SBS | 2.488 | 3.6 | 14.4 | 75.3 | 1.3 |
| SMA-CTRL | 2.434 | 4.0 | 16.8 | 76.2 | 1.0 |
| SMA-ECR | 2.440 | 4.1 | 17.4 | 76.2 | 1.7 |
| SMA-LDPE | 2.434 | 3.5 | 17.0 | 79.7 | 1.6 |

# Chapter 4: Testing and Analysis Methods

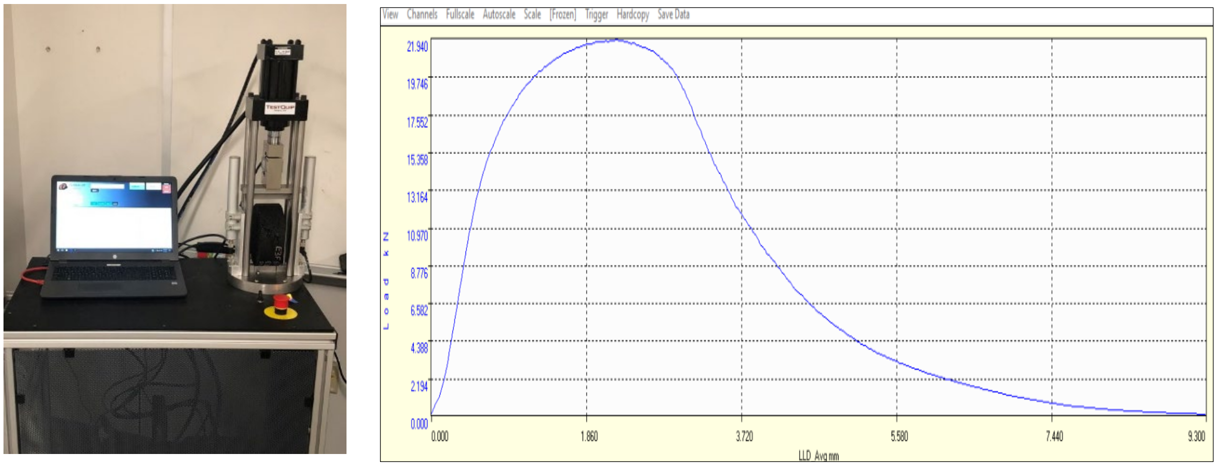
## 4.1 Overview

In this study, the MAPIL modified, and contractor designed unmodified mixtures were tested with the Hamburg Wheel Tracking Test and the IDEAL-CT cracking test prior to selection as paving mixtures, as specified by MoDOT. After paving, the IDEAL-RT rapid rutting test was also conducted on the plant mixed plant compacted specimens. Furthermore, the plant mixed laboratory compacted specimens were also tested with the disc-shaped compact tension (DC(T)) test and the dense graded specimens were tested with the tensile strength ratio (TSR) moisture susceptibility test.

## 4.2 Cracking Tests

### 4.2.1 IDEAL-CT Test

The IDEAL-CT cracking test is a recent mix cracking test developed by the Texas Transportation Institute (TTI). The test was developed for routine quality control (QC) and quality assurance (QA). The test set-up is similar to the traditional indirect tensile strength test, but it is performed at 25 ºC (77 ºF) and at a constant loading rate of 50 mm/min until failure occurs. The specimen does not require gluing, notching, drilling or additional cutting. The test procedure is detailed in ASTM D8225 (ASTM D8825-19, 2019). In this project, the specimens (150 mm diameter and 62 mm height) were conditioned in a temperature-controlled chamber for a minimum of two hours at test temperature. After conditioning, the specimens were centered between loading platens (see Figure 4.1 (a)). A seating load of 0.1 kN was applied in order to make appropriate contact between the loading platens and the sample. The sample was then loaded under a displacement control mode of 50 mm/min while the loading level was measured and recorded by the device. Figure 4.1 (b) shows a sample of the software output, i.e., the load-displacement curve. The larger the CT-index, the better the cracking resistance of the mixture. The cracking parameter for the IDEAL-CT test, called the CT-Index, was calculated using Equation (4) in the ASTM D8225-19 standard.




(a) (b)

**Figure 4.1. (a) The Test Quip IDEAL-CT apparatus at MAPIL, (b) Typical load-displacement curve from Test Quip software**

### 4.2.2 Disk-Shaped Compact Tension (DC(T)) Test

The DC(T) test was developed to characterize the fracture behavior of asphalt concrete mixtures at low temperatures. The testing temperature is 10 ºC (50 ºF) warmer than the PG low temperature grade of the mixture, per ASTM D7313-20 (ASTM International, n.d.). The DC(T) test procedure includes conditioning of the fabricated specimen at the selected test temperature in a temperature-controlled chamber for a minimum of two hours. After the conditioning, the specimens are suspended on loading pins in a DC(T) machine. A portable Test Quip DC(T) device was used in this project (see Figure 4.2 (a)). The test is performed at a constant Crack Mouth Opening Displacement (CMOD) rate, which is controlled by a CMOD clip-on gage mounted at the crack mouth. The CMOD rate specified in ASTM D7313-20 is 0.017 mm/s (1 mm/min). A seating load no greater than 0.2 kN (typically about 0.1 kN) is applied to 'seat' the specimen to begin the test. The test is completed when a crack has propagated, and the post-peak load level is reduced to 0.1 kN. The fracture energy can be obtained by measuring the area under the load-CMOD curve and dividing it by the fractured area (ligament length times thickness). A typical load-CMOD curve is shown in Figure 4.2 (b). The fracture energy is computed using Equation 4 in the ASTM D7313-20 standard.

Marasteanu et al. (2012) reported on the fracture energy thresholds on basis on various traffic levels as a part of a Federal Highways Administration (FHWA) pooled fund study on low-temperature cracking, which was later verified by Buttlar et al. (2019) (Buttlar et al., 2019; Marasteanu et al., 2012). The threshold for high traffic was 690 $J/m^2$, for moderate traffic was 460 $J/m^2$, and for low traffic was 400 $J/m^2$.

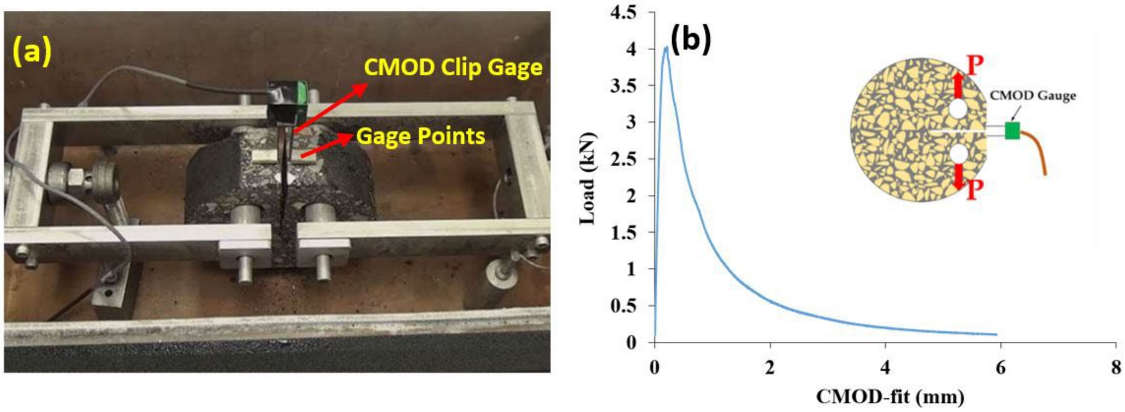



**Figure 4.2. Disk-Shaped Compact Tension (DC(T)) test; (a) Test loading fixture, and (b) Typical load versus crack opening displacement (CMOD) curve from DC(T) testing of asphalt mixtures**

## 4.3 Rutting Tests

### 4.3.1 Hamburg Wheel Tracking Test (HWTT)

Rutting (permanent deformation) in asphalt pavement is a result of shear flow and consolidation caused by traffic loading in hot weather. These combined factors result in a gradual accumulation of shear and volumetric strains in the hot mix asphalt (HMA) layers. The lack of shear strength in the asphalt layer lessens the asphalt's ability to resist the repeated heavy static and moving loads. This results in downward movement of the asphalt surface and produces the potential for upheaval and microcracking along the rut edges. In combination with structural failure issues, safety concerns emerge due to the increased potential for hydroplaning, increased stopping distances, and difficulties in vehicle steering due to uneven riding surfaces.

The most popular wheel load tracking (WLT) tests are the Asphalt Pavement Analyzer (APA, formerly known as the Georgia-loaded wheel tester) and the Hamburg Wheel Tracking Test (HWTT). The HWTT is performed following the standards set in AASHTO T324 (AASHTO, 2017). A loaded steel wheel, with an approximate weight of 71.7 kg, tracks over the asphalt samples, which are placed in a water bath of 50 ºC (122 ºF). The number of wheel passes is recorded, along with the vertical deformation of the specimen. The test typically ends when either the number of wheel passes reaches 20,000 or the specimen deforms by 20mm vertically. The testing is performed either on a compacted slab of asphalt or on 150mm diameter 62mm thick gyratory specimens. The asphalt specimens are compacted to 7.0 +/- 0.5% air voids for dense graded mixtures or 6.0 +/- 0.5% air voids for SMA mixtures. A requirement of 12.5 mm maximum rut depth at 15,000 passes was imposed for this project. The rut depth for each wheel path is calculated according to AASHTO T324. It is the average of the five center points in the wheel's travel. Figure 4.3 shows the HWTT machine used in this study.

**Figure 4.3. Hamburg testing device**

### 4.3.2 IDEAL-RT

The IDEAL-RT test was developed to characterize the rutting potential of asphalt mixtures during design and production. Figure 4.4 shows the testing apparatus. It utilizes a shear strength-based parameter called the Rutting Tolerance Index (RT-Index). The test uses asphalt specimens compacted to 62mm and an air void of 7.0 +/- 0.5% air voids for dense graded, and 6.0 +/- 0.5% air voids for SMA's. A specimen, heated to 50 ºC, is placed in a cradle jig and loaded at three points at a rate of 50.0 mm/min for the duration of the test. This creates two shear planes within the specimen. A higher RT-Index value represents higher rutting resistance and lower rut depth in the field. Equation (1) from ASTM D8360-22 was used to compute the shear strength of the mixtures and Equation (2) from the same standard was used to compute the RT-Index (ASTM D8360-22, 2022).

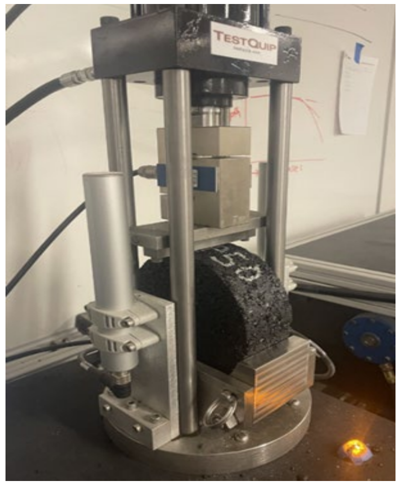



**Figure 4.4. IDEAL-RT testing apparatus**

## 4.4 Moisture Damage Tests

### 4.4.1 Hamburg Wheel Tracking Test (Stripping Inflection Point)

The HWTT also provides the opportunity to measure the stripping potential of the asphalt mix since the test is run under water. This value is measured by the Stripping Inflection Point (SIP). The SIP represents the number of passes at which there is an onset of moisture damage in the asphalt specimen. As shown in Figure 4.5, the SIP is at the intersection of the creep slope and stripping slope of the rut depth versus number of passes curve (Cooley Jr et al., 2000). The SIP is characterized by a sharp increase in rut depth (inflection point in the curve). In this study, the Iowa method was used to calculate the SIP mathematically. The Iowa method is described as follows:

- A 6th degree polynomial curve is fitted to the rut depth versus wheel passes data
- The stripping line is determined by using the tangent at the point nearest to the end of the test where the minimum of the first derivative of the fitted curve occurs
- The creep line is determined by using the tangent at the point where the second derivative of the fitted curve equals zero
- The wheel pass at which the creep line and the stripping lines intersect is the SIP

In this study, a MATLAB$^{TM}$ code was used to follow the steps outlined above and to determine the SIP for each of the replicates.

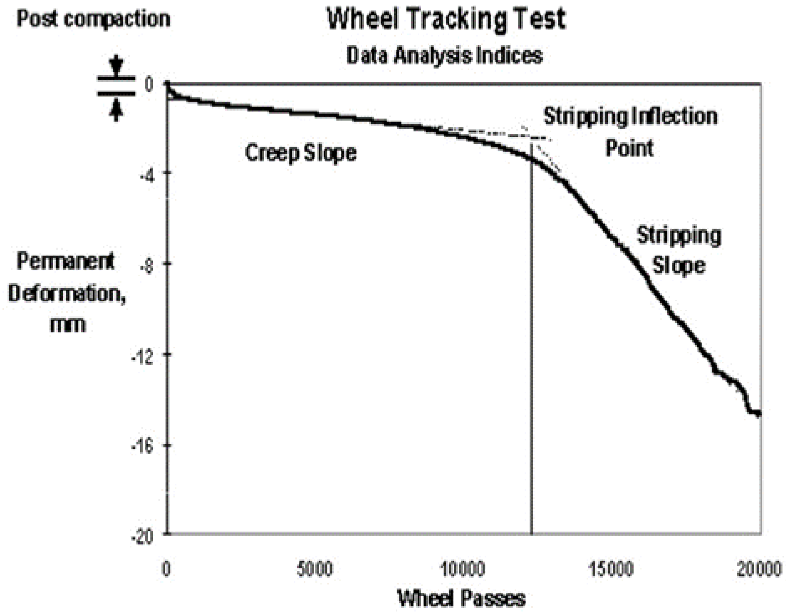


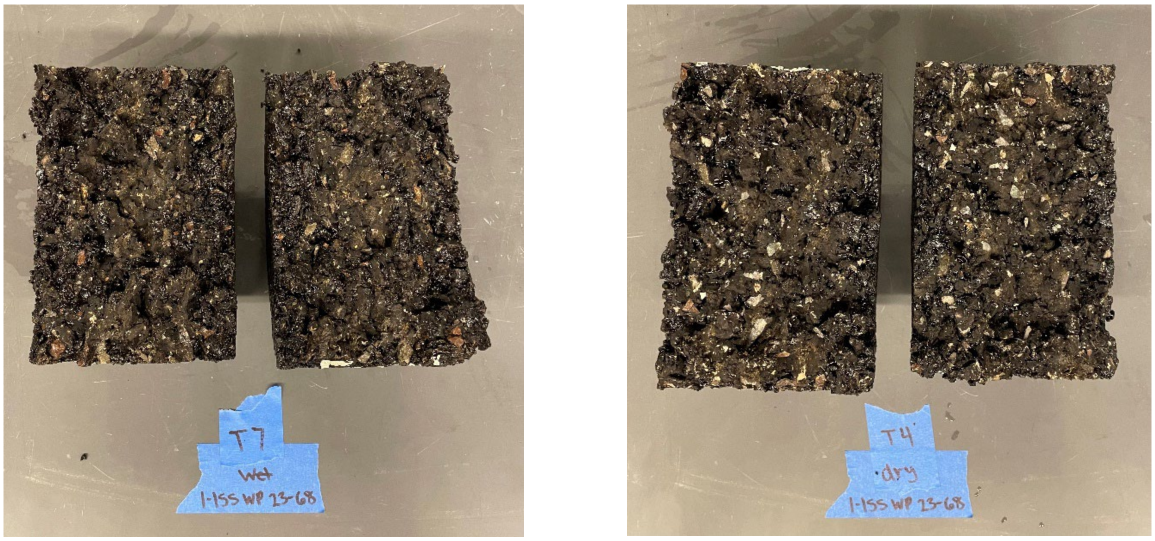

**Figure 4.5. Typical rut depth versus wheel passes data obtained from HWTT and computation of stripping parameters (after Cooley Jr et al., 2000)**

### 4.4.2 Tensile Strength Ratio (TSR)

The TSR tests conducted during this research project followed the AASHTO T-283 specification. In this testing a minimum of eight specimens are compacted to 95mm following loose mix conditioning. The compacted specimens are then paired off into two subsets of samples based on their measured air voids. A minimum of three specimens are needed for each subset, thus three matched pairs are needed, and two extra specimens will not be used. The first subset of samples, which included three replicates of gyratory samples with 95 mm thickness, were considered the dry subset. The dry samples were then conditioned in a water bath of 25 ºC for two hours. After the conditioning process, the samples were tested, and the dry indirect tensile strength was recorded.

The next subset of samples, the wet subset, included three replicates with the same air void content and geometry as the dry subset. This subset of samples was subjected to vacuum saturation with a target saturation of 70-80%. The specimens were placed in a vacuum container, on a perforated spacer that sat a minimum of 25 mm (1 in.) above the bottom of the vacuum container. Room temperature potable water was then poured into the container until the specimens had at least 25 mm (1 in.) of water above their surfaces. A vacuum pressure of 13 to 16 kPa (10 to 26 in. Hg partial pressure) was applied to the specimens for approximately 5 to 10 minutes. The vacuum pressure was then removed, and the percentage of saturation of the specimens was measured. This vacuum saturation process was repeated until the samples reached a saturation percent between 70-80%. After vacuum saturation, the samples were wrapped in plastic film and placed in a resealable plastic bag along with 10mL of water. The bagged samples were then placed in a –18 ºC freezer for >16 hours. After freezing, the samples were then placed in a warm water bath (60 ºC) for 24 hours. Following this, the samples were placed in water at 25 ºC for two hours. At the end of the two hours, the samples were then tested, and their wet indirect tensile strengths were recorded.

Finally, after both subsets were tested, the TSR value was calculated as the ratio of wet to dry indirect tensile strength. A higher TSR value indicated a higher resistance to rutting. An example of a test conditioned and unconditioned sample is shown in Figure 4.6.




(a) (b)

**Figure 4. (a) Tested conditioned (wet) specimens, (b)Unconditioned (dry) specimens**

# Chapter 5: Mixture Testing Results

## 5.1 Overview

The research team performed extensive testing on all the mixtures produced in this study during the design and production phase. The following sections report the cracking, rutting, and moisture damage results. Some of the results are available for the Lab Mixed Lab Compacted (LMLC), the Plant Mixed Plant Compacted (PMPC), and the Plant Mixed Lab Compacted (PMLC) mixtures while some are not due to time constraints in producing PMPC and LMLC mixtures. The LMLC mixtures were produced during the mixture design phase. To obtain the PMPC mixtures, the MAPIL research team setup a mobile asphalt testing laboratory in a 26-foot long box trailer with workbenches, bench ovens, balances, a PINE AFGB1 gyratory compactor and the associated tools for compacting hot mix asphalt (HMA), as shown in Figure 5.1. The research team was able to take PMPC asphalt mixture directly from the truck beds and run gyratory compaction tests on the specimens with no reheating. The sampled mixture was split into two-inch deep asphalt pans and placed in a forced draft oven at compaction temperature. Only 62 mm specimens were compacted to simplify operations in the trailer, which allowed for conducting IDEAL-CT tests, IDEAL-RT tests, and HWTT. A minimum of ten specimens were compacted for each mixture.

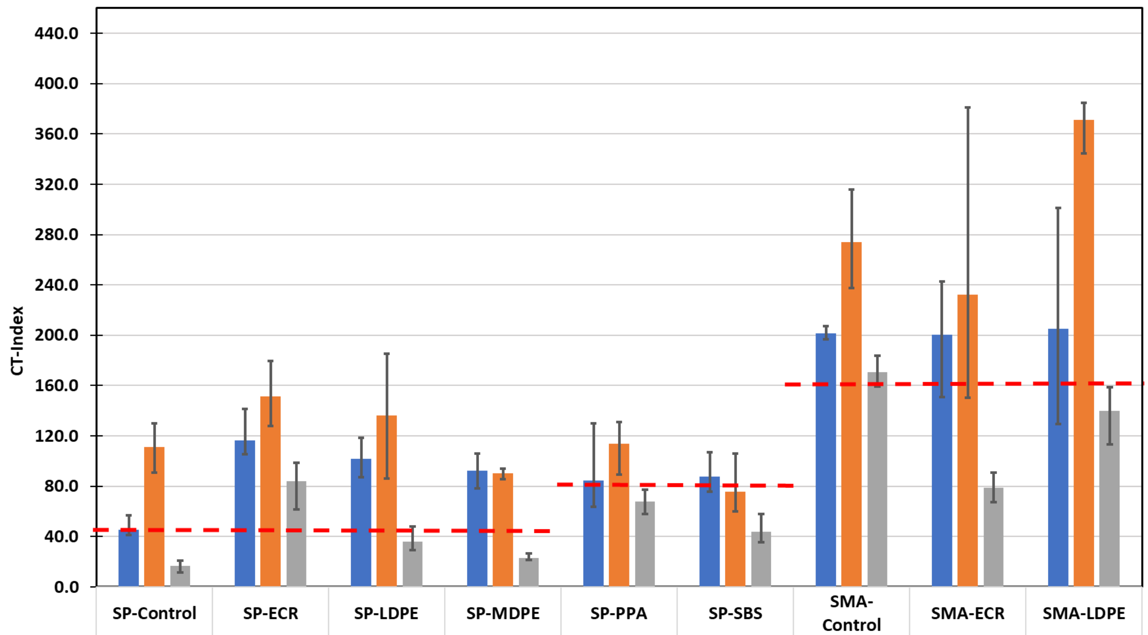
On the day of production for each mix, the MAPIL team also sampled eight five-gallon steel pails of each mixture from the bed of an asphalt truck. The sampling occurred sometime after the first 150 tons had been produced. Sampling a few hundred tons into a run ensures that the plant is at a steady state of temperature and feed rates. The pails were set aside to cool and then lids were placed on the pails. These pails were later transported back to the MAPIL laboratory located on the campus of the University of Missouri. These steel pails were put in a forced draft oven and the mixtures were split once the mixture temperature exceeded 110 $^{o}$C. The quartered splits were put in two-inch-deep asphalt pans and placed back into the forced draft oven. The mixture was compacted after it had reached compaction temperature.

(a) (b)

**Figure 5.1. (a) MAPIL's mobile asphalt testing laboratory, (b) Machine setup inside the mobile laboratory**

## 5.2 Cracking Test Results

The cracking tests conducted in this study included the IDEAL-CT test, as per ASTM D8825 standard, and the Disk-shaped Compact Tension (DC(T)) test, as per the ASTM D7313 standard. Both the test procedures were described in the previous section. The CT-Index results were available for the Lab Mixed Lab Compacted (LMLC), Plant Mixed Plant Compacted (PMPC), and Plant Mixed Lab Compacted (PMLC) mixtures. However, the DC(T) fracture energy results were only available for the PMLC mixtures. The results for the cracking tests are shown in Figure 5.2 for the IDEAL-CT and Figure 5.3 for the DC(T) test results. The average of four replicates was used to report the CT-Index for LMLC and PMLC mixtures, and three replicates were used to obtain the average CT-index for the PMPC mixtures. The DC(T) fracture energy results for the PMLC mixtures were obtained from an average of four replicates.




| | SP-Control | SP-ECR | SP-LDPE | SP-MDPE | SP-PPA | SP-SBS | SMA-Control | SMA-ECR | SMA-LDPE |
|---|---|---|---|---|---|---|---|---|---|
| LMLC | 45.5 | 116.4 | 101.6 | 92.4 | 84.3 | 87.6 | 201.3 | 200.4 | 205.2 |
| PMPC | 111.0 | 151.6 | 136.4 | 90.5 | 113.6 | 75.6 | 274.1 | 232.1 | 371.3 |
| PMLC (reheated) | 16.5 | 84.2 | 36.1 | 23.1 | 68.0 | 43.7 | 170.6 | 79.0 | 139.8 |

**Figure 5. CT-Index results for all mixtures**

As shown in Figure 5.2, there were several different CT-index thresholds followed in this project. Four of the six Superpave mixtures – SP-Control, SP-ECR, SP-LDPE, and SP-MDPE – were subjected to a CT-Index threshold of 45.0. The other two mixtures– SP-PPA and SP-SBS – were subjected to an "elevated" CT-Index threshold of 80.0. The SMA mixtures were designed and subjected to a CT-Index threshold of 160.0. As mentioned in the previous sections, the SP-Control mixture was actually modified with MDPE, albeit with a different base binder (PG64-22) compared to the SP-MDPE mixture (PG58-28). This decision was made based on the CT-Index results. Originally, the SP-PPA mixture was supposed to be the control mixture in this study, as highlighted in Table 2-1. But since the CT-Index for the SP-PPA mixture exceeded the elevated BMD requirements, a decision was made to not replicate it as the SP-Control mixture. Instead, the MDPE mixture with a different base binder was used as control since its CT-Index was close to the normal BMD requirements.

All the LMLC mixtures were above the required CT-Index thresholds since they were designed with the established criteria. Compared to the LMLC mixtures, all the PMPC mixtures showed an increase in the CT-Index except the SP-MDPE and SP-SBS mixtures, which were statistically similar to the LMLC mixtures, even if the average was different. The increase in CT-Index values is a likely indication of the lower stiffness of the PMPC mixtures as a result of the difference in aging conditions of the mixtures. It is worth noting that the LMLC mixtures were aged for two hours at the compaction temperatures of the respective mixtures. The PMLC mixtures, as expected due to the reheating process, showed lower CT-Index values, indicating additional stiffness in the mixtures. For the Superpave mixtures, the waste plastic mixtures (SP-Control, SP-MDPE, and SP-LDPE) had the maximum drop in CT-Index for the PMLC mixtures compared to the results of the PMPC mixtures. In the SMA mixtures, both ECR and LDPE mixtures had a similar decrease in the CT-Index with reheating.

The DC(T) fracture energy results are shown in Figure 5.3 and were produced from an average of four replicates for all the mixtures. None of the mixtures pass the nationally established threshold of 690 J/m$^2$, as per Marasteanu et al. (2012) in the Pooled Fund Study for low temperature cracking (Marasteanu et al., 2012). However, those thresholds are likely more applicable for much colder climates compared to the test location in Hayti, MO. In general, SMA gradation is known to provide significantly higher DC(T) fracture energy compared to the dense graded mixtures, but that was not the case in this study. The dense graded mixtures, except SP-MDPE and SP-PPA, all recorded a fracture energy in excess of 500 J/m$^2$. It is worth noting that both the SP-ECR and SP-LDPE mixtures were on par with the SP-SBS mixtures in terms of low temperature cracking performance for the PMLC mixtures.

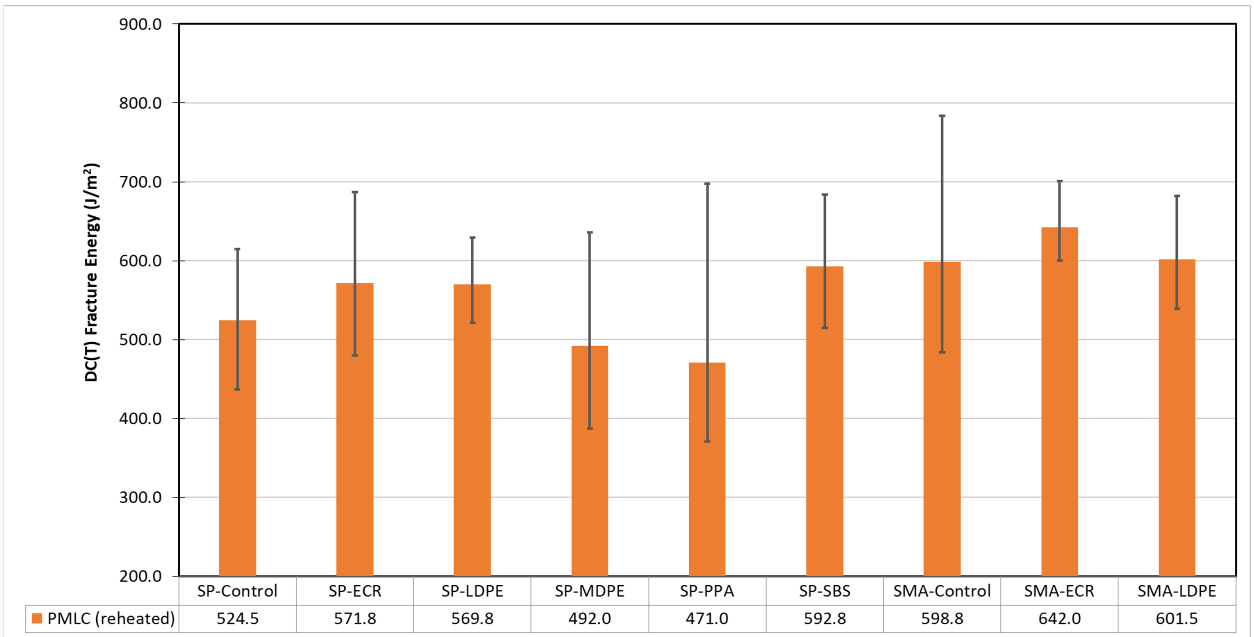
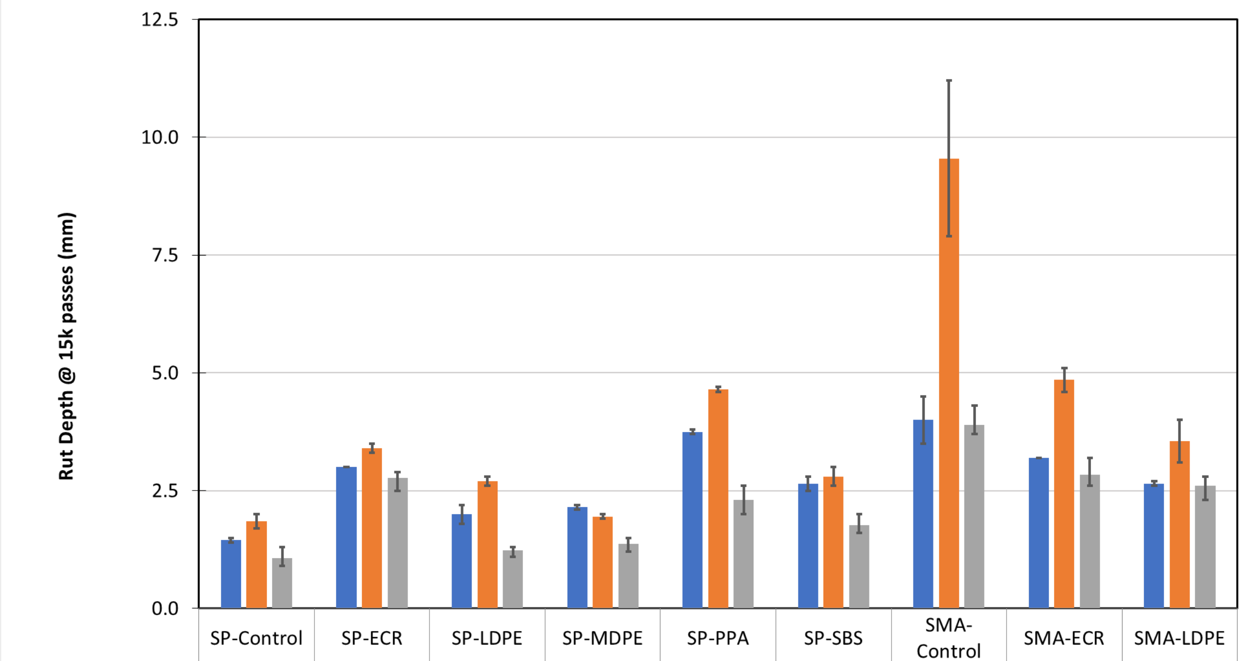



**Figure 5.3. DC(T) fracture energy results for PMLC mixtures**

## 5.3 Rutting Test Results

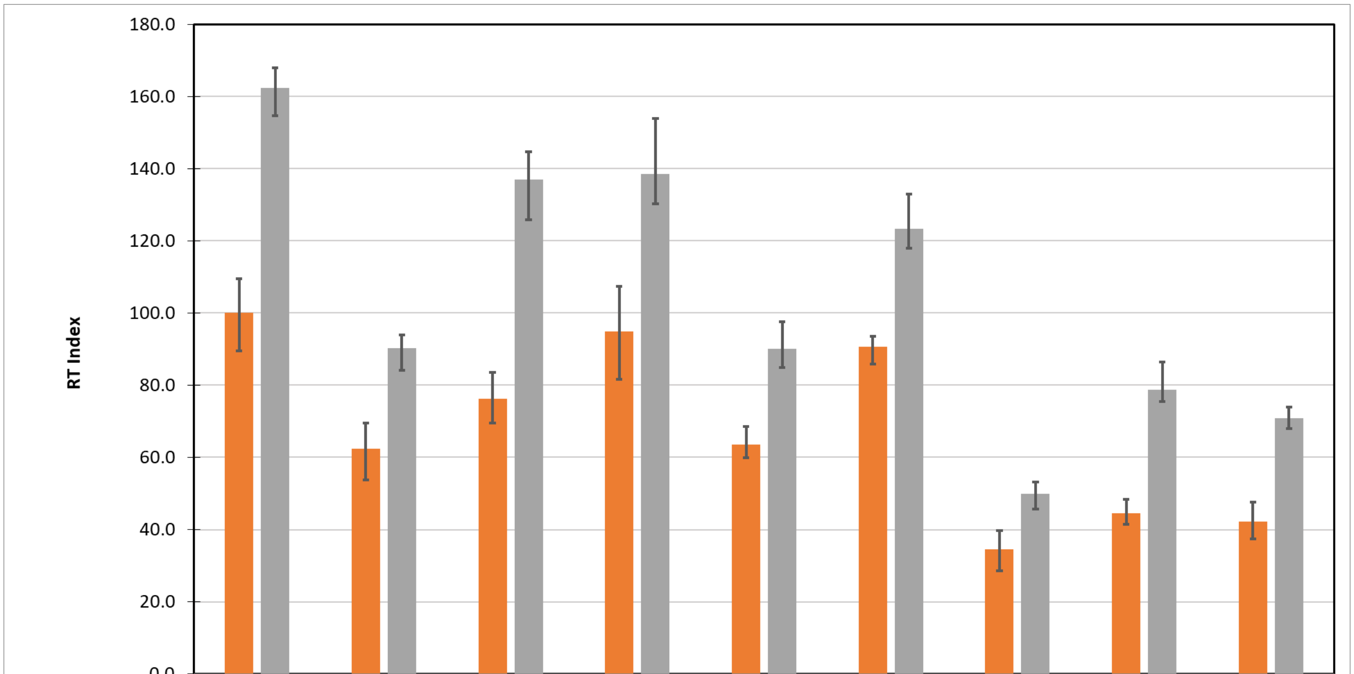
Figure 5.4 shows the rutting results obtained from the HWTT. All the Superpave mixtures showed excellent rutting results with rut depth below 5.0 mm at 20,000 passes, irrespective of the aging condition. Almost all of the SMAs had similarly lower rut depths below 5 mm, with the exception being the PMPC SMA-Control mixture, which recorded an average 9.6 mm rut at 15,000 passes. In general, the LMLC rut depths were lower compared to the PMPC rut depths due to aging conditions, except for the SP-MDPE mixture. The reheating of the mixtures resulted in oxidative stiffening and, in turn, lower rut depths. The SP-Control mixture, which was incorporated with MDPE and used a stiffer base binder (PG64-22) compared to the SP-MDPE mixture, recorded the best rut depths at 15,000 passes. It is worth noting that the SP-PPA mixture had the highest recorded rut depth amongst all the Superpave mixtures, although the absolute value is still low. In general, the PPA additive is known to provide stiffness to a mix, resulting in lower rut depths. However, in this study, the other additives/modifiers provided higher resistance to rutting. The HWTT rutting results tracked the trends seen in the CT-index results, which is why these tests are often paired in BMD methodology.




| | SP-Control | SP-ECR | SP-LDPE | SP-MDPE | SP-PPA | SP-SBS | SMA-Control | SMA-ECR | SMA-LDPE |
|---|---|---|---|---|---|---|---|---|---|
| LMLC | 1.5 | 3.0 | 2.0 | 2.2 | 3.8 | 2.7 | 4.0 | 3.2 | 2.7 |
| PMPC | 1.9 | 3.4 | 2.7 | 2.0 | 4.7 | 2.8 | 9.6 | 4.9 | 3.6 |
| PMLC (reheated) | 1.07 | 2.77 | 1.23 | 1.37 | 2.30 | 1.77 | 3.90 | 2.83 | 2.60 |

**Figure 5.4. HWTT rut depth results for all mixtures**

The IDEAL-RT test has been evaluated by several departments of transportation (DOTs), including MoDOT, to serve as a QC test and a surrogate for rutting evaluation. The HWTT includes sample fabrication and runs for several hours while the IDEAL-RT test is run on the same testing frame as the IDEAL-CT with an added support on the bottom of the specimen to induce shear failure in the specimens, as shown in Figure 4.4. The JSP for this project had no specified RT-Index threshold, but MoDOT's latest specification requires an RT-Index of 50, 65, and 80 for PG64-22, PG70-22, and PG76-22 contract grade binder, respectively. Unlike the CT-Index requirements, there are no separate RT-Index thresholds for SMA mixtures. The RT-index results are shown in Figure 5.5 and are computed from an average of three replicates for PMPC mixtures and four replicates for PMLC mixtures.




| | SP-Control | SP-ECR | SP-LDPE | SP-MDPE | SP-PPA | SP-SBS | SMA-Control | SMA-ECR | SMA-LDPE |
|---|---|---|---|---|---|---|---|---|---|
| PMPC | 100.1 | 62.3 | 76.3 | 94.8 | 63.6 | 90.7 | 34.4 | 44.6 | 42.3 |
| PMLC (reheated) | 162.4 | 90.4 | 137.0 | 138.5 | 90.1 | 123.3 | 49.9 | 78.8 | 70.8 |

**Figure 5.5. RT Index for all mixtures**

One peculiar aspect of the results obtained in this research is the lower RT-Index results recorded for the SMAs, which are known for being rut resistant. Even with the HWTT, the rut depths for SMAs were fairly low, at or below 5.0 mm in most cases. However, with the RT-Index test, most of the values recorded for SMAs were noticeably lower than the values for the dense graded mixtures, indicating a much higher resistance to rutting for the dense-graded mixtures. More research is needed into truly understanding the mechanism of failure in the IDEAL-RT test when testing different mixture types. The RT-Index was able to indicate additional stiffness due to reheating of the mixtures, as characterized by higher RT-Index for the PMLC mixtures compared to the PMPC mixtures.

## 5.4 Moisture Damage Test Results

The moisture damage tests used for this project include the Hamburg Wheel Tracking Test (HWTT) and Tensile Strength Ratio (TSR). The moisture damage evaluations were only conducted on the PMLC (reheated) Superpave mixtures. In this study, the rut depths were reported at 15,000 passes but SIP computations were done considering the rut depth curve obtained at the completion of the test at 20,000 wheel passes. As described in Section 4.2, the SIP parameter computation involves the determination of creep and stripping slope. In some cases, the mathematical computation of SIP is unrealistic if the stripping slope is very low, indicating that the mixture has no observable stripping issue. Thus, following the Iowa method, the SIP parameter is only computed when the Slope Ratio (SR), which is the ratio of stripping slope to the creep slope, is greater than or equal to 2.0. Table 5-1 shows the SR and SIP for the PMLC Superpave mixtures and it can be seen that none of the mixtures have a slope ratio of greater than or equal to 2.0, which invalidates the need to compute SIP. The results indicate that the mixtures are highly resistant to moisture damage.

**Table 5-1. Slope Ratio and SIP for PMLC Superpave mixtures**

| Mixture Name | Slope Ratio | SIP (# of passes) |
|---|---|---|
| SP-Control | 1.15 | NA |
| SP-ECR | 0.90 | NA |
| SP-LDPE | 1.68 | NA |
| SP-MDPE | 1.29 | NA |
| SP-PPA | 1.16 | NA |
| SP-SBS | 1.17 | NA |

The TSR results are shown in Figure 5.6. All the PMLC Superpave mixtures passed the 80% TSR requirement except for the SP-Control mixture, which was produced with PG64-22 and modified with MDPE. The TSR result for the SP-Control mixture is borderline at 79.1%. There have been recent concerns reported by MoDOT on the correlation of TSR results with field data. The HWTT SIP parameter and TSR results disagree on the SP-Control mixture. In the future, the field performance of this section will be evaluated with particular focus on the stripping distress to validate or invalidate the concerns over the TSR results.

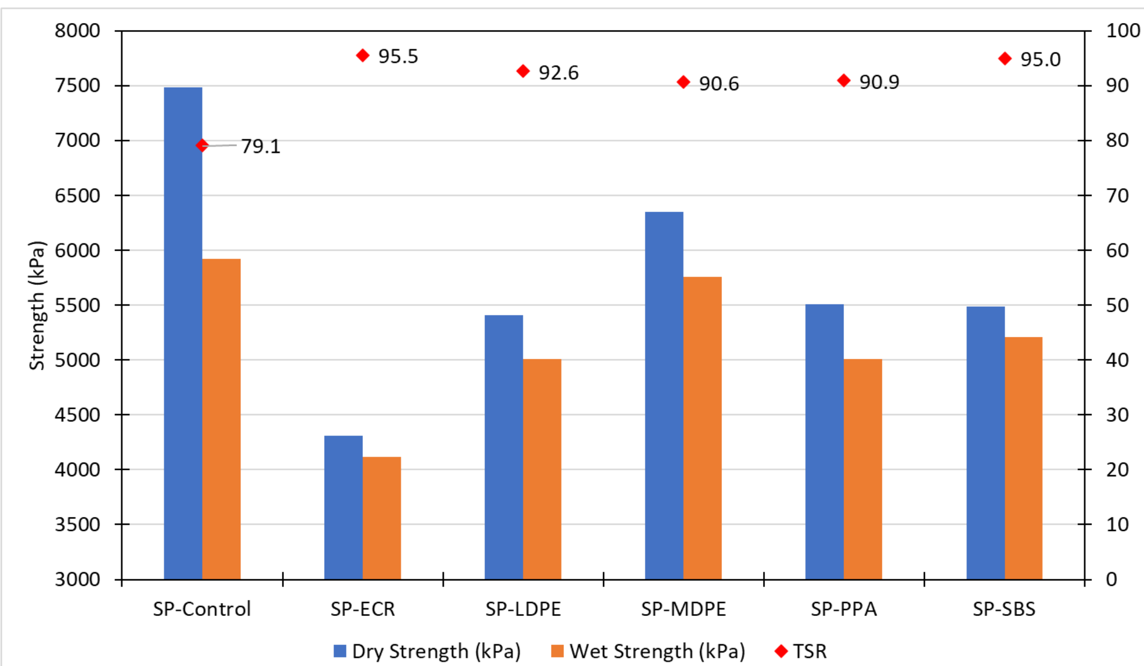



**Figure 5.6. TSR results for all Superpave mixtures**

# Chapter 6: Summary and Conclusions

The overarching goal of this study was to advance the deployment of innovative pavement technologies prevalent in the state of Missouri. In recent years, MoDOT has investigated the use of recycled polymers in their Superpave and SMA mixtures. Recycled polymers such as ground tire rubber and waste plastics have been the primary focus of this effort. The increasing adoption of Balanced Mix Design methodology has helped in the establishment of a framework wherein contractors could facilitate material innovation through the adoption of these recycled polymers. To that end, MoDOT has supported the construction of several test sections to showcase the constructability and evaluate the field performance of recycled polymer modified asphalt mixtures designed with BMD methodology. As an example, in 2021 MoDOT constructed four test sections on Route 740 (Stadium Blvd.) in Columbia, MO as a pilot implementation of BMD methodology and acceptance criteria, and as a demonstration for the use of recycled polymers in asphalt mixtures. This research project covers a similar demonstration project on I-155 near Hayti, MO, in the bootheel of Missouri. It builds on the Stadium Blvd. project by evaluating more variables such as different modifiers, mixture types, and traffic.

In 2023, MoDOT identified an approximately six mile long stretch of roadway on I-155, upon which to test nine asphalt mixtures. The mixtures included recycled (GTR and waste plastic) and virgin (SBS and PPA) polymers incorporated in dense graded and SMA mixtures. For the GTR section, an Engineered Crumb Rubber product was used, similar to product used on the Stadium Blvd. project. For waste plastics, a pelletized low-density PE product and a shredded/flaked mixed-density PE product were used in construction. The research team used the BMD requirements outlined in a MoDOT Joint Special Provision (JSP) specific to this project. The BMD requirements for the Superpave dense graded mixtures were broken into two tiers – normal and elevated. The normal BMD mixtures had a minimum CT-Index threshold of 45 and the elevated BMD mixtures had a minimum CT-Index threshold of 80. For SMA mixtures, the BMD requirements for the CT-Index was 160. The maximum rut depth requirement, utilizing the Hamburg Wheel Track Test (HWTT), for all mixes was 12.5 mm at 15,000 passes. The research team from MAPIL tested Lab Mixed Lab Compacted (LMLC), Plant Mixed Plant Compacted (PMPC), and Plant Mixed Lab Compacted (PMLC) mixtures. The research team designed and produced the LMLC mixtures in their lab and also produced PMPC mixtures in the field with their mobile asphalt testing laboratory. Additionally, the research team produced PMLC mixtures by reheating the mixtures sampled from the field and compacting them in the MAPIL laboratory.

The team conducted a variety of tests to determine mixture performance. Cracking tests included IDEAL-CT and DC(T), rutting tests included HWTT and IDEAL-RT, and moisture damage tests included TSR and the SIP parameter derived from the HWTT. The IDEAL-CT results showed good cracking resistance for all the mixtures. All PMPC mixtures except two showed an increase in CT-Index compared to the LMLC mixtures. The two exceptions were measured to have statistically similar CT-Index values as compared to their LMLC counterparts. Regarding CT-Index, the recycled polymer modified mixtures were on par with or better than the virgin polymer mixtures. Similar conclusions were drawn from the DC(T) fracture energy results of the PMLC mixtures. In terms of HWTT rutting, all the mixtures were exceptional. The PMPC mixtures had higher rutting compared to the LMLC mixtures and the PMLC mixtures showed the least rutting, indicating different aging levels in LMLC, PMPC, and PMLC mixtures. Once again, the recycled polymer mixtures performed similarly or better than the virgin polymer mixtures. The RT-Index values for the SMAs were lower than the dense graded mixtures, in general. Traditionally, SMAs exhibit better rutting resistance than dense graded mixtures and, thus, were expected to show higher RT-Index values, indicating better rutting resistance. This finding necessitates an in-depth evaluation of the failure mechanism prevalent in the IDEAL-RT test and its ability to correlate to field observations. Only the PMLC Superpave mixtures were evaluated for moisture damage. The SIP parameter showed that none of the mixtures were prone to stripping. TSR results highlighted one mixture that was a borderline failure (TSR = 79.1), but all the other mixtures had high TSR, above 90. Overall, the Superpave mixtures were resistant to moisture damage.

The research team will continue to evaluate the long-term performance of these sections with periodic field visits, with an aim of correlating field observations to laboratory results. This will help finetune the BMD thresholds and improve the mixture designs. In addition, the research team will also evaluate these additive sections for their capabilities to mitigate reflective cracking, as part of a national study in partnership with the National Road Research Alliance including researchers from the National Center for Asphalt Technology and the University of New Hampshire. Further, the long-term performance of the recycled polymer sections will inform the development of specifications to facilitate the adoption of recycled polymers in lieu of virgin polymers. While a specification exists for the use of ground tire rubber via the dry process in Missouri, a similar specification has yet to be developed to guide the use of recycled waste plastics in MoDOT asphalt mixtures. It is recommended that the results presented herein, along with those gathered in the earlier demonstration project conducted on Stadium Blvd. in Columbia, MO, be used address this technological gap, e.g., to create a specification for the proper use of recycled waste plastics in MoDOT asphalt mixtures.

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