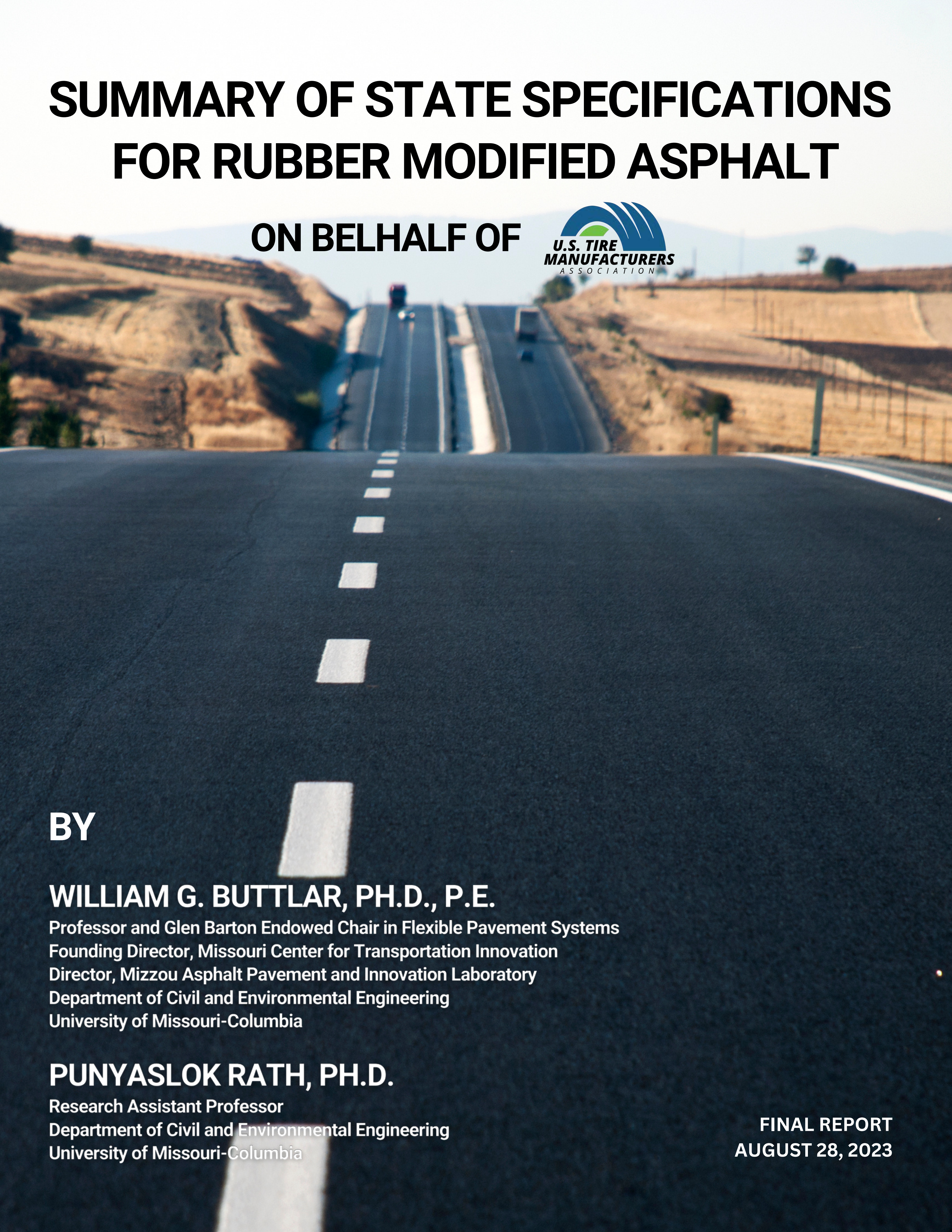

SUMMARY OF STATE SPECIFICATIONS FOR RUBBER MODIFIED ASPHALT

ON BELHALF OF U.S. TIRE MANUFACTURERS ASSOCIATION

BY

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EXECUTIVE SUMMARY

As the nation drives towards more sustainable infrastructure and, towards net carbon zero emissions targets, Rubber-Modified Asphalt (RMA) is gaining popularity for its combined sustainability, performance, and economic benefits. Ideally, scaling up the use of RMA across the United States would involve the inclusion of RMA in the material specifications published by each of the 50 State Highway Agencies (SHAs). Without such published specifications, RMA usage would be limited to smaller, isolated demonstration projects involving special provisions and/or value engineering applications. Furthermore, the majority of asphalt tonnage comes from cities, counties, and municipal work. Since these agencies generally base their specifications on, or directly allow the use of asphalt produced according to SHA specifications, the expansion of SHA specifications to include RMA is critical in order to more fully reap the aforementioned benefits of RMA.

In an effort to identify areas of opportunity for the expansion of RMA usage, an investigation was carried out to summarize the state of RMA specification availability across the United States as of the start of the 2023 construction season. Publicly available highway material specifications were collected from all 50 states, reviewed, and summarized in this report. The key findings of the study include the following:

(1) 21-of-50 states have some form of published RMA specification (i.e., wet and/or dry process specifications).

(2) A number of the states using RMA are concentrated in the Southwest, Southeast, and a handful of Midwestern and East Coast states.

(3) Of the 21 states with RMA specifications, 17 have published wet process specifications, while only four (GA, MO, VA, and PA) have published both wet and dry process RMA specifications.

(4) Eight states have formal specifications for rubberized chip seals.

These findings suggest that there is much more work to be done with respect to scaling the use of RMA across the US, especially in areas such as the Northwest. Sharing of best practices, for instance, at regional asphalt user-producer group meetings, and taking advantage of new federal funds being made available for green engineering projects may help in the scaling up of RMA use in the US.

Based on the findings of the study, the following recommendations were made:

(1) Investment in regional demonstration projects, scrap tire recycling infrastructure, and hot-mix asphalt plant recycling infrastructure to facilitate RMA usage, particularly in areas with little-to-no current RMA usage should be given priority. Significant opportunities exist for both states co-located in regions of expertise with dry and wet process RMA (SW, SE, Midwest, NE USA), and for regions such as the upper Midwest and Western states where little-to-no RMA is currently used.

(2) Gaps in knowledge with respect to RMA performance testing, modern performance specifications, and integrated pavement/materials design should be addressed with an eye towards national standardization, bolstered by a national clearinghouse of test results, field performance data, improved performance prediction models, and templates for new RMA construction and materials specifications.

(3) A national steering group should be established, which can help develop and coordinate national research priorities and studies for RMA and can provide oversight to a center of excellence for RMA research. The steering group can also help to prioritize and coordinate regional demonstration projects, strategic investments in recycling infrastructure, and provide overall industry leadership and advocacy towards increased pavement sustainability, resiliency, and circular economy solutions involving RMA.

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
APA	Asphalt Pavement Analyzer
AR	Asphalt Rubber
ARFC	Asphalt Rubber Friction Course
ASTM	American Society for Testing Materials
BBR	Bending Beam Rheometer
CRM	Crumb Rubber Modifier
DC(T)	Disc-Shaped Compact Tension Test
DGAC	Dense-Graded Asphalt Concrete
DOT	Department of Transportation
ECR	Engineered Crumb Rubber
ELT	End of Life Tires
FDOT	Florida Department of Transportation
GDOT	Georgia Department of Transportation
GTR	Ground Tire Rubber
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
HWTT	Hamburg Wheel Tracking Test
NAPA	National Asphalt Pavement Association
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal Maximum Aggregate Size
OGFC	Open Graded Friction Course
PCC	Portland Cement Concrete
QA	Quality Assurance
QC	Quality Control
RAP	Recycled Asphalt Pavement
RAS	Recycled Asphalt Shingles
RMA	Rubber Modified Asphalt

LIST OF ABBREVIATIONS

SBS	Styrene Butadiene Styrene (polymer)
SHRP	Strategic Highway Research Program
SOK	State of Knowledge (USTMA report, Buttlar and Rath, 2021)
SMA	Stone Matrix/Mastic Asphalt
TRB	Transportation Research Board
WMA	Warm Mix Asphalt

TERMINOLOGY

Asphalt Rubber	Blend of rubber (minimum 15% by weight of binder) and asphalt via wet process. It is often used in gap- and open-graded asphalt mixtures
Conventional Mixture	Asphalt mixture without any modification
ECR	Engineered Crumb Rubber refers to chemically-engineered rubber used in dry process modification of asphalt mixtures
ELTs	End of Life Tires or scrap tires
EPD	Environmental Product Declaration is a transparent, objective report that communicates the environmental impacts of a product
GTR	Ground Tire Rubber obtained by mechanical grinding of scrap tires
RMA	Rubber-Modified Asphalt is a generalized term used for any asphalt mixture with rubber incorporated in it via any process

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1 INTRODUCTION

1. INTRODUCTION

Developed countries such as the United States have begun to weave sustainability and resilience considerations into the ways that physical infrastructure systems such as roads and airport pavements are designed and maintained. A recent State-of-Knowledge (SOK) summary (Buttlar and Rath, 2021) demonstrated that modern approaches to rubber-modified asphalt (RMA) are leading to highly sustainable pavements that are also highly durable, economical, and provide excellent surface characteristics such as high skid resistance, low roughness, and reduced noise. Despite these advantages, the use of RMA in the United States has seen only modest growth over the past two decades. Modern, 'dry process' RMA approaches (detailed in Chapter 2) have led to an uptick in RMA usage in recent years, presenting a new value proposition to pavement owner-agencies. Other hurdles that have been gradually overcome in the past two decades include: (1) contextualization of early pavement failures in the 1980's and 1990's resulting from poorly designed or constructed RMA pavements, (2) extensive, positive field performance data for various RMA pavement approaches, and (3) competition leading to lower cost alternatives for RMA, such as modern dry process techniques. Other factors contributing to an increase in RMA usage over the past two decades include: (1) contextualization of early pavement failures in the 1980's and 1990's resulting from poorly designed or constructed RMA pavements, (2) the availability of extensively documented, positive field performance data across various RMA pavement types, and (3) competition leading to the introduction of lower cost RMA pavement alternatives, such as RMA pavements designed and constructed with the modern dry process.

A survey of State Highway Agencies (SHAs) in the SOK report revealed that a lack of comprehensive and robust agency specifications, along with a lack of contractor experience, was thought to be hindering the growth of RMA in many US states. This presents a 'chicken-vs.-egg' scenario because, on one hand, agencies are more comfortable adopting new technologies and subsequently developing specifications around products and/or processes that have been verified with extensive field studies. On the other hand, the motivation for contractors to experiment with and invest in new materials and technologies (and therefore to gain experience) is often driven by the existence of new specifications. Pilot studies can, and in a number of states have, provided an effective means to overcome this stalemate. A tipping point appears to be coming where a sufficient number of pavements built by early adopters of wet and dry process RMA have provided sufficient technical data to enable current non-users of RMA to reconsider its use in light of new data. Contractors that add RMA mixes to their design and construction capabilities will be able to reach new sustainability goals and will stay economically competitive in a construction marketplace that is steadily driving towards higher recycling levels.

To get beyond the aforementioned tipping point for increased RMA usage, the sharing of best practices amongst the 50 US states and territories will be essential. Towards this end, the primary goal of this report is to summarize the ‘state of the states’ with respect to their use of RMA, along with a summary of the number and type of RMA specifications included in SHA material and construction specifications across the US. The remainder of this report is organized as follows:

Chapter 2: Background and Definitions

Chapter 3: Summary of State RMA Specifications in 2023

Chapter 4: Case Studies of Modern RMA Specification Approaches and Resulting Benefits

Chapter 5: Looking Forward: Opportunities and Recommended Approaches

2

BACKGROUND AND DEFINITIONS

2.1. WET VS. DRY PROCESS RMA

2.1.1. WET PROCESS

2.1.2. DRY PROCESS

2.2. PAVING APPLICATIONS

2.2.1. FULL STRUCTURAL PAVEMENT SYSTEMS

2.2.2. PAVEMENT OVERLAY AND INTERLAYER SYSTEMS

2.3. SUMMARY OF PREVIOUS STATE DEPARTMENT OF TRANSPORTATION SURVEYS

2. BACKGROUND AND DEFINITIONS

For a comprehensive review of Rubber Modified Asphalt (RMA) history, composition, economics, sustainability, etc., the reader is encouraged to consult the State of Knowledge Report on Rubber Modified Asphalt (Buttlar and Rath, 2021), which can be downloaded from the USTMA's website. A brief summary, focusing on RMA composition and typical pavement applications, is now presented. A summary of previous surveys given to State Highway Authorities (SHAs) regarding RMA usage is also presented.

2.1. WET VS. DRY PROCESS RMA

Once Ground Tire Rubber (GTR) is produced from End of Life Tires (ELTs), various methods can be employed for its incorporation into asphalt pavements. At the highest level, RMA approaches can be broken into two major categories: the wet and dry process. The following sections discuss each method in detail.

2.1.1. Wet Process

The development of wet process in the US started in the mid-1960's with Charles McDonald's experiments on producing small patches that were made by embedding 3/8 in. chips in rubber-modified asphalt binder. Eventually, wet process rubber modification was defined to encompass the various processes in which ground tire rubber is used to modify the liquid asphalt binder, stored in tanks, possibly transported, and later used to produce an asphalt paving mixture. Wet process modification of an asphalt binder can be carried out either on-site at the asphalt mixture production plant or at an asphalt blending terminal. While a breadth of nomenclature has been reported in the literature with respect to wet process modification, the following classifications and terminology are the most broadly used:

Asphalt Rubber: By definition (ASTM D8, later defined in ASTM D6114), asphalt rubber is a blend of asphalt cement, reclaimed tire rubber, and certain additives, with at least 15% of rubber by weight of binder being used to reach the needed level of modification to achieve significantly enhanced asphalt mixture performance characteristics. Typically, coarser size rubber particles (about 1.5 mm in size) are used for production of asphalt rubber. The rubber-asphalt interaction takes place for about 30-60 minutes at elevated temperatures ranging from 175-190C (350-375F). There is a need for continuous agitation during production and storage of asphalt rubber. This process is carried out entirely on-site at the asphalt concrete mixture plant using portable equipment, including a ground tire rubber feeder along with blending and storage tanks equipped with agitation.

Terminal Blends: The production of terminal blends resembles that of the asphalt rubber production process, except that the production takes place at a liquid asphalt supplier terminal and usually, finer sizes of rubber particles (0.600 mm – 0.200 mm (#30-#80 mesh)) are used. Ground tire rubber and asphalt are mixed in blending tanks at elevated temperatures (175-190C (350-375F)) and for at least 60 minutes. The blends are then stored at elevated temperatures until they are delivered to the work site. Terminal blends generally contain about 5-12% rubber and could also include specialized chemicals or polymers such as styrene-butadiene-styrene, or SBS (Han et al., 2016). Currently, the most popular terminal blend is called the "Wright Process," which is prevalent mainly in Arizona, Texas, and surrounding states. The Wright process uses a longer rubber-binder interaction time and chemical additives to produce a blend that has good storage stability. Notably, rubber settlement, or lack of adequate storage stability, has been one of the main production and quality control (QC) issues with the wet process for RMA production.

2.1.2. Dry Process

The Dry Process for RMA asphalt mixture production was developed initially in Sweden in 1960's under trade names "Skega Asphalt" or "Rubit" before making its way to the US under the name of PlusRide™ (Esch, 1982). This RMA production process involved replacing a small portion of the fine fraction of the blended aggregate structure of the asphalt mixture - in the range of 1-3% by weight- with rubber particles ranging from 4.2 mm to 2.0 mm. This size of rubber particles is quite large as compared to those used in modern dry process RMA mixtures. The motivation behind the early dry process approach with larger rubber particles was to increase the skid resistance and durability of the resulting rubber-modified asphalt pavement (Esch, 1982; McQuillen Jr. & Hicks, 1987; United States Department of Transportation, 2016).

The PlusRide™ technology specified gap-graded mixtures to be used with rubber modification. Gap-gradations, in contrast to 'well-graded' or 'dense-graded' blended aggregate structures, contain a shortage or gap in particles across a range of aggregate sizes (or sieves) somewhere in the middle of the particle size distribution curve. This can produce 'room' for rubber particles, including the facilitation of rubber particle swelling during uptake of light ends from the asphalt binder. However, many road agencies only use gap-graded RMA mixtures in limited application categories. Dense gradations are preferred over gap and open graded mixtures in cold climates where pavement density and impermeability is preferred in an effort to limit freeze-thaw effects throughout the pavement structure. A notable exception is stone matrix asphalt, or SMA, which is gaining favor as a high performance, gap-graded surfacing mixture but with a similar, low air void level as compared to dense-graded asphalt.

In addition, SMAs feature very stringent aggregate requirements and require a tough, polymer-modified binder system. The rise of SMA usage in recent years notwithstanding, early over-reliance on gap-graded RMA mixture applications hindered the widespread adoption of dry process RMA across most of the US.

These limitations led to the development of the so-called "Generic Dry Technology," aimed at using any existing local mixture gradation for use in RMA, made possible through the use of finer rubber in the dry process (Takallou & Sainton, 1992). Specification of a range of rubber particles to be used in conventional mixture gradations allowed the dry generic technology to be assessed in field trials in many states. However, the flexibility in terms of particle size also led to an increase in cost of projects, as crumb rubber particles manufacturers had limited capabilities (Heitzman, 1992; United States Department of Transportation, 2016).

Today's modern dry process technologies use even finer rubber particles (0.600-0.300 mm (#30-#50 mesh)) and may incorporate chemical surfactants, for example Vestenamer^{R}, which facilitate the rate of rubber swelling and deliver other production, construction, and/or performance benefits to the resulting RMA mixture. In modern, dry process RMA production, rubber is injected into the mixing plant in the bottom portion of the mixing drum (typically through the RAP collar). Generally, an existing mix design is used, with only minor adjustment to the blended aggregate gradation needed, if at all. Trademarked products such as Asphalt Plus' Elastiko™, and Liberty Tire's SmartMix™ are examples of 'modern dry process' or 'dry-hybrid' approaches. Reports in the literature suggest that in the past decade more than five million tons of engineered crumb rubber (ECR) has been placed in multiple US states, the majority involving the Elastiko™ system (Baumgardner et al., 2020).

2.2. PAVING APPLICATIONS

Asphalt pavement structures and asphalt paving surfaces have evolved considerably since their inception in the late 1800's, resulting in a number of fundamentally different structural systems and materials systems involving pavements comprised with asphalt. A brief listing of these asphaltic paving systems is now provided, with a focus on describing applications where GTR is either prevalent or potentially useful.

2.2.1. Full Structural Pavement Systems

RMA is appropriate and commonly used in traditional hot-mix and warm-mix asphalt paving layers. This includes use in traditional, or conventional flexible pavement systems, which are placed over unbound, granular subbase and base layers of aggregate, and full-depth asphalt pavements, where the total combined thickness of the asphalt layers is increased and subbase and base layers are generally eliminated. In both systems, base (or binder) course and surface course asphalt mixtures are used. Both mixture types provide an excellent opportunity for RMA use. The base asphalt courses can benefit from the fatigue resistance of RMA, while the surface course can benefit from both the rutting and cracking resistance imparted by RMA. Another possible use of RMA in new pavement construction is in **composite pavement** systems. These involve the use of a Portland cement concrete pavement section topped with asphalt concrete in new pavement construction. Although involving high initial capital costs, these systems are gaining popularity in high traffic areas where 40+ year design lives are desired. For instance, the Illinois Tollway now frequently constructs new composite pavement systems, with durable SMA mixes placed on the new concrete pavement to promote favorable surface characteristics such as skid resistance, smooth ride quality, and reduced noise. GTR is now commonly used in Illinois Tollway SMA mixtures to arrive at economical surfacing materials that meet modern balanced mix design requirements (W. Buttlar et al., 2021).

2.2.2. Pavement Overlay and Interlayer Systems

From the perspective of lane-miles of highway treated per year, the restoration or enhancement of pavement structural integrity and/or surface characteristics via the placement of **asphalt overlays** far exceed new pavement construction. Asphalt overlays are also prime targets for the use of RMA for not only performance benefits but also functional enhancements such as reduced noise and better skid resistance. In some cases, **stress absorbing membrane interlayers (SAMIs)** are used as the first course of a multi-layer overlay system. These are generally thin layers of high-performance, ductile/crack resistant asphalt pavement designed to mitigate the reflection of cracking from existing, aged pavement (asphalt or concrete) into the new overlay surface. From the results of the survey presented earlier, it is clear that some states are using GTR to achieve the high-performance requirements of SAMIs. In fact, one of the first uses of RMA was in the form of SAMIs in Arizona to prevent reflective cracking (Way, 2012).

Data from the survey conducted in this study as well as published results show that RMA is used substantially in form of thin overlays. Depending on the sophistication of the pavement design system used, reduced layer thickness(es) may result from the use of RMA, increasing sustainability and leading to more attractive life cycle costs. In the late 1980's, California constructed various thicknesses of conventional DGACs and rubber-modified overlays over Rt. 395 in northeastern California. After a few years of monitoring, the authorities concluded that the performance of substantially thinner rubber sections was similar to the more traditional DGAC sections (J. L. V. Kirk, 1997; J.

V. Kirk & Holleran, 2000). In 1990's, Caltrans validated the work and showed that a reduction ratio of 3:1 was possible for rubber vs. DGAC overlay lifts, enabling similar performance along with substantial cost savings. Later, Harvey et al. (2000) reported rubber-modified overlays in California to have similar performance as DGAC asphalt mixtures that were 2.1 times thicker (Harvey et al., 2000). Buttlar et al. (2019) reported a cost savings of up to 43% could be achieved by using lesser lift thickness of RMA in place of thicker unmodified pavement without compromising on pavement performance (W. G. Buttlar & Rath, 2019). More recent field data exists that supports the use of GTR in thin, maintenance overlays as summarized in the following studies: Walubita and Scullion 2008 (Walubita & Scullion, 2008); Scullion et al. 2009 (Scullion et al., 2009); Zhou et al. 2009 (F. Zhou et al., 2009); Hu, Zhou, and Scullion 2014 (Hu et al., 2014); Chou, Datta, and Pulugurta 2008 (Chou et al., 2008). Another subset of this category is spray-paver applied, thin-bonded wearing courses, including ultra-thin varieties (Chen et al., 2019). The advantage of these systems is their ability to achieve a high degree of bonding through the use of a heavily applied tack coat, often polymer modified, which is spray-applied just centimeters in front of the deposited paving mixture and paver screed using a sophisticated, multi-function ‘spray paver.'

Rubberized chip seals and thin slurry seal systems have also utilized GTR with success (Van Kirk, 2003; H. Zhou et al., 2014). Chip seals are extensively used in the maintenance of low traffic volume roads, as they can restore surface characteristics such as smoothness and skid resistance at a low cost per square area. Chip seals simply involve a spray application of a heavy membrane of asphalt cement or asphalt emulsion, followed by the spreading and seating (by rolling) of uniformly-sized aggregate chips. A key aspect of successful chip seals is the retention of chips during service life, which can be enhanced by the use of a high toughness asphalt binder product. As such, a number of states have used polymer modified binders and emulsions, and so naturally, rubberized chip seals have been developed to provide an economical, green alternative for high performance chip seals. As will be detailed in the following section, eight states include rubberized chip seals in their standard specifications.

2.3. SUMMARY OF PREVIOUS STATE DEPARTMENT OF TRANSPORTATION SURVEYS

As part of the SOK study, a survey was conducted to assess state highway agencies (SHAs) in the US in terms of their current usage and perceptions of RMA. Detailed results, including bar charts and written comments provided by respondents, are presented in the Appendix of the SOK report (Buttlar and Rath, 2021). The survey consisted of 12 questions, where the full script of the survey instrument developed is provided in the Appendix. A list of 26 respondent states is also included in the Appendix of the SOK report.

Based on the survey results, it is clear that most state highway agencies (SHAs) are still hesitant to develop modern specifications for RMA. Among the key findings, the survey revealed that:

- 54% of the responding SHAs reported no current usage of RMA in their states.
- 73% of the respondents consider lack of contractor/agency experience in RMA as the chief barrier in adoption of RMA in their states/geographical areas.
- The complexity and variability introduced in materials storage, handling, and stability was cited as the second-most important barrier (65%).
- Only 28% of respondents cited the past field experiences of RMA to be a barrier in its adoption.
- 50% of the respondents reported that RMA performs the same as or better than the traditional polymer (SBS) modified asphalt mixtures. Only 8% responded that RMA is inferior to SBS modified mixtures.
- In terms of pavement sustainability, 58% of the respondents were unsure of the effects of RMA, while about 37% reported a net positive effect of RMA on pavement sustainability.
- In terms of life cycle cost savings, more than half (65%) were unsure of any cost benefits due to RMA as compared to standard HMA. There was an even split (17% each) between respondents who believed that RMA results in costs savings vs. those SHAs who did not. As previously mentioned, multiple studies have reported net life cycle savings when using RMA over standard HMA.

The survey results from SHAs seem to indicate that a number of state highway agencies are making current decisions regarding RMA usage, including delaying the development of RMA specifications for new approaches, based on results from initial RMA demonstration projects conducted decades ago. In fact, many states have not attempted RMA at all. For many states, the initial experiences with RMA occurred during the federal mandate period in the mid-1990's, as evident from published reports. During this time, RMA costs were still quite high in comparison to unmodified asphalt, and field performance results were still fairly inconsistent or not well documented. States that have yet to experiment with RMA often cite the lack of contractor interest in RMA. This is paradoxical, since contractor interest in RMA is likely driven by agency interest in RMA as evidenced by the existence of use of updated, or perhaps, permissive specifications. This has resulted in an apparent stalemate with respect to the prospect of increased RMA usage in those states.

Agencies becoming more active in RMA specification development and research in recent years have generally done so by hosting demonstration projects utilizing new RMA materials. This allows contractors to experiment with new production methods and to utilize new research and mix design methodologies. This in turn has led to adoption or local development of new construction specifications for RMA. This includes new specification architypes based on 'balanced mix design concepts,' i.e., specifications built on new asphalt mixture performance tests. Because RMA mixtures represent a novel, composite paving material (built with a recycled material), testing of the full mixture of binder, aggregate, and rubber is more realistic than testing of the liquid asphalt binder plus rubber (as seen in earlier RMA specifications). Binder-centric specifications have generally limited the use of RMA over the years, as certain crack inhibition mechanisms and benefits of rubber modification are not captured effectively by binder tests (Rath, Gettu, et al. 2021; D'Angelo, 2018).

SUMMARY OF STATE RMA SPECIFICATIONS IN 2023

3

3.1. SUMMARY OF RMA SPECIFICATION AVAILABILITY AS PUBLISHED BY SHAS IN 2023

3.2. SUMMARY OF RMA SPECIFICATION TYPES PUBLISHED BY SHAS IN 2023

3.3. ANALYSIS OF CURRENT RMA STATE SPECIFICATIONS

3. SUMMARY OF STATE RMA SPECIFICATIONS IN 2023

This chapter presents a summary of State Highway Agency (SHA) Specifications for RMA that were publicly available for use in the 2023 construction season. First, a graphical summary of available specifications for wet, dry, and other miscellaneous RMA applications are provided, and compared to previously published summaries. Next, a state-by-state summary of available RMA specifications is presented and discussed in tabular form.

3.1. SUMMARY OF RMA SPECIFICATION AVAILABILITY AS PUBLISHED BY SHAS IN 2023

Once Ground Tire Rubber (GTR) is produced from End of Life Tires (ELTs), various methods can be employed for its incorporation into asphalt pavements. At the highest level, RMA approaches can be broken into two major categories: the wet and dry process. The following sections discuss each method in detail.

Based on a recent survey conducted in our 2021 State of Knowledge (SOK) report as summarized in section 2.2.3 of this report, it was known that just under half of the US states reported to have specifications for one or more forms of RMA. However, widespread usage of RMA clearly cannot occur until finalized, published RMA specifications are made publicly available by the states. Otherwise, the necessary infrastructural and supply chain investments by RMA suppliers, blending terminals, and asphalt contractors to increase RMA usage will not be made. Therefore, a comprehensive search of SHA asphalt specifications as published on public-facing SHA websites was conducted.

Figure 3.1 provides a high-level summary of the publicly available RMA specifications published by SHAs as of the time of this report. As indicated, 21-of-the-50 states have some form of RMA specification available that allows the use of recycled GTR (wet and/or dry process). It is interesting to note that a number of the states using RMA are concentrated in the Southwest, Southeast states, and a handful of Midwestern and East Coast states. Very few upper Midwest or Northwestern states currently have RMA specifications. It is not exactly clear why this trend exists but it can be speculated that the early adoption of RMA by Arizona and California led to the spread of RMA in the Southwest states. Furthermore, early adoption by Georgia, Missouri, Michigan, and by the Illinois Tollway can perhaps further explain the spread of RMA in the Southeast, Northeast and parts of the Midwest.

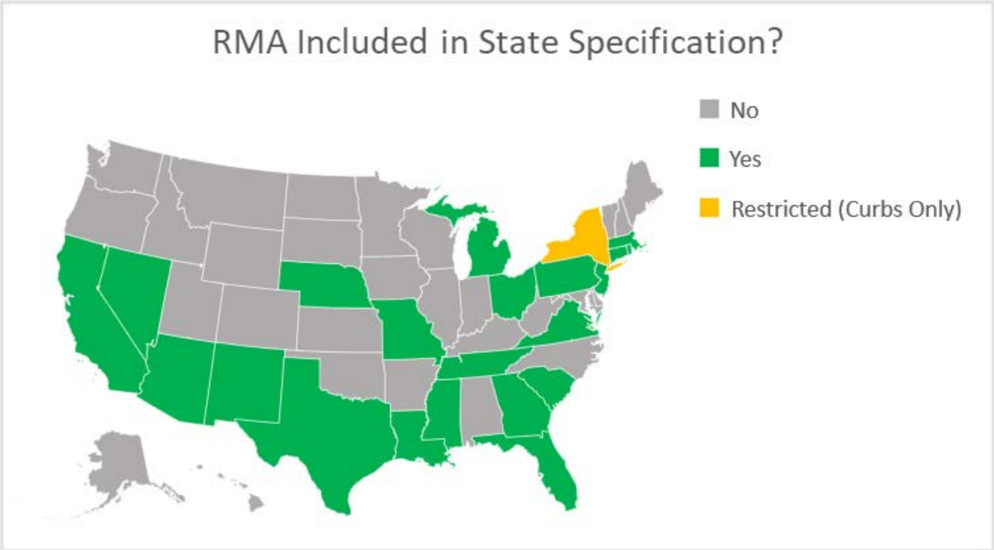


Figure 3.1. Graphical summary of publicly available RMA specifications published by SHAs in 2023

Figure 3.2 shows a breakdown of RMA specifications by specification type. Of the 21 states with RMA specifications, 17 have published wet process specifications, while only four (GA, MO, VA, and PA) have published both wet and dry process RMA specifications. The Illinois Tollway also specifies both wet and dry process RMA specifications.

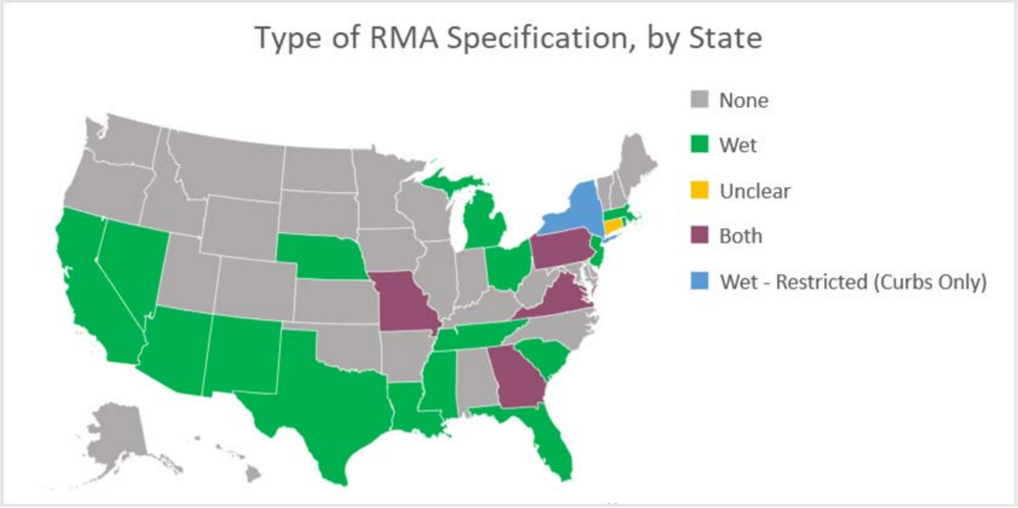


Figure 3.2. Graphical summary of publicly available RMA specifications by RMA type, as published by SHAs in 2023

3.2. SUMMARY OF RMA SPECIFICATION TYPES PUBLISHED BY SHAS IN 2023

A thorough review was conducted of the 21 states publishing RMA specifications as of the review conducted in 2023. Based on this review, a summary of the types and details provided in the published RMA specifications is given in Table 3.1. The first summary column, entitled “Do they use RMA?” coincides with the summaries provided in Figures 3.1 and 3.2, but provides additional details about the nature of the RMA specifications, including links to key, related documents such as special provisions. The next column tracks instances where one or more RMA-type specifications for a given state are currently contained in a special provision or similar document, i.e., outside of the standard specification document. The final column, entitled “Type of Specification (Wet, Both, Unclear, None)” coincides with the information provided in Figure 3.2, and is provided as a convenient reference to the reader. Cell shading in Table 3.1 is also provided for easy categorization of state specifications, where:

- The darkest green shading indicates states with both wet and dry RMA specifications,
- Medium green shading indicates states with only wet RMA specifications,
- Light green shading indicates states with limited RMA specifications or RMA material types allowed (e.g., NY, which specifies RMA only in asphalt curbs, and OK, which is currently conducting pilot projects in dry process RMA using provisional specifications)

Table 3.1. Summary of RMA Specification Types Published by SHAs in 2023

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
Alabama	No mention in their state specs.	No	None	No
Alaska	No mention in their state specs.	No	None	No
Arizona	Asphalt-Rubber included in their state Spec - Section 413. See AGC Chip Seal guide.	Yes	Wet	Yes
Arkansas	Not in their state specs. Specs mention only slurry seal.	No	None	No
California	Asphalt Rubber (wet process) is part of their state specs (see section 39 in https://dot.ca.gov/programs/construction/construction-manual/section-4-39-asphalt-concrete#_Toc57187538). Also developing performance-related specs for asphalt rubber. See Section 907.	Yes	Wet	Yes
Colorado	No use in asphalt mixtures mentioned in their state specs. Emulsified asphalt shall be polymerized or latex modified.	No	None	No
Connecticut	Addition of crumb rubber allowed in bituminous concrete (see section 4.06.02). But material specifications in section M.04 state that polymer modified binder can solely be modified with SBS. No other mention of crumb rubber in material specification. Rubberized asphalt allowed in longitudinal joint construction.	Yes	Wet	No
Delaware	No use in asphalt mixtures mentioned in their state specs.	No	None	No
Florida	Sec 919.2.2 states that GTR is allowed for use in asphalt rubber binder. Pelletized asphalt rubber is permitted as well for binder modification.	Yes	Wet	No

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
Georgia	Crumb rubber is allowed in lieu of polymer modification. Dry and wet process allowed. See Section 820.	Yes	Both Wet and Dry	No
Hawaii	No mention in their state specs.	No	None	No
Idaho	No mention in their state specs.	No	None	No
Illinois [1]	Recycled tire rubber not mentioned in specs. They allow use of SBR in modification of asphalt binders.	No	None	No
Indiana	Recycled tire rubber not mentioned in specs. They allow use of SBR in modification of asphalt binders.	No	None	No
Iowa	No mention in their state specs.	No	None	No
Kansas	No mention in their state specs.	No	None	No
Kentucky	No mention in their state specs.	No	None	No
Louisiana	Allows use of wet-process rubber. Max 10% by weight of binder. Allows latex modification too. See section 502.02.2. Allows polymer, latex, and GTR modified asphalt in chip seals. See http://wwwapps.dotd.la.gov/administration/dotdaz/definition.aspx?termID=405	Yes	Wet	Yes
Maine	No mention in their state specs.	No	None	No
Maryland	No mention in their state specs.	No	None	No
Massachusetts	Allows use of asphalt rubber (>15% by weight of binder) in gap-graded mixtures, and in SAMIs; see M.03.01 B. Their Municipal Pavement Program mentions rubber chip seal (see https://www.mass.gov/info-details/program-overview-municipal-pavement-program)	Yes	Wet	No

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
Michigan	Special provision for wet process rubber modified binder. Ingham County has special provision to use all kinds of rubber modification including wet, dry, and hybrid.	Yes	Wet	No
Minnesota	No mention in their state specs.	No	None	No
Mississippi	Terminal Blend GTR allowed in lieu of polymer. See Section 702.08.3. GTR modified emulsified asphalt (cationic) allowed. See Section 702.07.4.	Yes	Wet	Yes
Missouri	Has a wet and dry process spec. State specs main doc includes wet process/terminal blend GTR (see section 1015.10.3). See JSP1801 for dry spec (Page 3). https://perma.cc/53E7-NV33	Yes	Both Wet and Dry	No
Montana	No mention in their state specs.	No	None	No
Nebraska	Allows asphalt binder modification with crumb rubber. See 1029.02. Allows use of recycled tire rubber as joint sealant and crack filling material. See 508.02. Only SBR is allowed in emulsified asphalt used in chip seals.	Yes	Wet	No
Nevada	Allows terminal blend rubber. Min. 10% by mass. See 703.03.02.	Yes	Wet	No
New Hampshire	No mention in their state specs.	No	None	No

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
New Jersey	Allows wet process modification of asphalt binder with GTR to be used in their specified AR-OGFC mix. See 902.07. The spec has extensive guidelines on blending - See section 1009.03. New language has been added to sec 1012 which indicates that asphalt rubber is allowed in chip seals.	Yes	Wet	Yes
New Mexico	Allows use of terminal blend rubber. Min. 5% dosage. See Section 402.2.1.3. NMDOT special provision for rubberized asphalt chip seals (Section 401-A)	Yes	Wet	Yes
New York	Allows use of coarse recycled tire rubber only in HMA curbs. See Section 714-06.	Curbs only	Wet	No
North Carolina	No mention in their state specs.	No	None	No
North Dakota	No mention in their state specs.	No	None	No
Ohio	Allows terminal blend rubber. See 702.01.5.8. This section refers to Supplemental Specification 887. The supplemental spec has language that allows use of partially devulcanized pelletized GTR, or PGTR. Min. dosage 7%. Extensive guidelines on terminal blending.	Yes	Wet	No
Oklahoma	Oklahoma has no mention of GTR in their state specs but they have reports on field projects in 2019 that used dry process rubber (ECR).	No	None	No
Oregon	No mention in their state specs.	No	None	No

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
Pennsylvania	DOT allows crumb rubber as 'stabilizers' in SMA mixtures (alongside options of cellulose fibers, or mineral fibers). See Section 419.2. 0.3 - 1.0% CR by mix weight is allowed. PennDOT has special provisions for dry process and wet process rubber use in asphalt mixtures. See c04481 ITEM 9448 and c04491 ITEM 9449 for dry and wet process RMA respectively. Only polymer modified emulsions are allowed per Sec 407.02.	Yes	Both Wet and Dry	No
Rhode Island	Allows thin overlays with wet process rubber modified of binder (PG76-34). See Section 411.02.1. Sec 411 describes paver placed elastomeric surface treatment or PPEST, which is a 1" thin overlay, gap graded, 3/8" NMAS. See sec 412 for rubberized asphalt chip seals.	Yes	Wet	Yes
South Carolina	There is a supplemental spec in effect since Jan. 2019 which includes an addendum to Section 401.2.1.1 - Asphalt Binder Additives. Only terminal blend GTR is allowed, Min. 7%. The spec also states that when GTR binder is being used in SMAs, fibers are not required. Supplemental spec for high performance chip seal which calls for use of SBS and SBR.	Yes	Wet	No
South Dakota	No mention of using recycled tire rubber in specs. Allows for polymer chip seals.	No	None	No

State	Do they use RMA?	Do they have rubber in their spec?	Type of Specification (Wet, Both, Unclear, None)	Use of GTR in Chip Seal?
Tennessee	Allows use of terminal blend rubber. See Section 904.01.	Yes	Wet	No
Texas	Asphalt rubber binder (min. 15% GTR) is allowed in permeable friction course (Item 342), and in SMAs (Item 346). See Item 300-2.9. See item 318 for rubberized chip seals.	Yes	Wet	Yes
Utah	No mention in their state specs.	No	None	No
Vermont	No mention in their state specs.	No	None	No
Virginia	No mention in their state specs, but they have a provisional spec for dry and wet process RMA.	Yes	Both Wet and Dry	No
Washington	No mention in their state specs.	No	None	No
West Virginia	No mention in their state specs.	No	None	No
Wisconsin	No mention in their state specs. Study published in Oct. 2020 titled 'Rubber Asphalt Study for Wisconsin' aimed at developing a spec for GTR usage.	No	None	No
Wyoming	No mention in state specs.	No	None	No

[1] *The Illinois Toll Highway Authority has specifications for both wet and dress process RMA. See Section 4.1.*

3.3. ANALYSIS OF CURRENT RMA STATE SPECIFICATIONS

In reviewing the currently available RMA specification documents available among the 50 SHAs, the following general observations were drawn:

- The wet process continues to be the most prevalent RMA type represented in state specifications. However, based on survey data collected in the RMA SOK report (Buttlar and Rath, 2021), the tonnage of wet process RMA used annually is only significant in a handful of states such as Arizona, California, and Georgia, and at the Illinois Tollway, where the latter two agencies both specify, and use, a significant tonnage of both wet and dry process RMA.

- While modern, dry process specifications are only publicly available in four states (Georgia, Missouri, Pennsylvania, and Virginia), via literature review and participation in field demonstrations and workshops, the authors are aware of recent dry process pilot projects and/or provisional specifications being investigated in Oklahoma, Texas, Maryland, California, Illinois, Wisconsin, Michigan, Ohio, Kentucky, Alabama, and Louisiana. ***Thus, a total of 15 states are either specifying or in the process of developing specifications for dry process RMA.*** Once the majority of these states are successful in bringing dry process RMA specifications into routine practice, a better balance of wet and dry process RMA specifications will exist across the US.

- Similar to previously reported RMA usage summaries (Buttlar and Rath, 2021; Ghabchi et al., 2016), RMA can only be scarcely used in Western states due to a lack of specification availability and contractor and agency experience. Due to the prevalence of End of Life tires (ELTs) in all 50 states, supply chains could quickly emerge in these areas of underutilization of RMA. However, according to historical trends, pilot projects and provisional specifications would need to be pursued first and should be viewed as a priority technological gap to be pursued in this region of the US from a pavement sustainability and economics perspective.

MODERN RMA SPECIFICATION APPROACHES AND CASE STUDIES

4

4.1. ILLINOIS TOLLWAY
4.2. MISSOURI
4.3. VIRGINIA
4.4. MICHIGAN
4.5. GEORGIA

4. MODERN RMA SPECIFICATION APPROACHES AND CASE STUDIES

An important aspect of widespread adoption of a product is its impact on real-world performance and its ease of adoption, both logistically and economically. For the dry process, lessons learned from the work done in the 1990's has helped develop the product in a manner that has polymer-equivalent performance with minimal equipment alterations/requirements and a nominal cost addition. According to a report by FHWA published in 2020 (Baumgardner et al., 2020), more than five million tons of chemically engineered dry process asphalt has been placed in Georgia (Shen et al., 2014; Shen & Xie, 2012), Illinois (W. Buttlar et al., 2021; W. G. Buttlar & Rath, 2017; Rath, Love, et al., 2019), Missouri (W. G. Buttlar et al., 2019; Rath, Majidifard, et al., 2019), Michigan (Chen et al., 2019), Oklahoma, Texas (Scullion et al., 2009; F. Zhou & Scullion, 2008), Virginia, Indiana, and other states. On the wet process side, a new terminal blend technology called the Hybrid RMA, which is combination of SBS polymer and GTR (blended terminally), is currently being tested/used in states like Virginia, Wisconsin (Reichelt, 2021), Illinois (Buttlar and Rath, 2017), and in Philadelphia (Rideout, n.d.) and others locales. The hybrid RMA has shown superior performance with lower separation tendency compared to previous wet process products.

Another challenge to RMA adoption is the lack of appropriate and current specifications. There are a few challenges in that regard, for instance, post-production verification of binder properties in the asphalt mixtures is not as straightforward for rubber-modified mixtures as it is for other polymer-modified mixtures. In addition, volumetrics-based design for rubber modified mixtures could, at times, result in dry mixes and could starve the rubber grains of the lower molecular weight oils present in asphalt binder which is critical for adequate performance of the mix. However, in the last few years, an increasing number of DOTs have pivoted towards adopting Balanced Mix Design (BMD) methodology for all their mix designs which shifts the focus from binder properties and volumetrics to performance (index) tests. This has allowed the contractors to produce innovative mix designs to meet the test thresholds at lower costs. For instance, RMA has been used in lieu of SBS-modified asphalt mixtures in various projects due to its equivalent performance and lower costs.

In the following sections, field projects from five states are presented which have used the modern RMA technologies based on a BMD approach.

4.1. ILLINOIS TOLLWAY

The performance of RMA in cold climates is well-supported by field performance data in the Midwest. Illinois Tollway was one of the early adopters of balanced mix design method (previously also known as performance engineered mix design) for their projects. The agency has been using Disk-Shaped Compact Tension (DC(T)) and Hamburg Wheel Tracking Test (HWTT) as their primary cracking and rutting tests for measuring mix performance, respectively. The Tollway placed nine test sections on I-88 that included three rubber modifier products, two of which were produced via terminal blending and one produced via dry process using a chemically engineered crumb rubber product in 2016 (W. G. Buttlar & Rath, 2017). The fracture energy for all the mixes in this project exceeded the 690 J/m2 threshold required for high traffic applications and the rut depth for all mixtures was below 6.0 mm, indicating excellent crack and rutting resistance (Rath, Love, et al., 2019). Field surveys conducted in the summer of 2019 also revealed excellent performance in all of the 2016 sections. It should be noted that these sections went through a 50-year cooling event due to the polar vortex experienced in late January, 2019, where air temperatures in the vicinity of Chicago dropped below -32F (-34C) (Rath et al., 2021). Buttlar et al. (2021) also published information about other GTR sections placed on the Illinois Tollway that incorporated both wet- and dry-process GTR, dating all the way back to 2009. All mixtures were shown to perform well under the heavy traffic and cold weather of northern Illinois (W. Buttlar et al., 2021).

4.2. MISSOURI

Missouri has been one of the most rapidly advancing states in its adoption of using recycled materials including GTR. The state has funded several dry process RMA demonstration projects in the past decade, all of which have shown excellent structural and functional performance. In 2017, a dry process engineered crumb rubber (ECR) modified mixture was placed on I-35 located in Kansas City, MO. The mix was placed on a ramp and was expected to provide adequate rutting resistance to the slow-moving truck traffic. The pavement has been performing well for over five years. In 2019, another ECR mix was placed on I-44 located in St. Clair, MO (south of St. Louis, MO). In both these demonstration projects, mix performance (index) tests results were reported to the agency. MoDOT specifies Hamburg Wheel Tracking Test (HWTT) for rutting and has transitioned from using Illinois Flexibility Index Test (I-FIT) to using Indirect Tensile Cracking Test (IDEAL-CT) for cracking performance. Four years of field evaluation has revealed adequate performance by the RMA.

More recently, in 2021-22, MoDOT paved more ECR-modified mixtures on Route 740 (dense-graded) in Columbia, MO, and on I-70 (stone matrix asphalt) near Boonville, MO. In both the projects, Missouri DOT implemented preliminary BMD thresholds of CT-Index and Hamburg rut depths. For instance, for the mixtures paved on Rt. 740 (also known as Stadium Blvd.), the minimum CT-Index requirement was 32 and the Hamburg rut depth requirement was maximum of 12.5 mm at 20,000 passes. The Stadium Blvd. mixes have been monitored yearly and its two-year field evaluation has shown excellent performance. The I-70 section has been performing well both structurally and functionally. Skid resistance was measured using a skid trailer on I-70 ECR section and compared to the adjacent non-ECR sections. Data showed that newly constructed ECR pavements provided higher skid resistance (up to 15% higher) compared to the polymer (polyphosphoric acid)-modified sections. These successful demonstrations for dry process rubber modified technologies have led Missouri DOT to draft a specification which allows the contractors to include rubber modification in their bids. The implementation of the spec is expected to significantly progress the adoption of rubber modification in the state of Missouri. These successful demonstrations for dry process rubber modified technologies have led Missouri DOT to draft a specification which allows the contractors to include rubber modification in their bids (see Appendix).

4.3. VIRGINIA

Recently, rubber-modified asphalt has been used in several projects in Virginia. In 2019, Virginia DOT placed an asphalt rubber gap-graded mixtures (AR-GGM) using wet process on southbound Interstate-85 in the Richmond District (Nair and Hossain, 2022a). The study aimed to establish a baseline performance criterion for the rubber modified mixtures as well as compare AR-GGM with the standard gap-graded stone matrix asphalt (SMA) mixture which used polymer modified binder. Virginia DOT had developed a special provision for the project. Findings suggested that no special accommodations were required for the AR-GGM compared to the SMA, and the special provision was effective. Field performance data from three years of monitoring indicated equivalent performance of AR-GGM and SMA with minor distresses reported. The study also recommended the use of AR-GGM mixtures for reflective cracking mitigation.

In fall of 2019, VDOT used dry process GTR in another project which was on US 60 in the Richmond District for the first time (Nair and Hossain, 2022b). A special provision was implemented for use of dry process GTR in dense grade mixtures, which was found to be adequate by the researchers. The production was reported to be without any issues and the density requirements were easily met with the GTR mix.

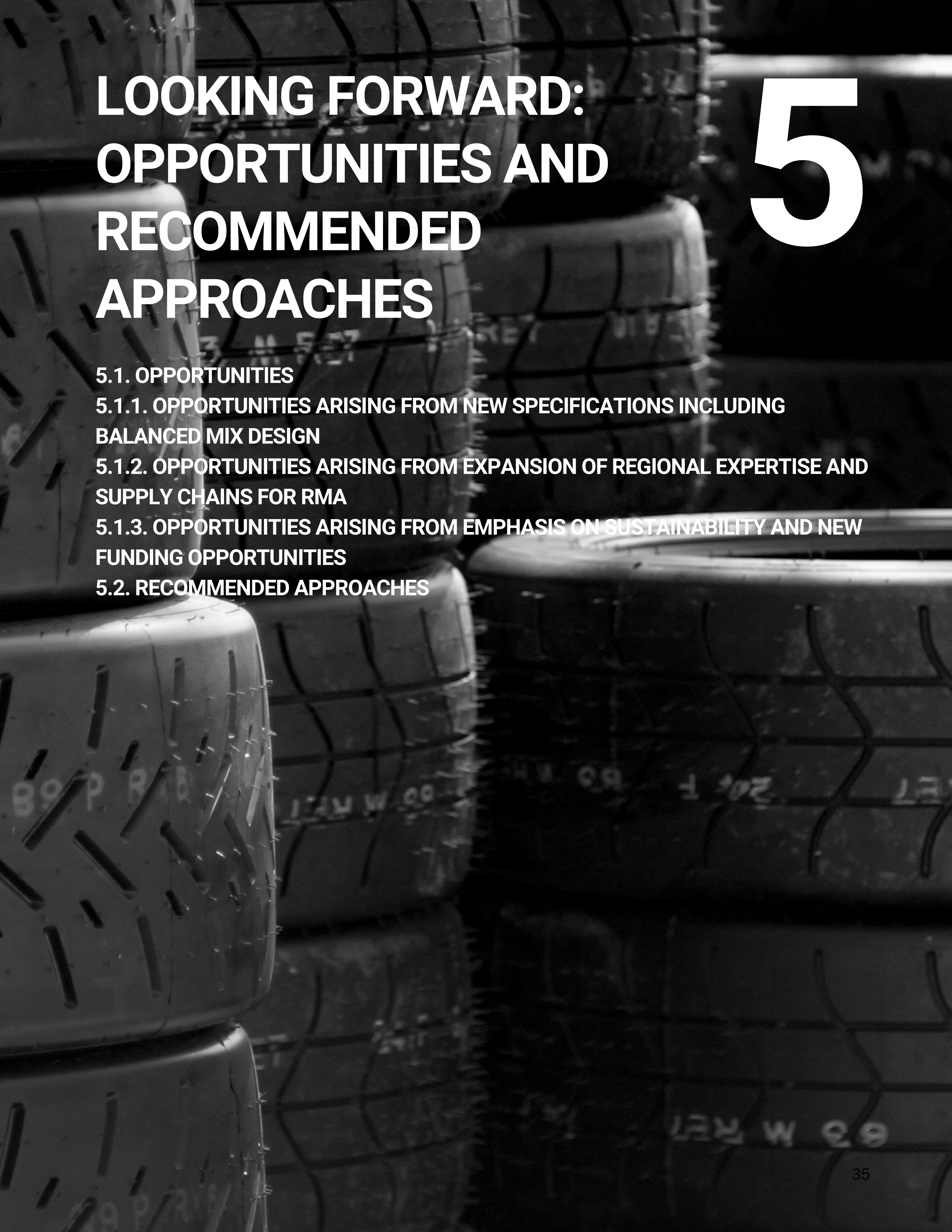
Laboratory comparison of the GTR mix with standard polymer-modified mixture revealed significantly better cracking characterization for the GTR modified mixture and marginally lower rutting resistance.

4.4. MICHIGAN

Between 2012 and 2019, about 40 test sections were constructed with RMA in various counties and cities of Michigan. The test sections included terminal blend GTR binders (e.g., section in Keweenaw County) and dry process GTR mixtures (e.g., sections in Kalamazoo, Dickinson, and Kent counties). Field and laboratory evaluation indicated that there was no significant difference between the performance of RMA and polymer-modified control sections. Apart from performance, researchers from Michigan have also quantified the noise reduction properties of RMA (Chen et al., 2020) . Results from a satisfactory survey conducted to gauge the acceptance/adoption barriers of RMA in Michigan, a majority of stakeholders (95%) reported a willingness to use RMA technology (Haider et al., 2023).

4.5. GEORGIA

GDOT has been paving heavy and medium-use roads with dry process rubber since 2006. It has been one of the states that had reported 100% use of dry process rubber in the previously published RMA State of Knowledge report by Buttlar and Rath (Buttlar and Rath, 2021). One of the early dry process projects built by GDOT was an overlay project near Perry, GA on I-75 (Shen et al., 2012). Interstate 75 is a major artery connecting Atlanta and central Georgia with Florida. A 1.25-in.-thick Porous European mix (PEM) overlay on milled asphalt pavement was used to rehabilitate the road surface. This was an experimental section with a polymer modified PEM pavement serving as a control surface. The rubberized pavement used a 64 -22 binder and 10% rubber with 30% RAP. The control pavement used a 76 -22 polymer-modified binder and 30% RAP. Both pavements were subjected to independent evaluations during the first few years of performance and those evaluations indicated that both pavements were performing comparably. This experiment was expected to last approximately five years when built in 2006, but both the rubberized and polymer pavements performed so well that they remained in place for an additional 10 years. Both pavements were replaced in 2020, and both pavements showed similar wear during their lifetimes. In 2010, GA Route 247 in Bibb County, was constructed with asphalt mixtures modified with terminal blend rubber, dry process rubber, and polymer modified asphalt for cross-comparison. Similar to I-75, these pavements continue to perform comparably. GDOT has approximately 1,500,000 mix tons in service that use dry process crumb rubber as a mix modifier.



LOOKING FORWARD: OPPORTUNITIES AND RECOMMENDED APPROACHES

5

5.1. OPPORTUNITIES
5.1.1. OPPORTUNITIES ARISING FROM NEW SPECIFICATIONS INCLUDING BALANCED MIX DESIGN
5.1.2. OPPORTUNITIES ARISING FROM EXPANSION OF REGIONAL EXPERTISE AND SUPPLY CHAINS FOR RMA
5.1.3. OPPORTUNITIES ARISING FROM EMPHASIS ON SUSTAINABILITY AND NEW FUNDING OPPORTUNITIES
5.2. RECOMMENDED APPROACHES

5. LOOKING FORWARD: OPPORTUNITIES AND RECOMMENDED APPROACHES

The goal of this final chapter is to recommend prioritized, actionable items that should be pursued by various stakeholders in order for more US states to realize the benefits afforded by allowing and specifying widespread RMA use. First, a summary of opportunities are presented, with a focus on maximizing the return on investment (or the strategic pursuit of the 'low hanging fruit') recommended for specific regions or specific states, based on the review of historical data and the state of SHA specifications collected and analyzed in this study. Next, a list of specific recommended actions and investments are provided in an effort to share best practices with the goal of minimizing redundant efforts and maximizing the rate at which RMA specifications can be developed and/or adopted wherever gaps exist.

5.1. OPPORTUNITIES

As outlined in the recent SOK report (Buttlar and Rath, 2021), multiple benefits are made possible through strategic RMA use in the general categories of asphalt pavement economics, durability, sustainability, and resilience. As pointed out in the SOK, the states that experimented with RMA in the early years (1980's, 1990's), but not subsequently, generally have a poorer opinion of the durability and economics of RMA, while states with experience with more modern wet- and dry-process RMA systems (past 20 years), generally have a positive viewpoint of RMA durability and cost vs. benefit. This highlights the importance of sharing new data on RMA durability, economics, and sustainability, as detailed in the SOK. A brief recap of the benefits summarized in the SOK executive summary is provided in Figure 5.1.

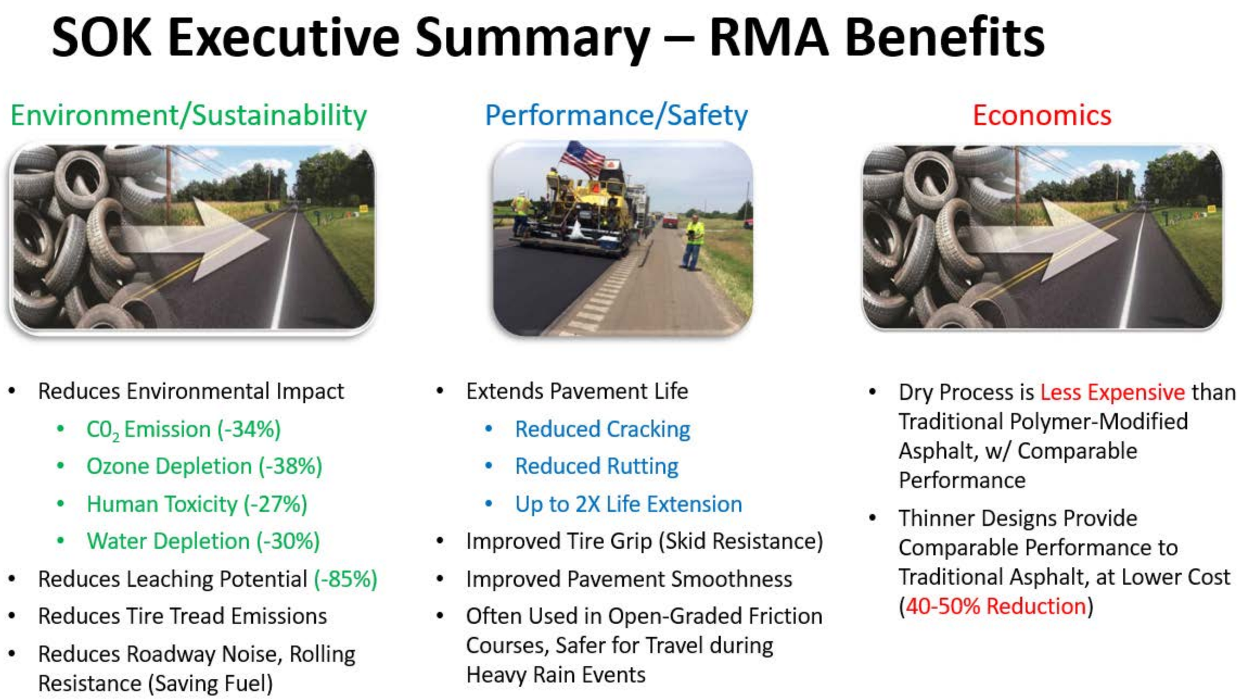


Figure 5.1. Summary of RMA Benefits (Buttlar and Rath, 2021)

5.1.1. Opportunities Arising from New Specifications Including Balanced Mix Design

The rapid expansion of Balanced Mix Design (BMD) across the US is opening the door for the expansion of innovative, sustainable approaches to asphalt mixture design, such as RMA. The use of cracking and rutting tests to supplement mixture volumetric design procedures gives new confidence to owner-agencies that innovative mix designs made possible through new specification approaches can be implemented with confidence in a shorter timeline than previously possible. Case studies from the Illinois Tollway and MoDOT, as presented in Chapter 4, demonstrate straight-forward pathways to the expansion of RMA usage by agencies in both cold and freeze-thaw climatic regions within the Midwest. By relaxing certain volumetric requirements and by providing specifications for both wet and dry process RMA, RMA usage has increased in these regions without subsidies in standard, low bid environments.

5.1.2. Opportunities Arising from Expansion of Regional Expertise and Supply Chains for RMA

With the expanded use of RMA across the US in recent years resulting from the availability of both wet and dry process RMA in many regions across the US, new opportunities exist for states that have yet to adopt RMA specifications. For instance, best practices being shared at regional asphalt user-producer group meetings is providing useful lab and field data to state agencies from neighboring states who have recently begun specifying RMA. Supply chains for newer dry process RMA products and associated feeder systems have strengthened in recent years, which will also serve to ease the burden of adoption of RMA for states opting to explore pilot projects and provisional specifications the coming years.

5.1.3. Opportunities Arising from Emphasis on Sustainability and New Funding Opportunities

Programs such as the Federal Buy Clean Initiative, and funding programs included in the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA), along with funding provided by the EPA and local departments of natural resources and economic development are creating new opportunities to jump start pilot projects across the US that can lead to expanded RMA usage. In Missouri, for instance, funding from the Environmental Improvement and Energy Resources Authority (EIERA) has been used to place several feeder units in the hands of contractors who were willing to innovate with mix designs containing dry process, Engineered Crumb Rubber (ECR) but needed a feeder unit to jump start their expanded use of RMA.

5.2. RECOMMENDED APPROACHES

Based on the results of this study, recommended approaches for the expansion of RMA usage across the US are now provided. These can be summarized as follows:

1. Investment in regional demonstration projects, scrap tire recycling infrastructure, and hot-mix asphalt plant recycling infrastructure to facilitate RMA usage, particularly in areas with little-to-no current RMA usage should be given priority. The strategic investment of existing tire recycling fees or the establishment of other funding streams to support the expansion of rubber recycling into pavements should be considered in light of the opportunity to build on the current positive momentum in RMA usage and innovation in the US and abroad. Significant opportunities exist both for states co-located in regions of expertise with dry and wet process RMA (SW, SE, Midwest, NE USA), and for regions such as the upper Midwest and Western states where little-to-no RMA is currently used.

2. Gaps in knowledge with respect to RMA performance testing, modern performance specifications, and integrated pavement/materials design should be addressed with an eye towards national standardization, bolstered by a national clearinghouse of test results, field performance data, improved performance prediction models, and templates for new RMA construction and materials specifications. Advances in data science and, in particular, machine learning should be developed and fully exploited in an effort to reduce the time-to-adoption of new research results, reduce testing, design, and pavement evaluation costs, and to bolster the efficacy of RMA performance prediction. This tool can be used to create a 'virtual scanning tour' and 'data clearinghouse,' where SHAs can view pictures, videos, performance data, performance curves, and other technical data for RMA projects around the US, all on a convenient visualization platform including heat maps, convenient data filtering tools, and links to more information (specifications, reports, papers).

3. A national steering group (expert task force) should be established, which can help develop and coordinate national research priorities and studies for RMA, provide oversight to a national center of excellence for RMA research, and help prioritize and coordinate regional demonstration projects, strategic investments in recycling infrastructure, and provide overall industry leadership and advocacy towards increased pavement sustainability, resiliency, and circular economy solutions involving RMA.

6

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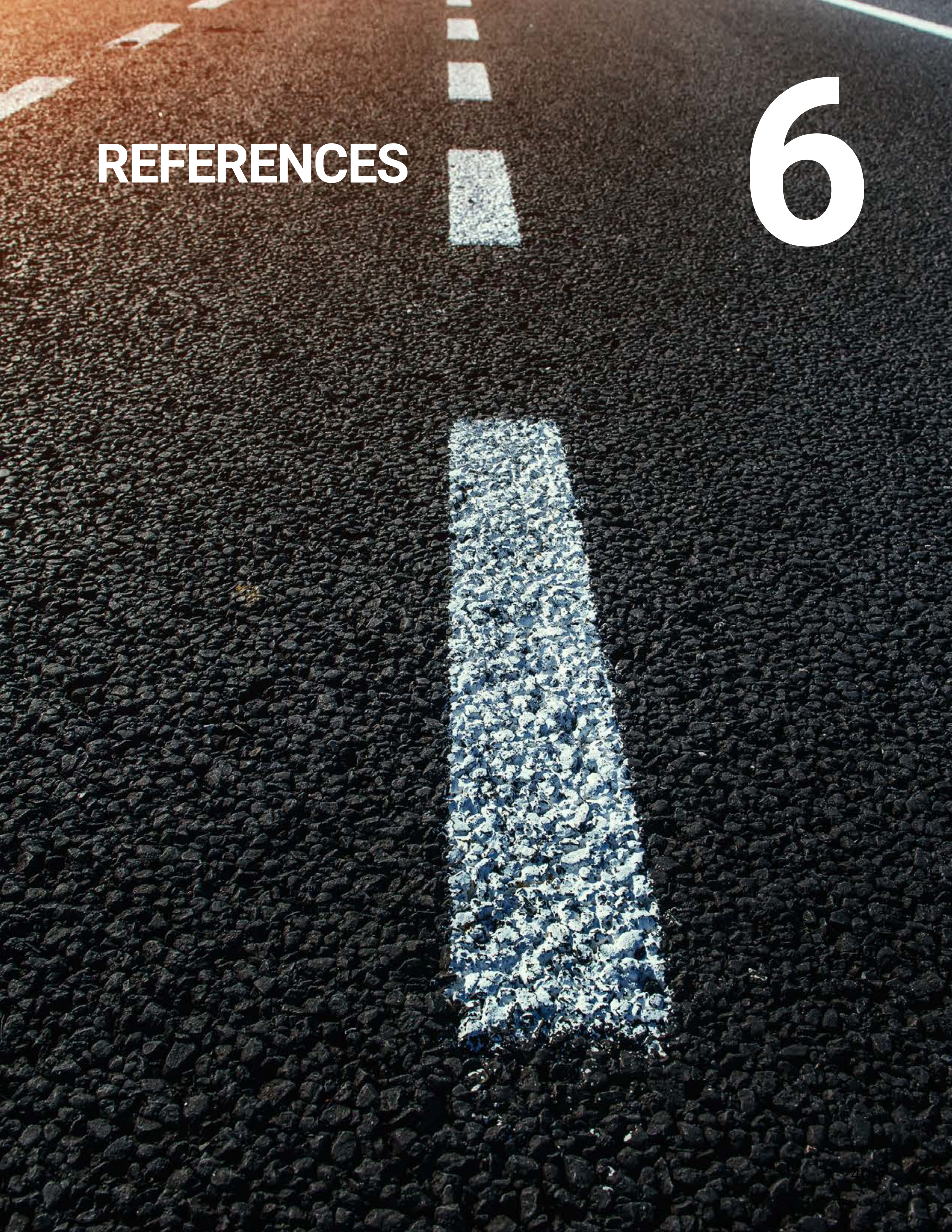

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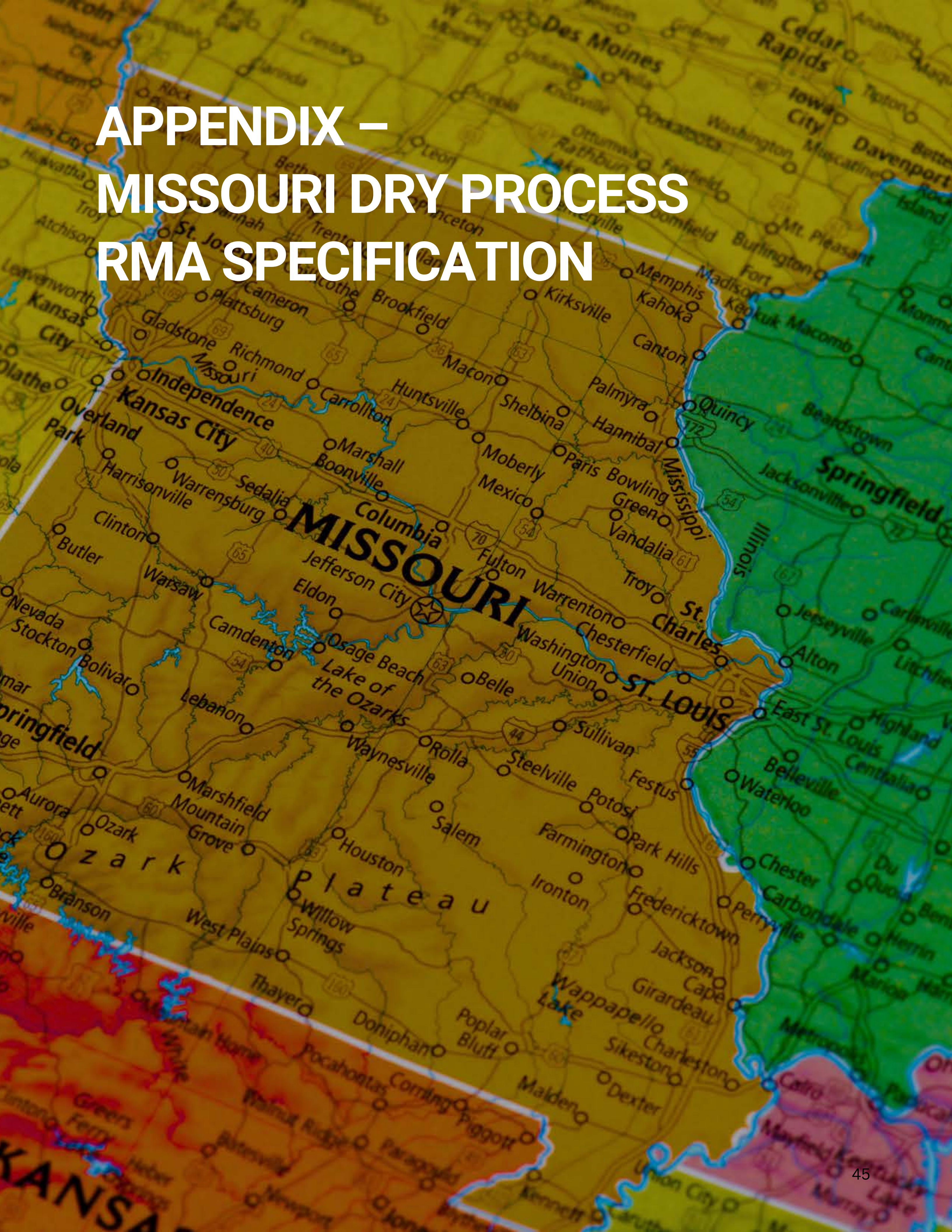
APPENDIX – MISSOURI DRY PROCESS RMA SPECIFICATION



MISSOURI DRY PROCESS RMA SPECIFICATION

Ground Tire Rubber (GTR) Dry Process Modification of Bituminous Pavement Material

1.0 Description. This work shall consist of the dry process of adding ground tire rubber (GTR) to modify bituminous material to be used in highway construction. Existing GTR requirements in Section 1015 pertain to the wet process method of GTR modification that blends GTR with the asphalt binder (terminal blending or blending at HMA plant). The following requirements shall govern for dry process GTR modification. The dry process method adds GTR as a fine aggregate or mineral filler during mix production. All GTR modified asphalt mixtures shall be in accordance with Secs 401, 402, or 403 as specified in the contract; except as revised by this specification.

2.0 Materials. The contractor shall furnish a manufacturer's certification to the engineer for each shipment of GTR furnished stating the name of the manufacturer, the chemical composition, workability additives, and certifying that the GTR supplied is in accordance with this specification.

2.1 Product Approval. The GTR product shall contain a Trans-Polyoctenamer (TOR) added at 4.5 % of the weight of the crumb rubber or an engineered crumb rubber (ECR) workability additive that has proven performance in Missouri. Other GTR additives shall be demonstrated and proven prior to use such as a five-year field performance history in other states or performance on a federal or state-sanctioned accelerated loading facility.

2.2 General. GTR shall be produced from processing automobile or truck tires by ambient or cryogenic grinding methods. Heavy equipment tires, uncured or de-vulcanized rubber will not be permitted. GTR shall also meet the following material requirements:

Table 1 – GTR Material Properties

Property	Test Method	Criteria
Specific Gravity	ASTM D1817	1.02 to 1.20
Metal Contaminates	ASTM D5603	≤ 0.01%
Fiber Content	ASTM D5603	≤ 0.5%
Moisture Content	ASTM D1509	≤ 1.0%*
Mineral Filler	AASHTO M17	≤ 4.0%

*Moisture content of the GTR shall not cause foaming when combined with asphalt binder and aggregate during mix production

2.3 Gradation. The GTR material prior to TOR or ECR workability additives shall meet the following gradation and shall be tested in accordance with ASTM D5603 and ASTM D5644.

Table 2 – GTR Gradation

Sieve	Percent Passing by Weight
No. 20	100
No. 30	98-100
No. 40	50-70
No. 100	5-15

3.0 Delivery, Storage, and Handling. The GTR shall be supplied in moisture-proof packaging or other appropriate bulk containers. GTR shall be stored in a dry location protected from rain before use. Each bag or container shall be properly labeled with the manufacturer's designation for the GTR and specific type, mesh size, weight and manufacturer's batch or Lot designation.

4.0 Feeder System. Dry Process GTR shall be controlled with a feeder system using a proportioning device that is accurate to within ± 3 percent of the amount required. The system shall automatically adjust the feed rate to always maintain the material within this tolerance and shall have a convenient and accurate means of calibration. The system shall provide in-process monitoring, consisting of either a digital display of output or a printout of feed rate, in pounds per minute, to verify feed rate. The supply system shall report the feed in 1-pound increments using load cells that will enable the user to monitor the depletion of the GTR. Monitoring the system volumetrically will not be allowed. The feeder shall interlock with the aggregate weight system and asphalt binder pump to maintain correct mixture proportions at all production rates.

Flow indicators or sensing devices for the system shall be interlocked with the plant controls to interrupt mixture production if GTR introduction rate is not within ± 3 percent. This interlock will immediately notify the operator if GTR introduction rate exceeds introduction tolerances. All plant production will cease if the introduction rate is not brought back within tolerance after 30 seconds. When the interlock system interrupts production and the plant has to be restarted, upon restarting operations; the modifier system shall run until a uniform feed can be observed on the output display. All mix produced prior to obtaining a uniform feed shall be rejected.

4.1 Batch Plants. GTR shall be added to aggregate in the weigh hopper. Mixing times shall be increased per GTR manufacturer recommendations

4.2 Drum Plants. The feeder system shall add GTR to aggregate and liquid binder during mixing and provide sufficient mixing time to produce a uniform mixture. The feeder system shall ensure GTR does not become entrained in the exhaust system of the drier or plant and is not exposed to the drier flame at any point after introduction.

5.0 Testing During Mixture Production. Testing of asphalt mixes containing GTR shall not begin until at least 30 minutes after production or per additive supplier's recommendation.

6.0 Construction Requirements. Mixes containing GTR shall have a target mixing temperature of 325 F or as directed by the GTR additive supplier. The additive supplier's recommendations shall be followed to allow for GTR binder absorption/reaction. This may include holding mix in the silo to allow time for binder to absorb into the GTR. Rolling operations may need to be modified.

7.0 Mix Design Test Method Modification. A formal mixing procedure from the additive supplier shall be provided to the contractor and engineer that details the proper sample preparation, including blending GTR with the binder or other additives. Samples shall be prepared and fabricated in accordance with this procedure by the engineer and contractor throughout the duration of the project.

8.0 Mix design Volumetrics. Mix design volumetric equations shall be modified as follows:

8.1 Additional virgin binder added to offset GTR absorption of binder shall be counted as part of the mix virgin binder

8.2 GTR shall be included as part of the aggregate when calculating VMA of the mix.

8.2.1 GTR SPG shall be 1.15

8.3 VMA shall be calculated as follows:

$$VMA = 100 - G_{mb}\left(\frac{P_s}{G_{sb}} + \frac{P_{GTR}}{G_{GTR}}\right)$$

$$where:$$

$P_s = percent\ aggregate\ by\ total\ mixture\ weight$
$P_{GTR} = percent\ GTR\ by\ total\ mixture\ weight$
$G_{sb} = bulk\ specific\ gravity\ of\ the\ combined\ aggregate$
$G_{GTR} = GTR\ specific\ gravity$

8.4 G_{se} shall be calculated as follows:

$$G_{se} = \frac{(100 - P_b - P_{GTR})}{\left(\frac{100}{G_{mm}} - \frac{P_b}{G_b} - \frac{P_{GTR}}{G_{GTR}}\right)}$$

8.5 P_{be} shall be calculated as follows:

$$P_{be} = P_b - \frac{P_{ba}}{100} * (P_s + P_{GTR})$$

9.0 Minimum GTR Amount. The minimum dosage rate for GTR shall be 5 % by weight of total binder for an acceptable one bump grade or 10 % by weight of total binder for an acceptable two bump grade as detailed in the following table. Varying percentage blends of GTR and approved additives may be used as approved by the engineer with proven performance and meeting the specified requirements of the contract grade.

Contract Binder Grade	Percent Effective Virgin Binder Replacement Limits	Required Virgin Binder Grade	Minimum GTR Dosage Rate
PG 76-22	0 - 20	PG 70-22	5 %
		PG 64-22	10 %
PG 70-22	0 - 30	PG 64-22	5 %
		PG 58-28	10 %
PG 64-22	0 – 40*	PG 58-28	5 %
		PG 52-34	10 %
PG 58-28	0 – 40*	PG 52-34	5 %
		PG 46-34	10 %

* Reclaimed Asphalt Shingles (RAS) may be used when the contract grade is PG 64-22 or PG 58-28. RAS replacement shall follow the 2 x RAS criteria when calculating percent effective binder replacement in accordance Sec 401.

SUMMARY OF STATE SPECIFICATIONS FOR RUBBER MODIFIED ASPHALT

ON BELHALF OF U.S. TIRE MANUFACTURERS ASSOCIATION