APPENDIX A

Topical Bibliography

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INTRODUCTION TO TOPICAL BIBLIOGRAPHY ON WARM MIX ASPHALT

Warm Mix Asphalt (WMA) technology and deployment were largely driven by the asphalt industry. Implementation progressed while a number of technological questions were identified for research. Research was performed at both the state and national levels as well as by private industry, and the FHWA WMA TWG was responsible for developing key research needs statements. WMA later became a focus area for the FHWA in its Every Day Counts (EDC) initiative, which encouraged state agencies to allow WMA in their specifications and track its usage.

A number of WMA technologies were developed and marketed during the mid to late 2000s. These technologies included the use of foam (water), waxes, and other specialty chemicals. A large number of demonstration sections were placed in the late 2000s by many states and contractor groups and performed favorably. This resulted in the continued and more rapid acceptance of WMA as the benefits gained more prominence. These benefits included lower production temperatures, reduced emissions and energy consumption, extended construction day and season, and additional opportunities for more uniform and higher density construction. In the 2014 construction season, over 32 percent of the asphalt mixture tonnage placed in the United States was produced with WMA technology.

A portion of National Cooperative Highway Research Program (NCHRP) Project 20-44(01) focused on a review of available literature and the compilation of a topical bibliography that concentrated on the field studies and implementation of WMA. The literature review included available research reports that have been conducted at the national and state levels, journal publications focusing on case studies, specification documents, and available information from various websites regarding WMA. It should be noted that this document is a Topical Bibliography and is not intended to be a critical and comprehensive literature review.

The Transportation Research Information Database (TRID) was the primary search engine used to identify NCHRP reports, state DOT reports, and other transportation research publications. In addition, literature documents were compiled as a result of interviews (e.g., research branch of the United States Army Corps of Engineers), review of state DOT and asphalt industry websites (including the National Center for Asphalt Technology among others), searches of gray literature (e.g., web articles on the use of WMA by cities or other local agencies), and information included on the FHWA website.

The emphasis of this task and the literature review is to summarize documented gaps in the state of the knowledge regarding WMA and identifying successful implementation and practices regarding WMA. This topical bibliography was used as background information in order to guide the discussion items for the two-day workshop held in Irvine, California, in May 2017.

The bibliography is divided into sections: NCHRP reports, Case Studies and State DOT reports, U.S. Army Corps of Engineers reports, documents detailing the LTPP SPS WMA experiments, and miscellaneous documents. Each section presents individual summaries of the various items in chronological order. A general overview of the information gleaned from each section is presented at the beginning of the section.

1. NCHRP REPORTS

Eleven NCHRP studies have been conducted to study various aspects and questions related to WMA technologies. These studies should assist the states in the deployment of the technologies. The products developed in those studies included guidelines for the laboratory testing of WMA, for the mixture design of asphalt that utilizes warm mix additives or foaming process, for guidance in terms of production and placement temperatures, a framework for approving new WMA technologies or processes, and the observed and predicted outcomes of both short- and long-term performance studies of pavements using WMA. In many of these projects, the comparative properties of hot mix asphalt (HMA) were also captured. The primary focus of the topical bibliography was to capture the products, outcomes, and suggested implementation efforts from the completed NCHRP WMA research projects. These projects are listed in Table A1 and the research topics included WMA mix design, WMA technology, laboratory performance, and field performance.

Table A1: Warm Mix Asphalt Projects Sponsored by NCHRP

NCHRP Project	Project Title	Funding	Research Team (PIs)	Research Panel Members	Status
9-43	Mix Design Practices for WMA	$522,501	R. Bonaquist; D. Christensen (AAT)	D. Maurer (Practical Asphalt Solutions Technology); D. Powers (Ohio DOT); C. Barros (California DOT); T. R. Clyne (Minnesota DOT); G. Huber (Heritage Research Group); L. Michael (Consultant); J. A. Prozzi (University of Texas – Austin); T. W. Whittington (North Carolina DOT); M. Corrigan (FHWA); D. Newcomb (NAPA)	Complete
9-47	Engineering Properties, Emissions and Field Performance of WMA Technologies	$79,000	Michael Anderson (AI)		Complete
9-47A	Properties and Performance of WMA Technologies	$1,121,000	**R. West;** C. Rodezno; G. Julian (NCAT); B. Prowell (Advanced Materials Services); B. Frank (Compliance Monitoring Service); L. Osborn; T. Kriech (Heritage Research Group)	B. Choubane (Florida DOT); K. A. Willoughby (Wash. DOT); C. Barros (Caltrans); G. Claros (Rodriguez Engineering); C. Franco (RI DOT); K. Jenkins (University of Stellenbosch); J. Kliewer (Arizona DOT); H. Marks (NAPA); J. Prozzi (University of Texas–Austin); R. Sines (Oldcastle Materials); M. Corrigan (FHWA); N. Gibson (FHWA)	Complete
9-49	Performance of WMA Technologies: Stage I-Moisture Susceptibility	$450,000	**A. E. Martin**; E. Arambula; F. Yin; L. Garcia Cucalon; A. Chowdhury; R. Lytton; J. Epps; C. Estakhri; E. S. Park (Texas A&M Transportation Institute)	K. Willoughby (Wash DOT); R. Brown; R. Chandran (ConnDOT); M. Corrigan (FHWA); D. Decker (Consultant); S. Diefenderfer, (Virginia CTIR); S. Haider (Michigan State University); J. Horn (Alaska DOT and Public Facilities); R. Leahy (California Asphalt Pavement Association); S. Schram (Iowa DOT); D. Weitzel (AMEC Environment & Infrastructure, Inc.); J. Springer (FHWA)	Complete
9-49A	Performance of WMA Technologies: Stage II-Long Term Field Performance	$900,000	**B. Muhunthan** (Washington State University; Louisiana Transportation Research Center; Pennsylvania State University Altoona)		Complete
9-52	Short Term Laboratory Conditioning of Asphalt Mixtures	$800,000	Texas A&M Research Foundation: **D. Newcomb;** A. E. Martin; F. Yin**;** E. Arambula**;** E. S. Park**;** A. Chowdhury National Center for Asphalt Technology**:** R. Brown; C. Rodezno; N. Tran University of California Pavement Research Center: E. Coleri; D. Jones; J. T. Harvey; J. M. Signore	F. Fee (Frank Fee, LLC); C. Barros (Caltrans); P. Capon (Rieth-Riley Construction, Inc.); T. R. Clyne (Minnesota DOT); J. DeVol (Wash DOT); J. Grieco (MassDOT); S. Schram (Iowa DOT); A. Smith (PQ Corporation); V. Tandon (University of Texas at El Paso); J. Williams III (Mississippi DOT); J. Youtcheff (FHWA); M. Corrigan (FHWA); K. Hansen (NAPA)	Complete

9-53	Properties of Foamed Asphalt for Warm Mix Asphalt Applications	$700,000	**D. Newcomb**; J. Z. Yin; E. Arambula; A. Bhasin; W. Li; Z. Arega	D. Powers (Ohio DOT); G. Geary (consultant); E. Crews (MWV Asphalt Innovations); D. Decker (consultant); B. Engstrom, (Mass. DOT); A. LaPlante, (Pace Construction); T. Liske (Manitoba Transportn); J. Peterson (Caltrans); R. Sines (Oldcastle Materials); T. Whittington, (North Carolina DOT); A. Copeland (NAPA); M. Corrigan (FHWA)	Complete
9-54	Long Term Aging of Asphalt Mixtures for Performance Testing and Prediction	$800,000	North Carolina State University **Y. R. Kim**	D. Maurer (Zydex Inc.); B. Choubane (Florida DOT); S. Dai (Minnesota DOT); D. Decker (consultant); C. Pan (Nevada DOT); M. Pradhan (Arizona DOT); M. Rodezno (Auburn University); M. Solaimanian (Penn State); J. Youtcheff (FHWA)	Complete
9-55	Recycled Asphalt Shingles in Asphalt Mixtures with WMA Technologies	$600,000	National Center for Asphalt Technology--Auburn University **R. West**	S. Diefenderfer (Virginia DOT); M. Buchanan (Oldcastle Materials); P. Capon (Rieth-Riley Construction); G. Claros (Rodriguez Engineering Laboratories); G. Hainsworth (Delaware DOT); B. Huang (University of Tennessee); J. Schrorer; K. Willoughby (WashDOT); J. Winford (Prairie Contractors); A. Copeland (NAPA); M. Corrigan (FHWA)	Complete
9-58	Effects of Recycling Agents on Asphalt Mixtures w/High RAS & RAP Binder Ratios	$1,500,000	A. E. Martin; F. Zhou; E. Arambula; E. S. Park; A. Chowdhury; F. Kaseer; J. Carvajal; E. Hajj; J. Daniel; C. Glover	J. Musselman (Oldcastle Matls); J. Bartoszek (Payne & Dolan); J. D'Angelo (consultant); J. DeVol (Wash. DOT); L. Johanneck (Minn. DOT); T. Gandhi (MeadWestvaco Corp); V. Woods-Bade (INVIA); P. Romero (Univ of Utah); P. Naidoo (Asphalt & Wax Innovations)	9/2018
9-60	Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications	$1,000,000	Western Research Institute, **J.-P. Planche**	H. Paul (consultant); D. Anderson (consultant); J. D'Angelo (consultant); R. Gribbin (Jas W. Glover); S. Haider (MSU); B. Lane (Ontario MOT); M. Mueller (Interra Services); G. Rowe (Abatech); H. Sadraie (Caltrans); R. Bradbury (Maine DOT); M. Corrigan (FHWA)	6/2019
20-07 Task 311	Development of a WMA Tech. Evaluation Program	$50,000	L. McCarthy		Complete

Synth 492	Performance Specifications for Asphalt Mixtures	$40,000	L. McCarthy, S. Scott	H. Paul (Louisiana DOTD); S. Kim (Virginia DOT); M. Juhasz (Alberta Transportn); H. Ajideh (City of San Juan Capistrano, CA); T. Clark (Virginia APA); G. Huber (Heritage Research Group); M. Pologruto (Vermont AOT); E. Dave (UNH); J. Dietz (FHWA)	Complete

This section summarizes the work that has been conducted under the NCHRP program with regards to WMA. Summaries of individual projects are presented below; however, projects that are currently underway only cover the overall project objectives because these reports are not yet available.

In general, the results of the NCHRP projects conducted to date indicated the following observations:

- Immediately after construction, WMAs have lower stiffness and are more susceptible to rutting than HMA, but become more similar or equal to HMA with field aging;
- Field densities were similar with slightly better compactability observed with the WMA materials;
- WMAs were observed to exhibit lower asphalt absorption levels during production, but that the volumetric properties of WMA and HMA are similar if a low absorption aggregate is used;
- Use of recycled materials increases the stiffness of WMA generally, but the effect depends on the specific material and WMA combinations;
- The measure properties of foamed asphalts were different when comparing between the material in the laboratory and material sampled during plant production;
- Lower stack emissions were measured when WMA was produced at lower temperatures; and,
- Lower levels of fumes were measured behind the paver when WMA was produced with a temperature reduction, as compared with emissions measured during the construction of HMA.

Gaps that have been identified through the NCHRP projects include identification of appropriate short and long term aging protocols for WMA to simulate field conditions, and evaluation of long term field performance of WMA. They also include the identification of performance tests, particularly for fatigue and low temperature cracking, which can be used in the laboratory at the mixture design stage.

Challenges to implementation of WMA that have been identified include: unknown long-term field performance, initial product approval, and the structure of specifications in terms of the allowance of various WMA technologies.

1.1 Anderson, M. R., Baumgardner, G., May, R., and Reinke, G. "Engineering Properties, Emissions, and Field Performance of Warm Mix Asphalt Technologies." NCHRP Interim Report. National Cooperative Highway Research Program, Transportation Research Board, 2008.

The NCHRP Project 9-47 evaluated the engineering properties, emissions, and field performance of WMA technologies. The objectives of this project were to:

- Establish relationships among engineering properties of WMA binders and mixes and the field performance of pavements constructed with WMA technologies;
- Determine relative measures of performance between WMA and conventional HMA pavements;
- Compare production and laydown practices and costs between WMA and HMA pavements; and,
- Provide relative emissions measurement of WMA technologies as compared to conventional HMA technologies.

The project included both laboratory and field experiments evaluating four categories of WMA technologies: Organic Additives, Water-bearing Zeolites, Water-based Foaming Processes, and Emulsion-based Processes. In this study, the WMA and HMA mixtures were compared to evaluate similarities and differences with regard to materials and production costs, emissions, and lab and field performance.

The comparison of materials and production costs indicated that WMA mixtures offer savings from reduced fuel consumption, but the savings may not be enough to offset the cost of the initial investment. Additionally, the WMA offers increased production or late-season paving as incentives. Comparison of emissions indicates that WMA mixtures result in lower stack emissions, with reductions in CO, CO_2, SO_2, and NO_x. All these emissions are a function of temperature during production. Finally, lab and field performance comparisons indicate that in many cases WMA is comparable to HMA. Field densities for WMA are similar to HMA, with a slight increase in compactability for WMA. It is noted that the lack of plant aging in WMA may cause the WMA mixture to be more susceptible to rutting, but this can be somewhat counteracted with proper binder grade selection and the use of Recycled Asphalt Pavement (RAP). The lack of plant aging may also improve the cracking resistance of early-age WMA compared to HMA. With regard to moisture susceptibility, testing had mixed results. The major concern is the effect of residual internal aggregate moisture in WMA mixtures on stripping resistance.

The interim report noted these challenges to implementation:

1. Ensuring comparable long-term performance of WMA to HMA;
2. Addressing initial product approval;
3. Addressing issues with existing specifications that may prohibit the use of WMA;
4. Adapting WMA products from low-production batch and drum plants to higher production plants;
5. Ensuring that coarse aggregate is dry (WMA needs lower water absorption aggregate); and,
6. Individual contractors need to determine what products and technologies will work over the widest range of applications.

1.2 Bonaquist, R. "Mix Design Practices for Warm Mix Asphalt." Publication NCHRP Report 691. National Cooperative Highway Research Program, Transportation Research Board, 2011.

The NCHRP Project 9-43 was conducted with the goal of developing mixture design and analysis procedures that can be used with the wide variety of WMA processes. The project consisted of these phases: development of preliminary procedure, testing and analysis based on preliminary procedure, revising the preliminary procedure based on testing, testing and analysis based on revised procedure, and final revisions to the procedure based on the second testing phase. The conclusions obtained were:

1. When the HMA mixtures are 1.0% binder absorption or less, the volumetric properties of WMA were the same as an HMA design;
2. WMA should use the same grade of binder as HMA, but high temperature grade bumping maybe needed in low production temperature WMA to meet the flow number rutting resistance requirements in AASHTO R 35;
3. To ensure good mixing of RAP and new binders, it is recommended that the field compaction temperature for WMA be higher than the high-temperature grade of the "as recovered" RAP binder;
4. Use 2 hours of oven conditioning at the planned field compaction temperature for WMA to simulate the absorption and aging of the binder during construction;
5. The degree of coating obtained is highly dependent on the mixer that is used;
6. Due to combinations of RAP and lower production and compaction temperatures, WMA is more sensitive to temperature changes;
7. WMA performed similarly or better than HMA in terms of tensile strength when anti-strip additives were used, but performed worse than HMA when none were used;
8. To improve rutting resistance, two-hour conditioning at the compaction temperature was used to simulate the binder absorption and stiffening that occurs during construction; and,
9. Overall, WMA has similar properties to HMA and it is thought that volumetric properties will be essentially the same, but the WMA mixture will probably have a lower stiffness.

The recommendations from this report were to use the design procedures developed in NCHRP 9-43 when designing WMA mixtures. In addition to this, AASHTO R 35 should be used on a trial basis with regard to moisture and rutting susceptibility of WMA. Lastly, additional mixing studies should be done with different mixers to achieve a standard mix design. The report also identifies barriers to implementation, that include the special equipment needed for the WMA foaming process, and the second, 16-hour step in conditioning which would have to be done overnight.

1.3 NCHRP Research Results Digest 374. "A Proposed Technology Evaluation Program for Warm Mix Asphalt." National Cooperative Highway Research Program, Transportation Research Board, July 2012.

NCHRP provided a recommended testing plan to define a WMA technology evaluation program that would be compatible with a centralized system of testing, evaluation, and data reporting of engineering materials for the state DOTs, AASHTO National Transportation Product Evaluation

Program (NTPEP). The suite of mixture performance tests recommended for the qualification of WMA, as part of the NTPEP program, is shown in Table A2.

Table A2: Summary of Laboratory Tests for WMA Mixture Performance (McCarthy et al. 2012)

Test	Specification
Mixture design verification with 150-mm diameter	AASHTO T 320
Rutting	AASHTO TP 79, T 324, and T 340
Dynamic modulus	AASHTO TP 79 and PP 61
Compactability	AASHTO R35 draft appendix section 8.3
Durability	AASHTO T 283 and T 324

1.4 Guidelines for Project Selection and Materials Sampling, Conditioning, and Testing in WMA Research Studies. National Cooperative Highway Research Program (NCHRP) Research Results Digest 370, Publication ISBN 978-0-309-21386-8, National Academies Press, 2012.

The NCHRP published a research results digest summarizing the results of a "Workshop to Coordinate Key WMA Research Projects." The objective of this workshop was to create guidelines for project selection, specimen preparation methods, conditioning methods, performance test methods, and binder and aggregate test methods. This was done through consensus-building workshop activities. This workshop consisted of researchers; practitioners from the public sector, academia, and industry; and representatives of the sponsoring organizations. The tables below summarize the field project selection for short- and long-term performance studies; performance testing and specimen conditioning; and the binder and aggregate testing.

Table A3 summarizes field project selection for short- and long-term performance studies. Tables A4 and Table A5 present the performance testing and specimen conditioning methods.

Table A3: Field Projects Selection for Short- and Long-Term Performance Studies (NCHRP RRD 370, 2012)

Project length	**The minimum test section shall be ½ lane-mile in one travel lane located between intersections or interchanges. The plant temperature may be increased to produce the HMA control section. Shorter sections may be allowed if they are well planned and documented.** Notes: The ideal production per test section is 800–1000 tons or ½- to 1 day production or 1 tanker load of binder (400–600 tons of non-foamed WMA); these amounts will vary depending on the nominal maximum aggregate size (NMAS) of the mix. Although 1 day's production is often possible, test projects with control sections often are difficult to find. Selection of the minimum section length also must consider the type of WMA additive and where it is introduced.
Project and construction documentation	**NCAT and the University of Minnesota (for cold-climate projects) have developed detailed checklists for documenting field projects (see Appendix A).** Notes: Key considerations are (1) a condition survey of the existing pavement, (2) the pavement cross-section, (3) evaluation of pavement structural support, and (4) WMA production and compaction temperatures.
Control section definition	**The HMA control section must be identical to the WMA sections (including any RAP or RAS content) in all aspects but the presence of WMA, with the exception that the binder content of the control section may differ if necessary to attain identical air void contents in all sections.**
Minimum number of WMA technologies	**Minimum two technologies, plus a control.** However, this minimum number may be waived, depending on whether the project is a new pavement or an overlay on an existing pavement.
Other key features	(1) WMA and control sections must be surface mixes in the same travel lane and with the same pavement support throughout all sections. (2) The correct mix discharge temperatures for the WMA must be verified throughout the project. (3) New projects are favored, but existing projects may be used if the necessary requirements are met. It is sometimes feasible to work with the state DOT and contractor to add WMA sections to an HMA project through a change order. (4) Specific and systematic performance monitoring plans are required for new versus existing WMA projects. Both plan types should include the provision for forensic analysis when pavements exhibit significant distress. (5) In the event that a WMA project of interest was constructed without a control section, it may be possible to pair the WMA project with an otherwise unconnected HMA project constructed with similar materials, structure, condition, traffic, and climate (e.g., see Von Quintus, Mallela, and Buncher [*1*]). (6) Future field projects should consider (a) roadway functional classification (average daily traffic [ADT] and trucks per day [% trucks]); (b) a variety of mix types (e.g., stone mastic asphalt and open-graded friction courses); and performance in intersections. (7) RAP and RAS are permitted as long as identical control mixes are available. (8) For overlay projects, the WMA and control sections must have comparable levels of existing distress.

Table A4: Summary of Performance Testing (NCHRP RRD 370, 2012)

Performance Testing					
Sample Type	Modulus	Rutting	Fatigue Cracking	Low-Temperature Cracking	Durability

		Conditioning		
Sample Type	Test For	2 hrs @ WMA compaction temperature	16 hrs @ 140°F + 2 hrs @ WMA compaction temperature	2 hrs @ WMA compaction temperature 16 hrs @ 140°F + 2 hrs @ WMA compaction temperature + 5 days @ 85°C
PMLC[1]	Volumetric analysis	X		
	Modulus		X	
	Rutting		X	
	Fatigue cracking			X
	Low-temperature cracking			X
	Durability		X	

Sample Type	Test For	Conditioning
PMFC	Volumetric analysis	Dry and test
	Modulus	
	Rutting	
	Fatigue cracking	
	Low-temperature cracking	
	Durability	

Table A6 presents the various binder and aggregate testing approaches.

Table A6: Summaries of Binder and Aggregate Testing (NCHRP RRD 370, 2012)

BINDERS	
Continuous performance grade of extracted WMA binder	AASHTO R 29 without RTFO aging. Note: Done before and after PAV aging. Use a DSR capable of handling stiff binders.
Continuous performance grade of original WMA binder, to include modifiers added at the plant	AASHTO R 29. Note: Use a DSR capable of handling stiff binders.
Aging Index	
Multiple Stress Creep Recovery Test	AASHTO TP 70.
Linear Amplitude Sweep Test	Per Hintz, Velasquez, et al. (*3*).
Frequency sweep to develop master curve	
AGGREGATES	
Gradation	AASHTO T 27.
Bulk specific gravity and absorption	AASHTO T 84 and T 85.
Flat and elongated or AIMS method	ASTM D 4791 or use state or contractor data.
Sand equivalent	AASHTO T 176 or use state or contractor data.
Fine aggregate, uncompacted voids	AASHTO T 304 or use state or contractor data.
Coarse aggregate angularity	AASHTO T 335 or use state or contractor data.
Stockpile moisture content	AASHTO T 255 or use state or contractor data.
Geologic type	Yes or use state or contractor data.
LA Abrasion Test or Micro Deval Test	AASHTO T 96 or T 327 or use state or contractor data.
Soundness	AASHTO T 104 or use state or contractor data.

1.5 Martin, A. E., Arambula, E., Yin, F., Cucalon, L. G., Chowdhury, A., Lytton, R., Epps, J., Estakhri, C., and Park, E. S. "Evaluation of the Moisture Susceptibility of WMA Technologies." Publication NCHRP Report 763. National Cooperative Highway Research Program, Transportation Research Board, 2014.

The NCHRP Project 9-49 was conducted to evaluate the moisture susceptibility of WMA technologies and develop guidelines for identifying and limiting moisture susceptibility in WMA pavements. This was accomplished through laboratory conditioning of WMA, moisture susceptibility testing of WMA, and WMA performance evolution experiments. In addition to this, four field projects were chosen based on the climate to be analyzed. The report provides a summary of the field projects, as shown in Table A7.

Table A7: Summary of WMA Field Projects (Martin et al., 2014)

Location and Environment Condition	Location	Construction Completion Date	Mixtures	Aggregates	Asphalt Binder	Additives: RAP	Additives: RAS	Additives: Anti-Strip Agent	Field Compaction Temperature (°F)	Coring Dates
Iowa (Wet, Freeze)	US 34, near Coming	Sep. 2011	HMA+RAP	Quartzite, Limestone, Field Sand	PG 58-28	17%	None	None	295-300	Sep. 2011 Mar. 2012 Sep. 2012
			Evotherm 3G+RAP						240-248	
			Sasobit+RAP						235-240	
Montana (Dry, Freeze)	IH 15, near Dillon	Oct. 2011	HMA	Siliceous	Modified PG 70-28	None	None	1.4% Lime	310-315	Oct. 2011 Apr. 2012
			Evotherm 3G						270-280	
			Sasobit						275-280	
			Foaming						270-275	
Texas (Wet, No-Freeze)	FM 973, near Austin	Jan. 2012	HMA	Limestone, Field Sand	Modified PG 70-22	None	None	None	275-285	Jan. 2012 Sep. 2012
			Evotherm DAT						230-235	
			Foaming						240-250	
New Mexico (Dry, No-Freeze)	IH 25, near Truth or Consequences	Oct. 2012	HMA+RAP	Siliceous Gravel	Modified PG 64-28	35%	None	1% Versabind	285-290	Oct. 2012
			Evotherm 3G+RAP						255-260	
			Foaming+RAP						265-270	

The WMA moisture susceptibility testing evaluated Lab-Mixed Lab-Compacted (LMLC), Plant-Mixed Lab-Compated (PMLC), and Plant-Mixed Field-Compacted (PMFC) samples. The results of lab testing suggest that WMA can be more susceptible to moisture in early life, but after a summer of aging it is equivalent to HMA. The use of anti-stripping agents may reduce the moisture susceptibility and compatability between anti-stripping agents and the WMA technology should be considered in design. The lab and field testing for the Montana and New Mexico projects were similar, showing good field performance for all mixtures. The Iowa field project showed poor field performance, while the Texas field project showed good performance. The report notes that Iowa is the only project that is showing distresses related to moisture susceptibility (raveling).

The report suggests further research regarding the following subjects:

- Mixture performance, with a focus on performance-related properties that indicate moisture susceptibility or resistance to rutting or cracking;
- The comprehensive effects of air voids (AV) in the asphalt mixture specimen on mixture stiffness, specifically between PMFC cores and LMLC specimens and PMLC specimens;
- Long Term Oven Aging (LTOA) methods need to be evaluated to find better ways to simulate field conditions in the laboratory for WMA;
- Assess the differences in saturation that result from different processes such as high relative humidity, water immersion, and use of the Moisture-Induced Stress Tester (MIST) equipment;
- LTOA protocols with shorter periods (less than five days) in order to produce LMLC specimens with properties more representative of those for PMFC cores after summer aging in the field; and,

- Simulating field aging via only short-term oven aging (STOA) of loose mix at higher temperatures is suggested to reduce the time required to evaluate mixtures.

1.6 West, R., Rodezno, C., Julian, G., Prowell, B., Frank, B., Osborn, L. V., and Kriech, T. "Field Performance of Warm Mix Technologies." Publication NCHRP Report 779. National Cooperative Highway Research Program, Transportation Research Board, 2014.

The NCHRP Project 9-47A was conducted to evaluate the field performance of WMA technologies. The project primary objectives were:

1. Establishing relationships between laboratory-measured engineering properties of WMA and field performance properties of WMA;
2. Comparing relative performance between WMA and HMA pavements;
3. Comparing production and placement practices, and if possible costs, between WMA and HMA; and,
4. Providing relative energy usage, emissions measurements, and fume exposure of WMA compared to HMA.

The project was split into two portions, the first was engineering properties and field performance of WMA technologies, and the second was the effects of WMA on plant energy and emissions and on worker exposures to respirable fumes.

The conclusions drawn from the first portion of the report are:

- In terms of production and construction, no issues were observed due to the lower mix production temperatures of WMA. Slightly higher moisture content was observed in WMA compared to HMA, but nearly all mixes met the 0.5% specification limit. The mix designs did not need to be altered for WMA, but the WMA mixes had slightly less asphalt absorption. Lastly, the densities were generally the same for WMA and HMA;
- In terms of energy and emissions, the energy savings from using WMA can be approximated by the relationship shown as Energy Savings (BTU) = 1100 BTU /Δ°F/ton. Additionally, the reduction in carbon dioxide was directly proportional to the reduction in fuel usage. Lastly, the worker exposure to respirable fumes during paving of WMA was significantly reduced;
- In terms of short-term field performance, WMA performed the same as corresponding HMA sections with regard to rutting. No project had any evidence of moisture damage, and the use of WMA did not appear to result in density changes under traffic loading. The cracking observed was generally equal on both WMA and HMA sections, and the surface texture and texture change after two years were similar on the HMA and WMA sections;
- In terms of engineering properties, the WMA binder aged slightly less than HMA and the true grades of the binders were similar for both WMA and HMA. The dynamic moduli of WMA are statistically lower than the HMA, on average 12% lower. Additionally, flow number of WMA was lower in two-thirds of the comparisons. Field cores showed that the indirect tensile strength of the WMA remained statistically similar to the HMA for at least two years, but laboratory specimens showed that the HMA has a higher indirect tensile strength. Rutting performance was equivalent to the HMA in 59% of the WMA

mixes, and statistically higher in the remaining 41%. Lastly, lab testing indicates there would be a small improvement in thermal cracking resistance in WMA; and,

- In terms of predicted performance, overall the Mechanistic-Empirical Pavement Design Guide (MEPDG) predicted similar long-term performance for WMA and HMA mixes, with slight increases in short-term rutting, and slightly less low-temperature cracking.

The following conclusions were drawn from the second portion of the report:

- WMA demonstrated reductions in fuel usage, and these reductions corresponded to reductions in stack emissions of greenhouse gases;
- WMA should receive credit for reductions in greenhouse gases in life-cycle assessments; and,
- In most studies, regarding worker exposure, the WMA resulted in at least a 33% reduction in total organic matter.

1.7 Newcomb, D., Martin, A. E., Yin, F., Arambula, E., Park, E. S., Chowdhury, A., Brown, R., Rodezno, C.,Tran, N., Coleri, E., Jones, D., Harvey, J. T., and Signore, J. M. "Short-Term Laboratory Conditioning of Asphalt Mixtures." Publication NCHRP Report 815. National Cooperative Highway Research Program, Transportation Research Board, 2015.

The NCHRP Project 9-52 was conducted to evaluate the short-term laboratory conditioning of WMA technologies and also to develop guidelines for identifying and limiting moisture susceptibility in WMA pavements. Objectives of this project were to:

1. Develop a laboratory short-term aging protocol to simulate the aging and asphalt absorption of an asphalt mixture as it is produced in a plant and then loaded for transport.
2. Develop a laboratory aging protocol to simulate the aging of an asphalt mixture through its initial period of performance.

This was accomplished through laboratory analysis and testing, consisting of simulated asphalt aging and absorption during plant production and construction, as well as simulated long-term aging. Laboratory testing provided the following conclusions:

- Laboratory STOA protocols produce representative specimens for performance testing.
- WMA had lower mixture stiffness and decreased rutting resistance compared to HMA, possibly due to the reduced production temperature.
- Rutting resistance and stiffness were unaffected by production temperature and plant type.
- Mixture stiffness increased significantly with the addition of recycled materials, but the results were not consistent due to the variability of the recycled materials.
- Mixtures had higher stiffness and rutting resistance when using low-absorption aggregates.
- Binder source had a significant impact on mixture performance.

Effects of WMA technology on mixture stiffness evolution with field aging compared to HMA fell into one of three categories, with category two being the most common (four out of seven):

1. HMA stiffness was always higher, but the difference decreased with field aging.
2. HMA stiffness was higher at early age, but with field aging they became equal.
3. HMA and WMA stiffness were equal at early age, but WMA became stiffer with aging.

The report suggests continued research including the further monitoring of the long-term behavior of the mixes. Additionally, more research should be done regarding moisture susceptibility, fatigue cracking resistance, and how aging affects the long-term low-temperature behavior of asphalt mixtures in order to quantify possible embrittlement with time. Further suggestions include developing additional STOA protocols in order to get equivalent volumetric properties in future research.

1.8 Newcomb, D., Yin, F., Arambula, E., Zhang, J., Bhasin, A., Li, W., and Zelalem, A. "Properties of FoamedAsphalt for Warm Mix Asphalt Applications." Publication NCHRP Report 807. National Cooperative Highway Research Program, Transportation Research Board, 2015.

The NCHRP Project 9-53 studied the properties of foamed asphalt for WMA applications. Objectives were to determine the properties of foamed binders as related to asphalt mixture performance and to develop laboratory foaming and mixing protocols that may be used to design asphalt mixtures. Both laboratory and field studies were conducted, with the following four parameters used for binder performance:

1. Maximum expansion rate (ER_{max})
2. Rate of collapse of semi-stable foam (k-value)
3. Foamability index (FI)
4. Surface area index (SAI)

The laboratory binder study investigated the influence of water content, binder source, temperature, liquid additives, and shearing action on the foamed binder characteristics. The observations from the study are:

- Binders from different sources with the same PG grade and water content had different values for ER_{max}, k-value, FI, and SAI.
- There was a linear correlation between ER_{max} and water content for most binders.
- For most binders, foam became more unstable (k-value increased) at higher water content.
- For most binders, FI and SAI decreased with water content.
- Temperature had no apparent effect on the foamed binder properties.
- Certain additives can improve the binder foaming characteristics.

Three field studies were conducted. The first aimed to apply laboratory test methods and metrics in a field setting and to compare the foamed binder measurements with the workability and coatability results. The results showed a clear difference when binder was sampled using an extension pipe vs. directly from the valve outlet. Additionally, the foaming metrics were different from laboratory measurements. Another observation was that the sampling container size had an effect on the foamed binder metrics. The results showed that, even after a correction factor was determined for ER_{max}, the values were smaller in the field than what was recorded in the laboratory. Finally, it was determined a 1.0% water content was optimum for workability, and the overall performance of the WMA was equivalent or better than the HMA control.

The second study compared field foaming units (Terex and Gencor) against foamed binder and foamed mixture measurements. As in the first field study, the field foaming measurements were different than the laboratory-foamed binder measurements with regard to ER_{max} and k-value.

The final study sought to validate the proposed foamed mix design approach with plant data. The data from the laboratory measurements showed that optimum water content was 1.5%, and this water content resulted in greatly improved workability and coatability compared to the HMA. At optimum water content, the WMA had equivalent or better performance than the HMA.

The report recommends that the diagram shown in Figure A1 be followed as a final WMA design method.

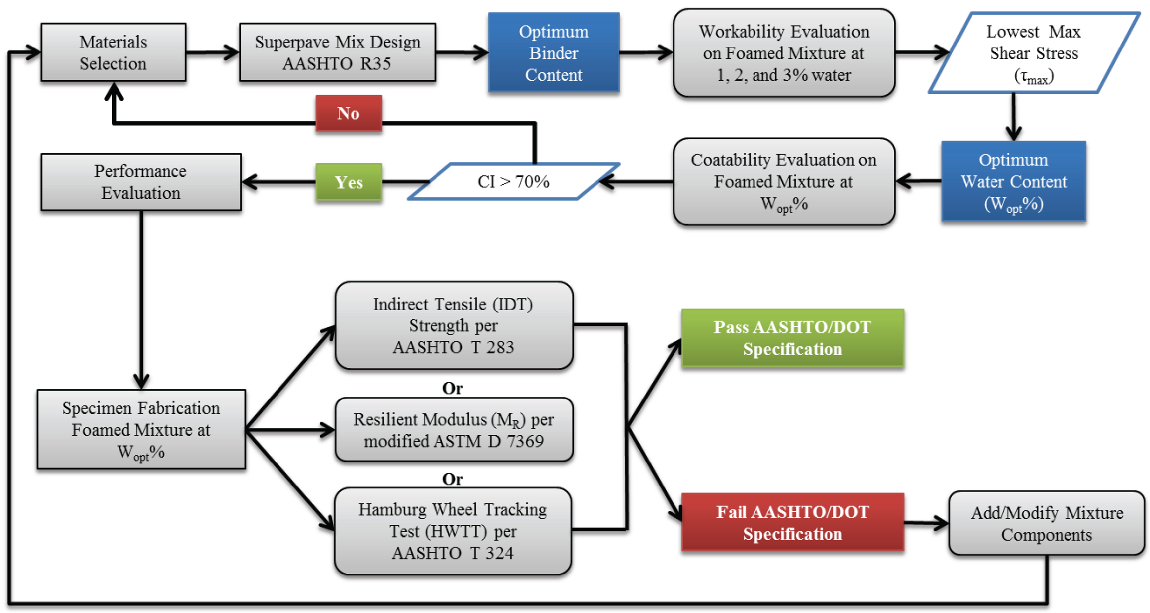

Figure A1: WMA Design Method (Newcomb et al. 2015)

1.9 McCarthy, L., Callans, J., Quigley, R., and Scott, S. "Performance Specifications for Asphalt Mixtures." NCHRP Synthesis Report 492, June 2016.

The NCHRP Synthesis 492, "Performance Specifications for Asphalt Mixtures", was reviewed to identify information related to WMA mixtures. The focus of this synthesis report was to document the performance tests used in conjunction with volumetric properties for mixtures. The synthesis provided examples of engineering tools used in the development and implementation of performance specifications for asphalt mixtures, examples of the contents of performance-based specifications (PBS) currently used or in development, information on test program implementation and research related to PBS for asphalt mixtures, and the reported benefits and challenges with implementing PBS.

The results of the synthesis project indicated that only a small number of DOTs and municipal agencies are currently using performance tests as part of standard mixture acceptance. The survey data indicated that the performance-based properties most commonly used and researched include the measurement of stiffness, thermal cracking, moisture resistance, and fatigue cracking.

The current state of the practice reported for asphalt pavement mixture design and acceptance is using volumetric properties in conjunction with performance properties. In a few cases, performance tests such as the Asphalt Pavement Analyzer (APA) and Hamburg Wheel Tracking Device (HWTD), which both measure the rutting resistance and resistance to moisture damage, have been incorporated into standard practice, including production acceptance testing at the option of the engineer. It was reported that further research is also underway to address premature fatigue cracking.

The survey data revealed that the HWTD test, APA test, bending beam rheometer, and flexural beam fatigue test were the most commonly used tests in support of PBS. There were 19 DOTs and three agencies in Canada that reported having the necessary equipment required for the laboratory testing that supports their PBS.

The most frequently reported reasons for the use of performance specifications for asphalt mixtures were to achieve longer pavement service lives (in terms of resistance to rutting and cracking and other distresses) and to quantify the quality and encourage better construction of flexible pavements.

The majority of states and Canadian provinces are building flexible pavements from asphalt mixtures produced with recycled materials such as reclaimed asphalt pavement, recycled asphalt shingles, crumb rubber or ground tire rubber, or warm mix additives. Many of these agencies reported that they require different test approaches than those used for traditional HMA mixtures as a result of incorporating nontraditional mixture designs.

A number of agencies have observed that Superpave mix designs may have issues when using recycled materials (e.g., recycled asphalt shingles and crumb rubber). Some of the issues noted by the agencies interviewed included overly dry mixes, increased stiffness, and development of premature cracking. For this reason, some agencies are working toward implementing a balanced mix design process that incorporates performance tests to achieve an optimal balance between rutting resistance and fatigue and thermal cracking resistance.

There were a number of individual findings reported that relate in some way to the use of WMA. For example, WMA was defined as asphalt produced between 215^0 to 275^0F, or at 30^0F below the production temp of HMA as based on the Federal Highway Administration Long Term Pavement Performance (LTPP) definition of WMA. The survey results in the synthesis reported that the definition of temperature may differ slightly among agencies when reclaimed asphalt pavement (RAP) is being used, depending on the percentage of RAP content.

It was reported that 98% of state DOTs have used WMA mixtures in addition to HMA. Nearly all agencies that responded had assessed the costs and benefits of WMA. Other specific findings include:

- A study by Jones et al. (2010)[1] conducted a series of tests to assess the differences in performance between HMA and WMA when the WMA additive Rediset® WMX was used. The tests were conducted to determine rutting potential, fatigue cracking performance, and moisture sensitivity of both mixture types. The tests conducted

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[1] Jones, D., J. Signore, and W. Tsai, *Warm-Mix Asphalt Study: Laboratory Test Results for AkzoNobel Rediset WMX*, UCPRC-CR-2010-01, University of California Pavement Research Center, Berkeley, April 2010 [Online]. Available: http://www.ucprc.ucdavis.edu/pdf/UCPRC-CR-2010-01.pdf.

included shear testing, fatigue testing, HWTD test, Cantabro test, and TSRST test. It was determined that in the TSRST test, the mixtures with the Rediset WMX additive exhibited significantly better moisture resistance than the control mixes. In each of the other tests, similar results with regard to performance were displayed:

- Sargand et al. (2009) [2]reported on a 20-month field experimental study of WMA sections with HMA control sections. The conclusion from the field experiment was that the WMA sections performed the same (if not better than) as the HMA control sections. Laboratory investigation of WMA was then conducted in order to measure the temperature, deflection, subgrade pressure, and longitudinal and transverse strains subjected to rolling wheel loads at temperatures of 40°F, 70°F, and 104°F (4°C, 21°C, and 40°C, respectively). All three of the WMA mixes experienced more initial consolidation than the HMA mix, and the WMA made with emulsion consolidated about twice as much as the other WMA mixes. After initial consolidation, any observed differences in further consolidation were negligible.
- A study by Alvarez et al. (2010)[3] focused on WMA in both the laboratory and field using the Hamburg wheel tracking device (HWTD) test to observe the differences in optimum asphalt content for WMA as compared with that of HMA. The research indicated that when allowed an appropriate cure time, WMA mixtures can achieve the same strength as HMA mixtures.
- Georgia DOT reported that when using WMA mixes, it increases the frequency of samples taken in order to verify volumetric mix design attributes.
- Georgia DOT reported that it has historical and documented issues with stripping owing to certain aggregate types. As a result, it requires an increased sampling frequency on WMA projects in order to test for moisture susceptibility.
- Ohio DOT reported that there was not much observed difference in the amount of aging between WMA and HMA mixes.

1.10 West, R. "Recycled Asphalt Shingles in Asphalt Mixtures with WMA Technologies" NCHRP Report 890. National Cooperative Highway Research Program, Transportation Research Board. In press.

The NCHRP Project 9-55 was conducted to 1) Evaluate the short-term performance of asphalt mixtures that use RAS in conjunction with WMA; 2) Quantify the effect of RAS on asphalt mixture properties; and 3) Develop guidance for designing and constructing WMA-RAS asphalt mixtures. The project included the evaluation of eight RAS-WMA field projects. Comparisons were made with seven RAS-HMA mixtures with respect to construction, short-term field performance, and laboratory measured engineering properties. The lower WMA production temperatures did not cause any plant or construction issues with the mixtures in this study and

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[2] Sargand, S., J. Figueroa, W. Edwards, and A. Al-Rawashdeh, *Performance Assessment of Warm Mix Asphalt (WMA) Pavements*, Report FHWA/OH-2009/08, Ohio Research Institute for Transportation and the Environment, Athens, Sept. 2009 [Online]. Available: http://ntl.bts.gov/lib/31000/31400/31425/WMA_Report_2009-09_final_complete.pdf

[3] Alvarez, A., J. Button, and C. Estakhri, *Field and Laboratory Investigation of Warm Mix Asphalt in Texas*, Report 0-5597-2, Texas Department of Transportation, Austin, July 2010 [Online]. Available: http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5597-2.pdf

statistically similar in-place densities were achieved. The short-term field performance was practically the same. The laboratory tests showed that the WMA mixtures had slightly lower stiffness and some cracking tests showed improvement in cracking resistance. Overall, the project found that the use of WMA technologies with RAS mixtures does not cause a detrimental effect.

1.11 Epps Martin, A. "The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios" Unpublished. National Cooperative Highway Research Program, Transportation Research Board.

The NCHRP Project 9-58 is being conducted to assess the effectiveness of recycling agents (RA) in mixtures with recycled binder ratios (RBR) above 0.3. The specific objectives of the project are to:

1. Assess the effectiveness of RA to:
    a. partially restore blended binder rheology; and,
    b. improve mixture cracking performance at optimum dosage rates;
2. Evaluate the evolution of RA effectiveness with aging; and,
3. Recommend evaluation tools for assessing the effectiveness of RA initially and with aging for mixtures with high RBRs at specific locations.

The project includes laboratory evaluation of blended binders, mortars, and laboratory and plant produced mixtures. The effort also included the procurement of field projects, including evaluation of the field materials and performance of mixtures over time. Several of the field projects also include the use of WMA.

The project is still underway and more information is available in interim reports published online.

1.12 Shen, S. "Evaluation of Long-Term Field Performance of WMA Technologies." NCHRP Report 843. National Cooperative Highway Research Program, Transportation Research Board, 2017.

The National Cooperative Highway Research Program (NCHRP) Project 9-49A was conducted to compare the long-term field performance of Warm Mix Asphalt (WMA) technologies and develop guidelines for identifying and limiting moisture susceptibility in WMA pavements. The objectives of the project were to:

- Compare the long-term performance of WMA and HMA pavements, and
- Identify material and engineering properties of WMA pavements that are significant determinants of their long-term field performance.

The project included the evaluation of pavement performance and material property data from 28 field projects. Each project consists of one or more WMA technology pavement sections and an HMA control section. WMA technologies evaluated included asphalt foaming additives, plant foaming units, chemical additives, and organic additives. Practically identical in-service performance was observed for the WMA and HMA sections with little to no rutting, no evidence of moisture damage, and some transverse and longitudinal cracking. The project also found that the effect of aging on the organic additives was more prominent than the other WMA technologies. The fracture work density value obtained from IDT testing at 14°F, IDT strength at 68°F, and rutting resistance index from Hamburg testing were found to be significant determinants for transverse cracking, longitudinal wheel-path cracking, and rutting in the field.

1.13 Kim, Y. R. "Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction" NCHRP Report 871. National Cooperative Highway Research Program, Transportation Research Board, 2018.

The National Cooperative Highway Research Program (NCHRP) Project 9-54 was conducted to study the long-term aging of asphalt mixtures for performance testing and prediction. The objectives were to 1) develop a calibrated and validated long term aging procedure to simulate long-term aging of asphalt mixtures for performance testing, and 2) determine an aging model for mechanistic-empirical pavement design and evaluation. The project used 18 different asphalt mixtures from in-service and test track pavements across the U.S. and Canada and included WMA.

Loose mixture aging at 203°F (95°C) is proposed as the long-term aging procedure for fabricating asphalt mixture performance test specimens for both HMA and WMA. Aging temperature of 275°F (135°C) was found to cause changes in the chemistry of the binder that do not occur in the field and also resulted in differences in cracking properties. A rheology-based kinetics aging model was developed and then simplified to develop a climactic aging index. This index is used to determine the appropriate aging time to match the desired location and depth within the pavement structure for the appropriate climatic location.

2. CASE STUDIES AND REPORTS FROM THE STATE DEPARTMENTS OF TRANSPORTATION, FEDERAL LANDS, AND NCAT

This section summarizes case studies and field projects that have been conducted by various agencies. Summaries of individual projects are described below and detail the observations with respect to laboratory-measured performance and field performance, including production metrics and measured emissions.

Generally, the laboratory evaluations of WMA materials have showed better compactability, lower air voids, lower asphalt absorption, and lower optimum binder contents than HMA. WMA materials were generally more susceptible to rutting and moisture damage although results depended upon the particular materials and test methods used. Stiffness values measured for WMA were lower than those measured for HMA.

Field trials showed that WMA materials had similar or higher densities and improved workability over HMA mixtures. WMA sections were observed to have higher rutting and less cracking in the early life of the pavement, but performance was similar to HMA after several years of field aging. During production, decreases in emissions and fuel usage were measured.

The gaps identified in these projects include long term monitoring of WMA field sections, the need for standard specifications, and establishment of appropriate curing time and temperatures during mix design. Also, several studies pointed out the unknown interactions with WMA and higher percentages of recycled materials.

2.1 Neitzke, B. "Warm Mix Asphalt Yellowstone National Park." Western Federal Lands Highway Division, Federal Highway Administration, 2008.

The Western Federal Lands Highway Division of the FHWA presented details of a WMA project that was used to evaluate two different WMA technologies. The two WMA technologies evaluated were Advera and Sasobit. In addition to these, HMA sections were constructed for the purpose of comparing the relative performances.

The density of the control mix was the lowest with an average of 93.2%, the Sasobit mixture had an average of 93.4% and the Advera mixture average was 93.9%. The Tensile Strength Ratio (TSR) of the control mix was the highest with an average of 85% retained, followed by the Sasobit mixture an average of 84% retained, and last was the Advera Mixture with an average of 81% retained. In the Hamburg rut testing, the HMA sections performed worse on average than either WMA technologies after the full 20,000 passes. The Asphalt Pavement Analyzer (APA) testing showed that the control performed marginally better than the Advera mixture, while the Sasobit mixture performed marginally better than the control.

One of the benefits of WMA that was quantified was the fuel usage for each mixture. The control HMA mixture used 2.12 gallons of fuel per ton of mix (gallons/ton), the Advera mixture used only 1.62 gallons/ton, and the Sasobit mixture used 1.80 gallons/ton. This resulted in 20-25% fuel savings, or an estimated $1/ton of mix. The presentation also notes that the approximate cost for the Advera mixture was $3.30/ton of mix, while the Sasobit mixture was approximately $2.30/ton of mix. Other observations were that the WMA mixes handled similarly to the HMA control, and workers had no handling difficulties with WMA. Another benefit was improved visibility and safety from the lack of smoke/steam and odors that are normally present in HMA. Lastly the presentation notes that moisture sensitivity was not an issue in their specimens. The presentation states that moving forward, the next step is field monitoring, more testing and evaluation, more trials with WMA, and the development of standard specifications.

2.2 Diefenderfer, S. D., McGhee, K. K., and Donaldson, B. M. "Installation of Warm Mix Asphalt Projects in Virginia." Publication FHWA/VTRC 07-R25. Virginia Department of Transportation, 2007.

This Virginia Department of Transportation (VDOT) report details the performance of WMA trial sections throughout Virginia. The purpose of this study was to evaluate the performance of three trial sections using WMA compared to a HMA control section. Two of the WMA sections used Sasobit (Trial A and Trial B) and one used Evotherm ET. This evaluation was performed over a two-year period and consisted of visual site assessments, laboratory testing of sample cores, and a survey of the underlying structure. The following observations and conclusions were drawn from the test results:

- Visual Assessment
    - The Sasobit trial B and the Evotherm trial showed no difference from the HMA section in the two-year period. Sasobit trial A showed some cracking along the centerline after a year of service.
- Air Void and Permeability measurements

    - The results of the air void testing showed that the performance was similar over the trial period. Some significant differences, likely due to a small sample size, were observed at various ages but no trends were presented.
    - The permeability testing showed that the no clear trends across all three trial sections, but it was noted that the permeability did not impact performance.
- Asphalt Binder Evaluation
    - The Sasobit trial A binder gained two high temperature grades (64 to 76).
    - The Sasobit trial B binder gained one high temperature grade and lost one low temperature grade (PG64-22 to PG70-16).
    - The Evotherm lost one low binder grade (-22 to -16).
    - The HMA performed similarly to the Evotherm, but the Sasobit had a reduced rate of stiffness gained.
- Underlying structure Evaluation
    - Each test section had variability in the underlying structure; the differences would not greatly affect performance of the pavement.

The report stated that HMA and WMA could be expected to perform equally, but some WMA additives might reduce the rate of in-service binder aging. The report recommended monitoring the performance of additional WMA sites and assessing their performance. Additionally, WMA sections under different traffic conditions and with high RAP content should be constructed and assessed.

2.3 Lai, J. S., "Evaluating Constructability and Properties of Advera and REVIX Warm Mix Asphalt." Publication FHWA-GA-08-0801. Georgia Department of Transportation, 2008.

This Georgia Department of Transportation (GDOT) report details a pilot study, performed with Advera and REVIX WMA technologies, regarding the relative performance of WMA to a HMA control mix. This report consisted of a summary of pre-construction activities; an assessment of asphalt plant and paving operations during construction; and a post-construction evaluation. The objectives were to:

- Assess the constructability of the WMA mixes;
- Evaluate the properties of the WMA mixes produced during construction; and
- Conduct an initial performance assessment of the WMA pavements

The preconstruction activities consisted of developing a pilot test plan and determining the material sources and properties for the mixes. A 9.5 mm Superpave was determined to be the appropriate mix for both the WMA and HMA.

The assessment of asphalt plant and paving operations section of the report summarizes the test sections locations, the haul distance, and the mix and paving reviews. During the paving of Advera and REVIX severe mat blemishes occurred, requiring significant amounts of handwork to repair them. This problem was attributed to a buildup of cold asphalt mix behind the end plates. The problem persisted even after increasing the paving temperature. A representative of Paragon Technical Services, Inc. (Ergon Asphalt and Emulsions, Inc.) stated that the problem was with the REVIX mix and likely caused by the insufficient use (less than 50% of the recommended dosage) of additive. Additionally, the representative noted there were protracted laydown/compaction delays. Another view was given from a representative of PQ Corporation.

Referencing Advera, he stated that the problem was due to improper mixing equipment; he notes that if the mix were produced using a "true drum plant" the problem would not have occurred. Lastly, the report noted that a hard crust was formed in the hauling truck when using WMA and, unlike HMA, the clumps could be easily broken loose in the auger chamber.

Due to the problems faced during construction, the post-construction evaluation was not completed.

2.4 Jones, D., Wu, R., Tsai, B. W., Lu, Q., and Harvey, J. T. "Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 1 HVS and Laboratory Testing. "Publication ca101562a. California Department of Transportation, 2008.

This California Department of Transportation (Caltrans) report details a project on the construction and analysis of a test track utilizing WMA. The objective of this project was to determine if the use of WMA additives (Advera, Evotherm DAT, and Sasobit) influenced the performance of the mixture. Performance was evaluated using a Heavy Vehicle Simulator (HVS), sampling during production and construction, and laboratory testing.

The HVS testing occurred over approximately one month, per test section, with 170,000 - 285,000 load repetitions. The following observations were made from the HVS test data:

- HMA max average rut depth = 12.4mm, max rut depth = 14mm;
- WMA with Advera max average rut depth = 12.4mm, max rut depth = 13.3mm;
- WMA with Evotherm max average rut depth = 12.5mm, max rut depth = 14.1mm;
- WMA with Sasobit max average rut depth = 7.8mm, max rut depth = 8.8mm (due to lower binder content it is stated that comparisons between this and HMA control are not possible); and,
- None of three WMA additives tested significantly influenced rutting performance.

The laboratory testing consisted of shear tests, fatigue tests, and moisture sensitivity tests. The following observations were made from the laboratory test data:

- Shear
  - All mixtures had approximately the same shear modulus.
  - Cycles to 5% Permanent Shear Strain (PSS) test indicate that the use of the additives and lower temperatures had no effect on the performance of the mixes.
  - PSS at 5000 cycles results show that the Sasobit had the most resistance to rutting, while the Evotherm was most resistant to the stress. There was no significant difference between the HMA and Advera.
  - The HMA, Advera, and Evotherm mixtures all performed similarly in terms of the complex modulus curve. The Sasobit mixture curve was significantly higher than the others.
- Fatigue
  - There was no significant difference in initial stiffness, initial phase angle, and fatigue life at 50% stiffness reduction for all mixes. This suggests that the additives and lower temperatures did not affect the performance of the mixtures.
  - In dry frequency sweep tests, the HMA, Advera, and Sasobit all had similar complex modulus curves; the Evotherm had a significantly lower curve than the others.

- In wet frequency sweep tests, the HMA and Sasobit had similar complex modulus curves; the Advera and Evotherm had similar but significantly lower curves than HMA and Sasobit.
- Moisture Sensitivity
    - In the Hamburg Wheel-Track Test it was noted that air-void content had the biggest influence on performance.
    - There were no significant differences between the HMA, Advera, and Evotherm moisture-resistance, but the Sasobit had a higher resistance. This was most likely due to the lower binder content used.
    - The Tensile Strength Ratio (TSR) testing showed no specific trend, all mixes showed no significant difference in terms of wet or dry strength.

Overall, the laboratory test results indicate that the use of WMA additives did not influence the performance of the pavement compared to the traditional HMA. It was noted that all the mixes, including the HMA, tested were potentially susceptible to moisture damage.

The report recommended the use of WMA technologies in full-scale pilot studies on in-service pavement. It also recommended more HVS testing to assess moisture sensitivity.

2.5 Diefenderfer, S. D., and Hearon, A. "Laboratory Evaluation of a Warm Asphalt Technology for Use in Virginia." Publication FHWA/VTRC 09-R11. Virginia Department of Transportation, 2008.

This Virginia Department of Transportation (VDOT) report details the laboratory evaluation of samples from two trial installations of WMA in Virginia. The purpose of this evaluation was to determine the differences in performance of the WMA, in this case Sasobit, compared to a HMA control section. For this evaluation, two mix designs were considered and are shown below in Table A8.

Table A8: Mixture Properties of WMA Trial Installations (Diefenderfer et al., 2008)

Properties	Mixture A	Mixture B
Mixture type	SM-9.5A	SM-12.5A
Binder type	PG 64-22	PG 64-22
Design gyrations	65	65
Cumulative percent passing		
¾ in (19.0 mm)	100	100
½ in (12.5 mm)	100	96
³/₈ in (9.5 mm)	92	86
No. 4 (4.75 mm)	60	-
No. 8 (2.36 mm)	43	34
No. 200 (75 μm)	5.7	6.0
Aggregate type	Granite and siltstone	Limestone and gravel
Binder content	5.50%	5.20%
Antistripping agent	Morelife 3300, 0.5% by weight of asphalt	Hydrated lime, 1.0% by weight of asphalt
Recycled asphalt pavement	20%	10%
Sasobit	1.5% by weight of asphalt	1.5% by weight of asphalt
Production temperature	HMA, 300°F; WMA, 250°F	HMA, 325-330°F; WMA, 300°F

HMA = hot-mix asphalt, WMA = warm-mix asphalt.

The laboratory evaluation consisted of four performance measures: compactability, volumetric properties, moisture susceptibility, rutting resistance, and fatigue performance. The following observations and conclusions were drawn from the laboratory testing results:

- In volumetric testing, the only noted difference was a variance in total air voids between the plant-compacted and lab-compacted samples.
- In the Tensile Strength Ratio (TSR) test, the WMA in mixture A did not meet the 80% specification, even after reheating and lab compacting, while the HMA did. Mixture B samples met the 80% specification and were statistically similar.
- Additional TSR tests were conducted to evaluate the effect of aging and production temperature. The HMA strength did not increase with short-term aging or antistripping agents but did increase with long-term aging. The WMA strength was improved with the addition of antistripping agents, long-term aging, and increases in production temperature.
- Overall the TSR results were similar between HMA and WMA except for the Mixture A. A wet stockpile may have contributed to the poor results for the WMA.
- The Hamburg Wheel Test results showed all plant-produced mixtures being well under the 10mm limit after 20,000 passes, suggesting that all mixes are resistant to stripping.
- The Hamburg Wheel Test results for the lab-produced mixtures showed that lower production temperatures resulted in higher rutting, with the 230°F sample failing the 10mm criteria. The long-term aged samples performed the best and were well under the 10mm criteria.
- The effects of entrapped moisture were evaluated. It was determined that none of the samples, HMA or WMA, met the 80% TSR specification when a moist stockpile was used.
- The HMA and WMA samples were found to have sufficient rutting resistance. The WMA had slightly less rutting in both mixtures.
- It was determined that rutting potential of WMA decreased with increases in production temperatures.
- Fatigue resistance was similar between WMA and HMA for both mixtures. WMA performed slightly better at higher strain levels. At lower strain levels, the HMA performed slightly better.
- An MEPDG analysis suggested that the long-term performance of HMA and WMA would likely be similar.

The report recommended implementation of a permissive specification allowing the use of WMA produced with reputable technologies. Additionally, acceptance requirements for WMA should not differ from HMA requirements except for temperature and TSR values. VDOT recommended continued monitoring of existing field sections and investigation additional WMA technologies.

2.6 Sholar, G., Nash, T., Musselman, J. and Upshaw, P. "Summary of FDOT's Experience with Warm Mix Asphalt." FDOT Research Report FL/DOT/SMO/09-527, Florida Department of Transportation, October 2009.

The Florida Department of Transportation (FDOT) publication, "FDOT's Experience with Warm Mix Asphalt", summarizes the usage of WMA in Florida pavements as of 2009. They found that the temperature of WMA is much lower than conventional HMA. WMA can be around 40-75°F below HMA via additives, either water or chemical, in the asphalt binder prior to mixing. Benefits included the reduction of burner fuel at the asphalt plant, lower emissions from mixing, better workability and compactability in the field, an extended paving season that includes colder months, and less aging of asphalt binder during production. However, the challenges to using WMA included incomplete drying of aggregate, increased moisture susceptibility, unknown long term effects of chemical additives on long term performance of binder, increased concern with WMA's ability to provide radiant energy to heat reclaimed asphalt pavement (RAP), and lack of long term performance information.

When tested for laboratory performance and in measured pavement condition survey data (including rutting, cracking, and ride evaluation), no noticeable differences between WMA and HMA had been recorded. HMA and WMA also show no significant differences in variability of measured quality control properties including binder content, air voids, gradation, and roadway densities. As of 2009, no construction or performance problems have been noted in any of the 16 WMA projects constructed in the state of Florida.

2.7 Hurley, G., Prowell, B., and Kvasnak, A. "Michigan Field Trial of Warm Mix Asphalt Technologies: Construction Summary" NCAT Report 09-10.

The National Center for Asphalt Technology conducted a study in Michigan during 2006 to evaluate the field performance of a WMA mixture produced with Sasobit as compared to an HMA control section. The study included the evaluation of mixture volumetric properties, rutting, moisture resistance, and stiffness in the laboratory. In-place field performance and plant emissions data were also collected.

The mixtures were 9.5 mm NMAS, 86 gyration Superpave mixtures. The WMA mixture was placed as a 1.5" overlay and the HMA was an adjacent surface course. Mixing temperatures for the WMA and control mixtures were 260°F and 325°F, respectively. Compaction temperatures were approximately 250°F and 300°F. The in-place densities of the WMA and HMA control sections were similar after construction. Measured performance of the two sections was similar after two years of traffic.

Laboratory density measurements indicated that the air void content for the WMA was lower than the HMA material when compacted hot, but not when measured on reheated material. The laboratory rutting and moisture susceptibility tests indicated similar performance with the WMA and HMA materials. The stiffness of the two materials was also statistically similar.

A decrease in the asphalt stack emissions and fuel usage was observed during the WMA production.

2.8 Hurley, G., Prowell, B., and Kvasnak, A. "Ohio Field Trial Of Warm Mix Asphalt Technologies: Construction Summary" NCAT Report 09-04, 2009.

The National Center for Asphalt Technology conducted a study to evaluate the field performance of three different WMA technologies in Ohio. The WMA technologies included Evotherm emulsion, Sasobit, and Aspha-min. The WMA sections were constructed in 2006 on in-service roadways with companion HMA control sections.

The study included the evaluation of field-mixed, laboratory-compacted volumetric properties, laboratory performance tests, and field performance data. Differences in fumes emitted at the asphalt plant and the paving site and energy consumption between HMA and WMA were also measured.

The mixtures were 9.5 mm NMAS, 50 blow Marshall mixtures, and were placed in a 1.25" overlay atop a 0.75" leveling course. Compaction temperatures for the WMA sections ranged from 30 to 60°F lower than the control test section. The in-place densities of the WMA sections were all higher than that for the HMA control section. Various degrees of raveling were observed in the three WMA sections 18 months after construction.

Laboratory density measurements indicated that the air voids for the WMA materials were 0.7 to 1.2% lower than the HMA section. The APA testing showed the Evotherm mixture had statistically higher rut depths compared to the HMA mixture; the Sasobit and Aspha-min mixtures were statistically equal to the HMA. AASHTO T 283 testing indicated that all three WMA technologies had higher susceptibility to moisture damage than the HMA mixture, however this was not observed with the Hamburg wheel-tracking stripping inflection points. The stiffness of the Aspha-min and Evotherm WMA technologies were statistically lower than those measured on the HMA control materials for some temperatures and frequencies.

WMA technologies reduce the emissions at the paver by 67 to 81% based on total particulates and benzene soluble matter. Stack emissions testing indicated a reduction of emissions (CO_2 and VOC) produced for both the Aspha-min and Sasobit WMA technologies.

2.9 Perkins, S. W. "Synthesis of Warm Mix Asphalt Paving Strategies for Use in Montana Highway Construction." Publication FHWA/MT-09-009/8117-38. Montana Department of Transportation, 2009.

The Montana Department of Transportation (MDT) published a synthesis report of WMA paving strategies for construction of highways in Montana. The objective of this synthesis was to review and summarize WMA specifications and case studies from other states regarding WMA. The synthesis provided the following observations and conclusions:

- WMA technology falls into one of the following four categories: water-based additives, water-bearing additives, chemical additives, and organic additives.
- NCHRP Project 9-43 Phase I showed that the mix design methodology for WMA followed the practice for HMA. Modifications were made to account for reduced aging during production; practices for evaluation workability at lower production temperatures; recommendations for short-term aging prior to gyratory compaction; and a higher percentage of RAP use is encouraged.
- The only changes to construction practices noted were the plant modifications necessary for the WMA technology.
- A majority of the WMA demonstration projects showed satisfactory results, with the main concern being premature rutting and stripping of mixtures. This was most likely due to excessive moisture in the aggregate not being removed due to the lower production temperature.

Based on these findings, the report recommended further WMA research and implementation studies. The report specifically stated that a comprehensive mixture design study, using the recommendations from the NCHRP 9-43 report, be performed with the aggregate and binder materials common to Montana's region. Additionally, the report recommended that an approval system and specification for WMA be established, and that field trials be constructed based on that specification.

2.10 Schmitt, R., Bahia, H., Johnson, C., and Hanz, A. "Development of Recommendations for Compaction Temperatures in the Field to achieve Density and Limit as-built Permeability of HMA in Wisconsin." Publication 08-08. Wisconsin Department of Transportation, 2009.

This Wisconsin Department of Transportation (WisDOT) report details the development of recommendations for compaction temperatures to achieve density and limit permeability in HMA. The goals of this research study were to:

1. Investigate and establish the minimum temperatures at which commonly used compaction efforts will achieve required density for HMA;
2. Investigate the relationship between "as-built" density and permeability and how it affects performance;
3. Investigate the relationship between HMA mixture properties, temperature, in-place density, and permeability;
4. Develop temperature-stress profiles as guidelines for field compaction; and
5. Quantify the effects of WMA additives on the minimum temperature and temperature-stress profiles.

This review will only address the WMA-related portion of the report. The WMA portion of this report detailed the results of an initial laboratory and field analysis of WMA. The laboratory evaluation consisted of measuring air voids and the Construction Densification Index (CDI). The following provided these conclusions and observations:

- WMA allowed for an increased RAP percentage without significant changes to workability.
- HMA (20% RAP) and WMA (30% RAP) mixtures were close to the 4% air voids limit, but the WMA (40% RAP) was considerably lower. This was attributed to the increased use of P200 in the mix.
- One project was not sufficient to draw any firm conclusions.

The field investigation consisted of density measurements and provided these conclusions and observations:

- Final densities were nearly identical between HMA and WMA at approximately 92%, with WMA having a higher variability likely due to the varied RAP content.
- The density of the WMA (30% RAP) was higher, at 93% on average, than that of the WMA (40% RAP), 90.4% on average. Based on this, lower RAP levels were recommended, with the caveat that additional research was needed.
- The report recommended a more rigorous evaluation of the impacts of WMA additives, specifically the impacts on workability and the relationship between field and lab test results.

2.11 Jones, D., Wu, R., Tsai, B., Harvey, J. T. "Warm-Mix Asphalt Study: First-Level Analysis of Phase 2 HVS and Laboratory Testing, and Phase 1 and Phase 2 Forensic Assessment." Publication CA112221A. California Department of Transportation, 2009.

This California Department of Transportation (Caltrans) report details the HVS and laboratory testing, as well as forensic assessments of in-service test sections of WMA. The objective of this project was to evaluate the influence of three WMA additives (Advera WMA, Evotherm DAT, and Sasobit) on the performance of the pavement in comparison to HMA. Observations and conclusions were drawn from these evaluations include:

- HVS Testing (14-day presoaking with water prior to HVS trafficking and a constant flow of water during trafficking)
- The HVS rut measurements are shown in Table A9 and indicate that there is a 12.5-mm maximum rut depth specified.

Table A9: HVS Rut Test Results for HMA Control and WMA Sections (Jones et al., 2009)

Test Section	Rut Depth (mm)	Load Repetitions
Control (HMA)	12.5 (max)	371,000
Advera	11.5	620,500
Evotherm	12.5 (max)	352,020
Sasobit	10.8	464,275

- All sections showed transverse cracking beginning at approximately 200,000 load repetitions, but showed no pumping in the cracks. Additionally no moisture damage was observed besides some wear on all three of the WMA sections.
- Based on the results, the lower production temperature of the WMA might only have an influence the rutting performance in the first few months after construction.
- The large differences in performance between the control and the Evotherm sections compared to the Advera and Sasobit were attributed to the location conditions. The Advera and Sasobit were in a predominantly sunny area, increasing the rate of oxidization and therefore stiffness.
- Forensic Investigation
    - Rutting was only present in the upper region of the top layer for all sections.
    - Top-down cracking was observed in the top section for all sections.
    - There was no evidence of moisture damage in any section.
- Lab Testing
    - At higher temperatures, all mixes had similar shear moduli, and the WMA had higher cycles to 5% permanent shear strain (better performance). Sasobit had the best performance with regards to shear.
    - There was no significant difference in initial phase angle, complex modulus curves, and fatigue life at 50% stiffness reduction for any mixes, except a slightly lower curve for the Advera.
- Overall, the WMA additives did not significantly affect performance.

2.12 Hurley, G., Prowell, B., and Kvasnak, A. "Field Trial Of Warm Mix Asphalt Technologies: Construction Summary" NCAT Report 10-02, 2010.

The National Center for Asphalt Technology conducted a study to evaluate the field performance of three different WMA technologies in Missouri. The WMA technologies included Evotherm ET (emulsion), Sasobit, and Aspha-min. The WMA sections were constructed in 2006 on an in-service roadway with companion HMA control sections. The study included the evaluation of mixture volumetric properties, laboratory performance tests, and field performance data.

The mixtures were 12.5 mm NMAS, 100 gyration Superpave mixtures. Compaction temperatures for the WMA sections ranged from 40 to 100°F lower than the control test section. The in-place densities of the Evotherm and Sasobit sections were lower than the Aspha-min section after construction. Field performance two years after construction was satisfactory and similar for all sections.

Laboratory density measurements indicated that the air voids for the Evotherm mixture were 0.6% higher than the HMA section and the Sasobit was 0.9% lower than the HMA. The APA testing showed the Sasobit had statistically lower rut depths compared to the HMA mixture; the Evotherm and Aspha-min mixtures were statistically equal to the HMA. The Hamburg wheel-tracking tests showed that all three WMA mixtures had improved rutting performance as compared to the HMA. AASHTO T 283 testing indicated that all three WMA technologies had higher susceptibility to moisture damage than the HMA mixture. However this was not observed with the Hamburg wheel-tracking stripping inflection points. The stiffness of the Aspha-min mixture was statistically lower than the HMA, while the included Evotherm and Sasobit were statistically similar to the HMA.

2.13 Hurley, G., Prowell, B., and Kvasnak, A. " Field Trial of Warm Mix Asphalt Technologies: Construction Summary." NCAT Report 10-04, 2010.

The National Center for Asphalt Technology conducted a study to evaluate the field performance of two WMA technologies in Wisconsin. Trial sections with Evotherm™ and Sasobit® were constructed in 2006 on an in-service roadway. The study included the evaluation of mixture volumetric properties, laboratory performance tests, and field performance data.

The mixtures were 12.5 mm NMAS, 75gyration Superpave mixtures and were placed as a 1.75" surface course. Compaction temperatures for the WMA sections ranged from 50 to 85°F lower than the control test section. The in-place densities of the WMA sections were similar to the HMA section after construction. Field performance, four months after construction, was similar for all sections.

Laboratory density measurements indicated that the air voids for the Evotherm™ mixture were lower than the HMA section. The Sasobit® was statistically the same as the HMA section. The APA testing showed the Sasobit® had statistically lower rut depths and the Evotherm™ has statistically higher rut depths as compare to the HMA.

The Hamburg wheel-tracking tests indicated similar performance for the WMA mixtures as compared to the HMA. The stiffness of the Evotherm™ mixture was statistically different than the HMA while the stiffness of the Sasobit® mixture was statistically similar to the HMA.

Stack-emissions testing and an industrial hygiene survey showed a decrease in asphalt fumes, emissions, and fuel usage during the production of WMA. An increased level of VOCs was measured for the stack emissions during the production of the Evotherm™ mixture. However, that could be attributed to unburned fuel in the asphalt drum during production.

2.14 Jones, D., Tsai, B. W., Signore, J. "Warm-Mix Asphalt Study: Laboratory Test Results for AzkoNobel Rediset™ WMX." Research Report UCPRC-CR-2010-01, AzkoNobel, 2010.

The University of California Pavement Research Center (UCPRC) produced a report for AzkoNobel Inc. that detailed the laboratory testing for the AzkoNobel Rediset™ WMX WMA additive. The objective of this project was to determine if the use of this additive to reduce construction and production temperatures of HMA influenced the performance of the mixture. This report aimed to follow the same procedure as in a 2009 California Department of Transportation report. The results were compared, as appropriate. To achieve this, the Rediset WMA and a control HMA, were evaluated using shear tests, fatigue tests, and moisture susceptibility tests. The observations from the test results include:

- Shear
    - At 55°F the average resilient shear moduli of the HMA control and the Rediset mixtures were similar. At lower temperatures the Rediset was decreased due to less aging of the binder.
    - Compared to the previous results in the Caltrans study, the cycles to 5% Permanent Shear Strain (PSS) test results were not significantly different. However, the control HMA sample performed significantly better.
    - PSS at 5000 cycles test results showed that at 45°F the HMA and Rediset mixtures performed similarly. At 55°F the Rediset had higher strain values. Additionally, the results from the previous Caltrans study showed significantly lower strain values compared to these lab prepared samples.
    - In the shear frequency sweep test, the Rediset was less stiff at low frequencies, but performed similarly to the HMA at high frequencies.
- Fatigue
    - Initial stiffness was not significantly different in the dry condition, but in the wet condition the HMA control showed a higher reduction of stiffness as compared to Rediset.
    - There was no significant difference in initial phase angle and fatigue life at 50% stiffness reduction between the Rediset and HMA mixtures. The results were similar to the previous Caltrans test.
- Moisture Sensitivity
    - In the Hamburg Wheel-Track Test, the HMA and Rediset mixtures, on average, performed the same. This indicated that there is no influence on moisture sensitivity from the Rediset additive.
    - In the Tensile Strength Ratio (TSR) test, the Rediset performed significantly better than both the HMA control and the test track in the previous Caltrans study.
- Durability

- In the Cantabro test, the Rediset mix had slightly higher mass loss on average. The difference between the Rediset and HMA result was within typical variation in Cantabro test results.
- It was suggested that the addition of Rediset is unlikely to influence the durability of the mix with respect to raveling.

The report recommended that Rediset WMX additive as an acceptable WMA additive. It was noted that Rediset could potentially increase moisture resistance but further studies are needed.

2.15 Saboundjian, S., Liu, J., Li, P., and Brunette, B. "Late-Season Paving of a Low-Volume Road with Warm-Mix Asphalt." Publication No. 2205. Transportation Research Board of the National Academies, 2011.

The Alaska Department of Transportation detailed their experience with the late-season paving of a low-volume road using WMA. This paper described the project details and the performance of the WMA as compared to traditional HMA. The following observations and conclusions were drawn from this project:

- No major alterations were needed to produce, place, and compact the WMA which used 1.5% Sasobit.
- There were no difficulties with handling the WMA.
- The addition of the Sasobit additive stiffened the binder and increased the temperature grade from PG 58-28 to PG 70-22.
- WMA required less compactive effort to achieve the same density as HMA.
- Mix plant fuel savings were approximately 30% and the fumes from the WMA were visibly reduced compared to the HMA.
- The WMA was stiffer and had higher rutting-resistance than HMA, and had a similar susceptibility to moisture as HMA.
- Field observations showed that there was no significant difference between HMA and WMA.

The report stated that overall performance of the WMA was similar to HMA. Alaska DOT stated it would continue to utilize WMA in the future, especially for late-season paving and low-volume roads.

2.16 Aschenbrener, T., Schiebel, B., West, R. "Three-Year Evaluation of the Colorado Department of Transportation's Warm Mix Asphalt Experimental Feature on I-70 at Silverthorne, Colorado." Colorado Department of Transportation, 2011.

The Colorado Department of Transportation (CDOT) 2011 report evaluated WMA. The objectives of the study were to compare the production, constructability, laboratory performance, and three-year field performance of WMA technologies to a HMA control section. Sasobit, Advera, and Evotherm DAT were the three WMA technologies. The evaluation consisted of laboratory testing, construction data, and visual inspection of the pavement condition.

The first portion of this report addressed the construction process and laboratory testing. The construction process, air temperature data, WMA temperature, fuel usage, and surface temperature were recorded. Additionally, Field-Produced, Field-Compacted (FPFC) and Field-

Produced, Lab-Compacted (FPLC), samples were taken to measure densities, indirect tensile strength, volumetric and strength properties, moisture susceptibility, binder grading, and dynamic modulus and flow number. The following conclusions and observations are drawn from the data and testing listed above:

- No problems were encountered during the production and placement of the WMA mixtures.
- Moisture susceptibility testing showed that WMA could be more prone to moisture damage. The TSR values were generally lower but still passing.
- The addition of WMA additives did not significantly affect the binder grade.
- Dynamic modulus and flow number testing showed that WMA was slightly less stiff than HMA on average.
- The WMA had comparable field density to the HMA with lower temperatures; it is also suggested that the additives facilitated cold-weather placement.

The next portion of this report addressed the evaluation of field performance after three years. The performance criteria for this evaluation were rutting, in-place void monitoring, cracking, raveling and weathering. The following conclusions and observations are drawn from the evaluation:

- Rutting had low severity across all sections, including the control; all sections were considered to be performing well.
- In-place void monitoring showed that the consolidation, in the three-year time, is consistent with the rutting that is present.
- Generally all sections performed well, including the control, in terms of cracking. The cracking was not frequent and it was usually of low severity.
- The WMA and HMA sections performed similarly with regard to raveling and weathering. Both performed very well.
- Overall, the WMA sections performed comparably to the control sections, and all sections performed very well.

2.17 Bennert, T. "Evaluation of Warm Asphalt Technology." Publication FHWA-NJ-2011-005, New Jersey Department of Transportation, 2012.

This New Jersey Department of Transportation (NJDOT) 2012 report evaluated the production and performance of WMA technology. The evaluation, which was prefaced by a feasibility study, aimed to address the following concerns:

- Effect of moist aggregate during WMA production;
- Compactability characteristics of WMA;
- Rutting potential of WMA;
- Effect of WMA additives and technologies of PG Grade;
- Blending potential of RAP content and virgin binders under WMA production; and
- Evaluation of pilot projects produced and placed in the field.

This evaluation utilized laboratory testing in conjunction with field studies done through pilot projects. The combination of these two methods provided the NJDOT with the following conclusions:

- WMA was most beneficial when used as a compaction aid and to reduce emissions during production and placement of asphalt mixtures;
- WMA used reduced temperatures, which lead to incomplete drying of aggregate. This could lead to moisture damage/stripping issues. Additionally, the lower temperature might not stiffen/age the asphalt as much as the standard HMA does;
- When temperatures were reduced, the 80°F decrease dropped the PG of the binder by one grade;
- WMA had a reduced resistance to rutting, but an increased resistance to fatigue;
- A test based around the Marshall Compactor should be used to evaluate the workability of WMA; and
- When using RAP, the temperature must be higher to achieve good blending.

The report recommended that WMA as an implementable technology for the NJDOT to aid in compaction and reduce emissions during asphalt production and placement. It is also noted that until the field history of the WMA is proven, the rutting potential and moisture damage susceptibility should continue to be evaluated.

2.18 Estarkhri, C. "Laboratory and Field Performance Measurements to Support the Implementation of Warm Mix Asphalt in Texas." Publication FHWA/TX-12/5-5597-01-1. Texas Department of Transportation, July 2012.

This Texas Department of Transportation (TxDOT) 2012 report details the findings of laboratory and field performance measurements of a three-year WMA research study. The study's goal was to confirm that WMA had, at minimum, equivalent performance to HMA during the first three years of service. The WMA technologies that were evaluated included the following: Evotherm; Advera; Sasobit; Akzo Nobel Rediset; Maxam Aqua Black; and Astec Double Barrel Green. The field performance was measured from a total of 11 projects.

In addition to field performance, a laboratory evaluation was performed on several of the WMA technologies. The performance criteria measured compactability, rutting resistance, asphalt absorption, and crack resistance. The tests were performed at a range of temperatures and curing times to identify the relationship between the performance measures and the curing conditions and time. A general trend was found. WMA compacted as well or better than the HMA, but as the curing time increased the density decreased, especially in the lower temperature mixes. Additionally, mixes that were allowed to cool and then reheated later had similar density to those with a two-hour cure time. As WMA curing time increased, asphalt absorption increased. HMA generally had a higher percentage of asphalt absorbed. In terms of rut depth, curing time was a significant factor in the performance of the mixture. Initially, HMA performed better with regard to rut resistance, but as the cure time increased the difference in rut resistance became insignificant. Finally, the overlay test showed that the mix behavior was very dependent on oven curing time and temperature. There was a significant increase in the WMA crack resistance when the curing time was increased from two hours to four hours.

The field evaluation of the WMA projects included testing of cores for rut resistance and IDT strength; linear feet of cracking, and ride score measurements. In cores taken early in the pavement life, the rut resistance of the WMA was significantly less than HMA. As the time increased the rut resistance of WMA improved; it was similar to the HMA at the end of the full three years. A similar trend was observed in the Indirect Tensile Strength (IDT) results, as the

WMA aged, IDT values increased to the levels of the HMA. In terms of field cracking, the WMA mixes initially performed better than HMA. As time went by, the WMA and HMA performance became similar. Finally, ride score measurements showed that there was not a significant difference in the ride quality of HMA over WMA.

The researchers determined that the results support full-scale implementation of WMA. Additionally, the results supported the current curing time and temperature selection procedures of the TxDOT. Lastly, the researchers recommended additional testing on mixture types with different binders and aggregates to further support the curing time and temperature selection procedures.

2.19 Putnam, B. J., Xiao, F. "Investigation of Warm Mix Asphalt Technologies and Increased Percentages of Reclaimed Asphalt Pavement in Asphalt Mixtures." Publication FHWA-SC-12-05. South Carolina Department of Transportation, 2012.

This report, prepared for South Carolina Department of Transportation (SCDOT), investigates the effects of increased percentages of Reclaimed Asphalt Pavement (RAP) with regards to WMA technologies. The report was broken down into three sections: an investigation of WMA, an investigation of HMA with increased RAP percentages, and an investigation of WMA with increased RAP percentages.

The first portion of the report focused on WMA technology, specifically Evotherm and a foaming system. The experiments were conducted with two sources of binder and two sources of aggregate. The following tests were performed on the specimens; Viscosity, Dynamic Shear Rheometer, Bending beam Rheometer (Stiffness), RTFO (short-term aging of binders), PAV (long-term aging of binders). The tests showed that Evotherm had no significant effect on the binder performance and the optimal binder content for WMA was generally lower than HMA. The indirect tensile strength (ITS) was generally lower for WMA, but all specimens were above the minimum requirements. The researchers note here that the aggregate appeared to have a significant effect on the performance: one aggregate had the WMA out-performing the HMA but the opposite was true of the WMA with the other aggregate. Evotherm showed that the compactability across all test temperatures was consistently higher than the HMA, and as temperature increased, the foam became more compactable. The rutting performance of WMA was either similar to HMA or more susceptible to rutting than HMA depending on the aggregate source. Finally, stiffness was statistically the same as HMA with some variance based on the aggregate used.

The third portion of the report focused on the relationship between WMA technology and increasing percentages of RAP in the mix. The RAP percentages varied from 20-50%, increasing at 10% increments. In terms of stiffness, Evotherm lessens the stiffening effect of increasing RAP content. Creep stiffness was similar in that Evotherm reduced the stiffening effects of RAP, but this varied based on the binder source. HMA and WMA mix designs with RAP were very similar, but as the RAP increased the VMA decreased due to more fines being present in the RAP. There was no distinct effect of WMA technology on the indirect tensile strength of the mixtures made with RAP, but the aggregates had a large effect on this test. WMA with RAP may increase compactability but this is largely dependent on the stiffness of the RAP binder. Results from the rutting tests show that generally, as RAP is increased the rut depth decreases. Finally, the resilient modulus of WMA mixtures containing RAP increases as the RAP percentage is increased, similar to HMA.

2.20 Jones, D., and Tsai, B. "Warm-Mix Asphalt Study: First-Level Analysis of Phase 2b Laboratory Testing on Laboratory-Prepared Specimens." Publication CA152385A. California Department of Transportation, 2012.

This California Department of Transportation (Caltrans) report details the laboratory testing on laboratory-prepared WMA specimens. The objective of the testing was to evaluate the influence of WMA additives on the performance of the mix. The study assessed three WMA technologies: Advera WMA, Evotherm DAT, and Sasobit. The test results with an additional WMA additive, Rediset, were also included. The laboratory testing measured rutting performance, fatigue, moisture sensitivity, and durability. Observations and conclusions were drawn from the results of the laboratory testing include:

- Rutting
  - The HMA control had the highest resilient shear modulus at each temperature, with the Sasobit mix slightly lower. This measurement was closely related with the air void content.
  - The Permanent Shear Strain (PSS) at 5000 cycles provided similar results to the resilient shear modulus, with the control performing the best.
- Fatigue
  - After air voids were factored in, there was no statistical difference in initial stiffness or initial phase angle, but the control had the highest stiffness. All mixes, except Rediset, had a reduced stiffness after soaking.
  - Fatigue life at 50% stiffness reduction showed that the mixture performance was heavily dependent on air voids and binder content. The Sasobit had the shortest fatigue life. Soaking generally reduced fatigue life in all mixes.
- Flexural Frequency sweep testing
  - Air voids and binder content had a large influence on the performance of all mixes. All mixes showed signs of moisture damage.
- Moisture Sensitivity
  - The Hamburg Wheel-Track test results suggested that none of the mixes were considered moisture sensitive.
  - The Tensile Strength Retained (TSR) test results showed that no mixes met the 75% TSR specification. This suggested that all the mixes were moisture sensitive
- Durability
  - The average mass loss was slightly higher on the Evotherm, Advera, and Sasobit specimens. The difference between all the samples was considered acceptable.

The report compared the results of this phase of testing to the previous (phase 2A) phase of testing. The primary difference was the change in temperature-sensitivity (higher in Phase 2a) in terms of complex modulus values. Additionally, the TSR results for the control was significantly lower in Phase 2b. The results were comparable once the air-void content, binder content, and degree of aging were taken into consideration.

The final portion of this report stated that there is no evidence to suggest that WMA additives cannot be used in place of traditional HMA in dense- or open-graded mixes in California. It was recommended that moisture content in aggregate should be strictly controlled when using WMA additives, to prevent the chance of moisture damage.

2.21 Jones, D. "Warm-Mix Asphalt Study: Field Test Performance Evaluation." Publication CA13-2385D, California Department of Transportation, 2013.

In this report, prepared for the California Department of Transportation (Caltrans), a field test performance evaluation was performed on six WMA test sections and compared to HMA control sections. The objective of this project was to assess different WMA technologies implemented in open-graded friction course mixes and compare their performance to HMA sections under the same conditions over approximately a six-year period. The WMA technologies that were tested consisted of Advera WMA, Evotherm, Gencor Ultrafoam GX, Rediset, and Sasobit. Visual assessment and a photographic record of all test sections were used to evaluate the performance. The observed results were an increase in rutting in WMA test sections within the first twelve months, but at the end of the study both WMA and HMA test sections were similar in terms of rut depth. The report attributed this increase in early rutting to lower oxidation of the binder due to lower production and placement temperatures. In terms of raveling, stone loss, and permeability, the WMA sections performed in line with the HMA control sections, there was no significant difference.

The benefits of using WMA noted in the report were improved workability, better compaction (which can lead to improved durability and improved resistance to early-age raveling), the ability to use WMA with longer haul distances, and the ability to use WMA in colder placement temperatures.

2.22 Jones, D., Wu, R., Tsai, B., and Harvey, J. T. "Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3a HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #1)." Publication CA132221A. California Department of Transportation, 2013.

This California Department of Transportation (Caltrans) report details the HVS and laboratory testing, as well as forensic assessments, of rubberized asphalt produced with WMA technologies. The objective of this project was to evaluate the influence of WMA additives, (Cecabase, Evotherm DAT, and Gencor Ultrafoam GX) on the performance of rubberized asphalt. This performance was compared to a HMA control section by evaluation through HVS testing, laboratory testing, and a forensic investigation of the HVS test sections. The observations and conclusions include:

- HVS Testing: The HVS rut depth results are shown in the Table A10.
- Apart from rutting, no distresses were observed in any of the test sections.
- Based on the results, the three WMA additives tested would not have a significant impact on the rutting performance of the rubberized mix.

Table A10: Rut Depth Results from (Jones et al., 2013)

Test Section	Average Deformation (mm)	Load Repetitions to Reach 12.5 mm	Total Load Repetitions
Control (HMA)	6.4	46,000	74,000
Gencor	6.7	112,000	159,000
Evotherm	7.2	42,000	200,000
Cecabase	7.5	200,000	224,000

- Forensic Investigation
  - All sections showed rutting primarily in the top lift, with some evidence of rutting in the bottom lift.
  - All sections moisture content was rated as moist.
  - All sections showed some punching of the base into the subgrade.
  - The HMA section showed signs of segregation, and the Gencor section showed signs of bleeding in the wheel path and some visible voids.
  - No evidence of moisture damage was observed.
- Lab Testing
  - In terms of resilient shear modulus, cycles to 5% Permanent Shear Strain (PSS) test, and PSS at 5000 cycles test, there were no statistically significant differences in performance across the mixtures.
  - In the dry tests, initial stiffness was similar across all mixes, but in the wet test, the initial stiffness was reduced in each mix, with the Gencor mix having the greatest reduction.
  - Initial phase angle and fatigue life at 50% stiffness reduction were similar for all mixtures.
  - The shifted complex modulus curves of the WMA were less than the HMA, with the Gencor being the lowest.
  - In the Hamburg Wheel-Track test, the mix performances were similar with Gencor having slightly higher rutting.
  - Tensile Strength Retained (TSR) testing showed the HMA having slightly higher strengths but the dry strengths for all mixes were similar. The wet strengths had a higher variability.

2.23 Jones, D., Wu, R., Tsai, B., and Harvey, J. T. "Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3B HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #2)." Publication CA132221B. California Department of Transportation, 2013.

The California Department of Transportation (Caltrans) report by Jones et al. (2013) details the HVS testing, forensic evaluation, and laboratory testing of rubberized asphalt produced with WMA technologies. A previous study was conducted using the same methods with a different rubberized asphalt mix design. The objective of this project was to evaluate the influence of WMA additives (Advera WMA, Astec Double Barrel Green, Rediset WMX, and Sasobit) on the performance of rubberized asphalt. This performance, as compared to a HMA control section, was evaluated through HVS testing, laboratory testing and a forensic investigation of the HVS test sections. The observations and conclusions include the results of the HVS rut testing, shown in the Table A11.

Table A11: HVS Test Results for Rutting (Jones et al., 2013)

Test Section	Average maximum rut depth (mm)	Average deformation (mm)	Load Repetitions to reach 12.5 mm	Total Load Repetitions
Control Test 1 (HMA)	13.3	7.8	290,000	320,000
Sasobit Test 1	13.5	9.0	313,000	365,000
Advera Test 1	11.9	7.1	-	50,000
Astec	15.1	8.3	183,000	242,000
Rediset	13.5	7.8	240,000	309,000
Advera Test 2	25.0	12.0	7,500	73,500
Advera Test 3	18.0	8.0	-	5,000
Sasobit Test 2	11.5	-	-	85,000
Control Test 2	8.5	4.3	-	80,000

    - The Advera performed very poorly and a later forensic investigation attributed this performance to high subgrade moisture and the thin combined asphalt concrete layers.
    - Additional tests were performed for Sasobit and the HMA control to confirm the results of the previous tests. Results were similar.
    - No other distresses, besides rutting, were observed in any of the test sections.
- Forensic Investigation
    - The subgrade moisture content ranged from 15.6% to 19.2%, the higher moisture contents resulted in worse rutting performance.
    - Most of the rutting was confined to the upper lift of the asphalt concrete, with some rutting in the bottom lift, base and top of subgrade. The Advera was an exception with significant rutting in all layers and the subgrade.
    - No evidence of moisture damage was noted.
- Laboratory Testing
    - The WMA sections had slightly higher resilient shear moduli compared to the HMA, but it was not statistically significant.
    - The first day Advera and Control mixes performed poorly in the cycles to 5% Permanent Shear Strain (PSS) test, and the PSS at 5000 cycles test due to higher air voids, but all samples from day two performed similarly.
    - There were no statistically significant differences in performance in all fatigue tests for all specimens, but some loss of stiffness was attributed to moisture damage in all mixes.

- In the Hamburg Wheel-Track test, the Sasobit and Rediset performed better, the Advera performed similarly, and the Astec performed worse as compared to the HMA control.
- Lower moisture resistance was seen in Advera and Astec in the TSR test.

2.24 Farshidi, F., Jones, D., and Harvey, J. T. "Warm-Mix Asphalt Study: Evaluation of Rubberized Hot- and Warm-Mix Asphalt with Respect to Emissions." Publication CA142385B. California Department of Transportation, 2013.

This California Department of Transportation (CalTrans) report details an evaluation of the use of rubberized HMA and WMA mixtures on the level of emissions generated. The objective of this report was to compare the environmental impacts of conventional and rubberized HMA and WMA in terms of fugitive emissions during construction and paving. A methodology for collecting emissions in the field and an analytical method for characterization of emissions in the laboratory were designed and developed. In addition, the qualitative and quantitative characteristics of emissions were analyzed and the chemical structural effects associated with the different WMA technologies were investigated. The following observations and conclusions were made:

- There was a significant difference between emissions VOC concentrations in loose mix and in the road surface immediately after compaction.
- Most of the reactive organic gases were volatilized in the first hour after construction.
- The gaseous phase Polycyclic aromatic hydrocarbon (PAH) compounds in asphalt fumes were present at trace levels; the concentration varied depending on mixture temperature at the time of sampling.
- Particulate phase PAHs were below the detection limit of this study for all mixes.
- Depending on the mixture type and temperatures at the time of sampling, the total alkane emissions from the WMA were usually significantly lower than those measured in HMA.
- In some cases, specific WMA had higher alkane concentrations than the HMA. Therefore, any generalization that WMA reduces emissions would be inappropriate. Only specific WMA technologies should be compared against HMA.
- PAH concentrations correlated with initial mixture production temperature. Lower temperatures yielded lower PAH concentrations.

The report recommended that a laboratory procedure be developed to simulate asphalt fume generation over a wide range of temperatures in order to further understand emission kinetics. Additionally, the crumb rubber gradation, reaction time, and reaction temperature in rubberized asphalt binders, and the effect that WMA had on these in terms of performance and emissions properties, should be researched.

2.25 Zinke, S., Mahoney, J., and Morrison, K. "Connecticut Warm Mix Asphalt (WMA) Pilot Projects 2010 and 2011." Publication CT-2269-F-13-14. Connecticut Department of Transportation, 2014.

The Connecticut Department of Transportation (ConnDOT) utilized a wide variety of WMA technologies in multiple pilot projects to compare the performance and constructability of WMA with standard HMA. The technologies used included the following; Sasobit, Evotherm, Advera, SonneWarmix, and Astec Double-Barrel foamed asphalt. In addition, one test section had SBS polymer added, which significantly improved its performance in comparison to the sections without it. Some observed benefits of the WMA were reduction in emissions, reduction in visible smoking of the asphalt, and reduction of temperature.

With regards to construction and placing the WMA, there were two isolated issues with achieving adequate compaction of the WMA. The researchers believe that the cause in one instance was the addition of the SBS polymer in combination with Sasobit. The other compaction issue also occurred with Sasobit, without SBS polymer added, but was fixed by increasing temperature and changing to a different binder supply.

The following three tests were run on each mix: Tensile Strength Ratio test (TSR), Hamburg test, and Asphalt Pavement Analyzer test (APA). The researchers stated that the main concern with WMA is the rutting and permanent deformation, which is why these tests were selected. In the TSR test, two WMA specimens (Advera and Laboratory-Fabricated Mechanical Foaming) and two HMA specimens failed but there was no hypothesis as to why. Generally, the WMA performed similarly to the HMA, and both HMA and WMA benefitted greatly when SBS polymer was incorporated. In the Hamburg test only the specimens with SBS polymer, and one HMA specimen, completed the full 20,000 passes of the test. Generally, the WMA performed statistically similar to the HMA in terms of rut depth, with some samples performing slightly better than the HMA and others performing slightly worse. Signs of stripping were present in one HMA specimen. In the APA test the WMA specimens had on average higher rut depths than the HMA, although there were two outliers, a SonneWarmix pre-production trial mix and a plant fabricated specimen using Sasobit mix. The researchers believe that these outliers were not cause for concern because the production mix rut depth for SonneWarmix was in line with other WMA rut depths, and the Sasobit laboratory-fabricated specimens for the project registered a much lower rut depth. In summary, the WMA performed similarly to the HMA in all regards except a slight increase in rutting during the APA test.

The researchers recommended allowing substitution of WMA technologies in place of HMA, allowing the use of all three classifications of WMA technologies, and encouraging producers to lower their production temperatures but not at the cost of satisfactory density. The main concern from the researchers was rutting due to the lower production temperature reducing the hardening of asphalt during construction.

2.26 Anderson, K., Russell, M., Uhlmeyer, J., Weston, J., Roseburg, J., Moomaw, T., and DeVol, J. "Warm Mix Asphalt Final Report." Publication WA-RD 723.2. Washington State Department of Transportation, 2014.

This Washington State Department of Transportation (WSDOT) report details the differences in performance between HMA and WMA, made through the addition of Sasobit directly to the binder. One of the detriments of using WMA included a $6/ton increase in cost to produce the WMA; this was not all material cost, but partially due to the result of a change order being needed. In terms of implementing the pavement mixes, there were incidents where clumps of the mix would be stuck together in the WMA. The suspected cause of this was the excessive cooling of the mix during a long haul resulting in the temperature not being high enough to break up large chunks of RAP (RAP percentages were 20%). Another concern was that at temperatures below 216°F, the Sasobit material loses its ability to reduce binder viscosity, which results in the mix hardening. The solution proposed is to remix the WMA before applying it to the road.

In terms of performance comparisons, the study concluded that the HMA and WMA were relatively equal in performance. More specifically, the WMA was generally stiffer than the HMA (higher dynamic modulus), but in terms of rutting, stripping, and friction resistance as well as ride quality, the WMA was approximately the same as the HMA. In terms of reflective cracking, the WMA section showed higher percentages of low-severity longitudinal cracking return (9% for WMA vs. 3% for HMA), as well as higher percentages of low-severity transverse cracking return (100% for WMA vs. 41% for HMA). Fatigue cracking was not considered since fatigue cracking was not expected to appear within the 5-year study. The report also included the findings of the Washington State University study. These findings stated that the WMA section had lower resistance to fatigue cracking, but otherwise is equal in performance to the HMA section. It was noted that the actual field section did not show a difference in fatigue cracking; it was only shown through laboratory testing. In terms of the binder, the WMA binder had a lower complex shear modulus, lower resistance to fatigue, higher resistance to thermal cracking, and equal resistance to rutting compared to the HMA binder. It was also noted that the researchers thought the Sasobit may only delay the reflective cracking and not actually lower it compared to HMA. However, this was not shown in the short study period.

With regard to widespread implementation of WMA, WSDOT wants to assess the long-term performance, evaluate WMA technologies other than Sasobit, develop and refine specifications for WMA, investigate the use of higher percentages of RAP (greater than 20%), investigate the formation of clumps in WMA, and include provisions to allow substitution of WMA in place of HMA in future Standard Specifications. Lastly the report notes that the use of WMA has decreased greatly due to contractors using higher percentage of RAP (greater than 20%) in their mix designs. WSDOT General Special Provisions do not allow the use of WMA with RAP percentages greater than 20 or when any percentage of recycled asphalt shingled (RAS) is incorporated.

2.27 Farshidi, F., Jones, D., and Harvey, J. T. "Warm-Mix Asphalt Study: Evaluation of Hot and Warm Mix Asphalt with Respect to Binder Aging." Publication CA142385A. California Department of Transportation, 2014.

This California Department of Transportation (Caltrans) report details an evaluation of both HMA and WMA mixtures with respect to binder aging. This comparison was made to determine the effect that WMA additives may have on the long-term oxidative aging. The materials were sampled from two previous Caltrans construction projects. One project was a conventional mix design (Phase 1), and the other was a gap-graded rubberized asphalt (Phase 2). Each project had a control HMA section, a chemically foamed (CF) WMA, a chemical surfactant (CS) WMA additive, and an organic wax (OW) WMA additive. Additionally, the rubberized test section had a mechanically foamed (MF) WMA section. The conclusions and observations were drawn from laboratory testing of these samples include:

- Zero Shear Viscosityand Viscosity-Shear Susceptibility
    - Generally, the WMA additives did not influence results, but lower production temperatures did have some influence on the rutting performance. A better performance was seen in the OW sample. This was attributed to crystallization in the binder at in-service temperatures associated with the additive used.
    - Zero shear viscosity was found to be a good indicator of rutting performance that is seen in the field.
- Multiple Stress Creep Recovery
    - For Phase 1, the WMA additive combined with the reduced production temperature appeared to influence the rutting behavior with regards to non-recoverable compliance values. The OW binder had the best rutting resistance.
    - For Phase 2, the low production temperatures may have influenced rutting performance in the early stages of service.
- Dynamic Mechanical Analysis
    - For Phase 1, the lower production and placement temperatures did not appear to change the shear susceptibility of the binders after field aging.
    - For Phase 2 there was more variability in the results, but after 18 months of field aging, the results between the control and the WMA sections were similar.
- Oxidation Kinetics Analysis
    - For Phase 1, all binders showed that the complex viscosity increased and the phase angle decreased at an exponential rate as aging time increased.
    - For Phase 2, over time the mechanically foamed WMA had a higher phase angle and complex modulus compared to the other mixes.
    - Short-term oxidative aging analysis showed that laboratory simulation provided a reasonable indication of field performance.
    - Oxidative susceptibility aging rate tests showed the HMA and chemically foamed WMA had similar results with the OW more susceptible.
- Effects of Air Voids and Asphalt Film Thickness
    - Air voids did not appear to affect the short-term oxidative aging behavior of the binders.
    - Asphalt film thickness did not appear to influence the binder oxidative aging behavior.
- Effect of Base Asphalt Binder
    - The unmodified and modified binders, used in one of the mix designs in Phase 2, showed a lower range of phase angles compared to the other mix designs used. The addition of crumb rubber increased elastic behavior at given complex modulus values.
- Comparison of Binder Results with HVS and Hamburg Wheel-Track Test
    - The comparison of the tests done in this study to the previous tests had mixed levels of correlation. The results for mix design #1 in Phase 2 had a relatively strong correlation while the others did not.
- Thermal Cracking Properties
    - No thermal cracking was observed on any test sections, and all test values were within the specifications from Superpave.

The report recommended that NCHRP 9-52 report be reviewed and that the recommended changes to binder aging protocols be implemented, if appropriate. Additionally, the applicability of any recommendations to rubberized binder aging should be investigated.

2.28 Jones, D. "Warm-Mix Asphalt Study: Field Test Performance Evaluation." Publication CA142385D. California Department of Transportation, 2014.

This California Department of Transportation (Caltrans) report details the field test performance of WMA. The purpose of this report was to evaluate six WMA open-graded friction course (OGFC) test sections constructed in California between 2007 and 2010. These sections were located in Morro Bay, Point Area, Orland, Marysville, Mendocino, and Auburn. This monitoring consisted of a visual assessment with a photographic record; no physical measurements were taken. Observations, which were done every 6 months, include:

Morro Bay – Advera, Evotherm, Sasobit

- All sections started out with a rating of "good".
- In the first 48 months, no deterioration was observed compared to the baseline measurement.
- The final observation, after 73 months, showed no deterioration. There was minor stone loss consistent with the age of the surface. Permeability also remained effective on all sections.

Point Area – Evotherm

- At the beginning of monitoring, the Evotherm section was rated "good" with no stone loss noted.
- After 18 months, some longitudinal cracks were noted, this was attributed to slope movement of a hill section and not to the performance of the WMA.
- After 36 months, some additional longitudinal cracks were observed in the vicinity of a sharp curve along the road.
- The final observation, after 54 months, noted no new increase in cracking; the drainage through the OGFC was still effective.

Orland – Evotherm

- At the beginning of monitoring, the Evotherm section was rated "good" with no stone loss noted. The water was draining effectively through the OGFC.
- After 6 months, minor rutting (average between 0.08-inches and 0.10-inches), was measured in the wheelpaths of the truck lane of the Evotherm section, but not the control (HMA).
- After 12 months, the rutting was similar between the Evotherm and the control section, approximately 0.16-inches.
- The final observation, after 24 months, noted no addition rutting past the previous measurements. No other deterioration was noted.

Marysville - Evotherm

- At the beginning of monitoring, the Evotherm section was rated "good" with no stone loss noted. The water draining effectively through the OGFC.
- The final observation, after 24 months, showed no deterioration compared to the baseline. It was noted that the frequent and aggressive turning movements by large agricultural equipment is unlikely to negatively influence the WMA.

Mendocino – Advera, Gencor, Rediset

- All sections started with a rating of "good", with some evidence of compacted binder strings in the Advera sections. No early stone loss was observed.
- After 30 months, some minor raveling was observed on the Advera section. It was located a short section on the outside wheel path on a sharp bend.
- The final observation, after 42 months, noted no deterioration as compared to the baseline measurement. The minor raveling in the Advera section had not increased since the previous observation.

Auburn – Evotherm

- At the beginning of monitoring, the Evotherm section was rated "good". Some localized areas of segregation in the mix were observed, as well as some open longitudinal joints. No stone loss was noted. The water was draining effectively through the OGFC.
- The final observation, after 23 months, noted some transverse cracking and minor raveling in the outside wheel path. It was not clear if these distresses were related to the WMA. No other deterioration was noted.

All sections performed well. The performances of those with a control (HMA) section were considered equal. The report stated that based on these observations, the use of WMA in OGFC appears to be beneficial.

2.29 Jones, D., Farshidi, F., and Harvey, J. T. "Warm-Mix Asphalt Study: Summary Report on Rubberized Warm-Mix Asphalt Research." Publication CA142385C. California Department of Transportation, 2014.

This California Department of Transportation (Caltrans) report summarized the research conducted regarding Rubberized Warm-Mix Asphalt (RWMA). This summary included the following reports:

1. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3a HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #1). (UCPRC-RR-2011-02);
2. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3b HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #2). (UCPRC-RR-2011-03);
3. Warm-Mix Asphalt Study: Evaluation of Rubberized Hot- and Warm-Mix Asphalt with Respect to Binder Aging. (UCPRC-RR-2013-02);
4. Warm-Mix Asphalt Study: Evaluation of Rubberized Hot- and Warm-Mix Asphalt with Respect to Emissions. (UCPRC-RR-2013-03);
5. Warm-Mix Asphalt Study: Field Test Performance Evaluation. (UCPRC-TM-2013-08); and,
6. Warm-Mix Asphalt Study: Summary Report on Rubberized Warm-Mix Asphalt Research. (UCPRC-SR-2013-03)

The following conclusions and observations were included in the report:

- Heavy Vehicle Simulator Testing: RWMA-G
  - Minimal asphalt plant modifications were required to accommodate the WMA.
  - No problems were noted with producing the WMA mixes.

    - Curing had no influence on stability and no moisture was measured in the mixes after production.
    - The rutting performance varied across all tests in Phase 3A but the performance is attributed in part to the lower production and paving temperatures in some mixes.
    - The rutting performance was similar in all tests in Phase 3B.
- Laboratory Testing: RWMA-G Performance
    - The use of WMA technology did not significantly impact performance.
    - Mix temperature, binder content, air-void content, test temperatures, and stress and strain levels influenced performance.
- Laboratory Testing: Binder Aging
    - The use of WMA technology did not significantly impact performance, however the organic wax additive improved rutting resistance across all tests. Additionally, the additives had limited effect on aging kinetics.
    - Zero Shear Viscosity was a good indicator of rheological behavior of rutting performance of the asphalt binder.
    - The WMA technologies did not result in grade change regarding thermal cracking properties at low temperatures.
- Laboratory Testing: Emissions
    - The total Alkane emissions of WMA were significantly lower than those of HMA, depending on the temperature at the time of sampling.
    - Polycyclic Aromatic Hydrocarbon (PAH) concentrations correlated with initial mix production temperatures meaning that the WMA with the lowest temperature had the least PAH concentrations.
- Long-Term Field Performance
    - The WMA sections generally showed equal performance to the controls.
    - All sections performed well.

The report recommended the use of WMA in rubberized asphalt mixes. Moisture sensitivity should be closely monitored due to the lower production temperatures of WMA. Additionally, care must be used when selecting production temperatures for mixes to be placed on roads with heavy traffic in hot climates, as the lower oxidation from the lower production temperatures may lead to early rutting.

2.30 Graves, C. "Regional Implementation of Warm Mix Asphalt." Publication FHWA/LA.14/534. Louisiana Transportation Research Center, 2014.

This Southeast Transportation Consortium report quantifies the use of WMA technology in the Southeast region of the United States. The report consisted of a survey sent to 12 southeastern states as well as research to determine specification and policy changes in the subject states regarding WMA technology.

Performance evaluation was focused on four criteria: moisture susceptibility, rutting, cracking, and long term performance. The report aggregated conclusions from various research agencies and compared the results. When comparing WMA to HMA mixtures, it was reported that WMA mixtures frequently had higher or similar moisture susceptibility but this was dependent on aggregate properties. WMA had similar, occasionally greater, rutting; specifically, the WMA technology Sasobit (wax) had high rutting but resisted stripping well. WMA had higher resistance to reflective cracking but had similar performance to HMA with regards to non-reflective cracking. The report stated that the performance can be widely variable based on the materials used in WMA, therefore transferring, or extrapolating from one study to another is not recommended. It also recommended that WMA mix be designed individually using local aggregate and binders.

The survey results showed different states had different levels of implementation of WMA. All 12 states surveyed use WMA in some way, mainly in surfaces or bases and sub-bases. The most common WMA technologies used were foamed WMA or WMA containing chemical additives; organic additives (wax) were the least common. Table A12 presents the number of responses to each of the survey questions.

Table A12: Regional Implementation of WMA Survey Responses (Graves, 2014)

Questions	Number of States		
	Yes	No	No Response
Have you modified your standard specifications to allow WMA?	11	1	-
Is WMA permitted on an experimental basis?	8	2	2
Does your state have an approved list for allowing the different WMA technologies?	-	-	12
Does your state have an approved procedure for allowing the different WMA technologies?	9	2	1
Have you modified your mix design procedures to facilitate the use of WMA?	1	11	-
Has the use of WMA created more competition among bidders on projects due to the ability to haul mix further prior to placement?	3	8	1
Has WMA allowed you to extend the construction season in your state?	1	11	-
Have you increased in-place density on projects where WMA has been utilized?	2	9	1
Are any contractors using less compactive effort to achieve the same in-place density as HMA?	7	3	2
Have you observed any constructability differences among the different types of WMA technologies?	5	7	-
Has your agency modified their construction specifications to specifically address WMA?	8	3	1
Have you observed any performance differences between conventional HMA and WMA?	0	11	1
Are there particular distresses that seem more prevalent in WMA versus HMA pavements?	-	12	-
Are you currently monitoring any specific WMA sections for long-term performance?	10	2	-

Table A13 shows the state-by-state listing of the allowable RAS and RAP percentages, along with the oldest WMA projects that are in service.

Table A13: Survey Results on RAP, RAS and Oldest WMA Projects (Graves, 2014)

State by State responses			
States	Allowed RAP (%)	Allowed RAS (%)	Oldest WMA Project in Service (Years)
Alabama	35	5	8
Arkansas	30	3	5
Florida	-	-	7
Georgia	40	5	3
Kentucky	25	6	-
Louisiana	20	-	3.5
Mississippi	30	-	4
North Carolina	50	6	9
South Carolina	35	5	6
Tennessee	35	-	6
Virginia (Bases)	35	5	7
West Virginia	15	-	3

Generally, no states have observed performance differences between HMA and WMA. Some benefits and detriments of WMA were noted. Benefits were: less energy required during compaction, more consistent mixtures, and longer possible haul distances. Some detriments were: placement issues (associated with cold asphalt), workability issues, and contractors preferring HMA.

The report concludes that the use of WMA technology appears to be a viable alternative to HMA and will continue to increase in use.

2.31 Kim, Y. R., Lee, J., and Wang, Y. "MEPDG Inputs for Warm Mix Asphalts." Publication FHWA/NC/2012-01. North Carolina Department of Transportation, 2015.

This North Carolina Department of Transportation (NCDOT) report details the development of calibration factors for the use of WMA with AASHTOWare Pavement ME program (MEPDG). The objective of this research was to develop recommendations for the MEPDG software input parameters and local calibration factors for WMA mixtures commonly used by the NCDOT. Laboratory testing on the properties of WMA (Evotherm 3G and Double Barrel Green foaming technology) and HMA were performed to achieve this objective.

The laboratory testing consisted of dynamic modulus testing, rutting testing, and fatigue properties. The testing conclusions include:

- The WMA mixtures exhibited a similar stiffness, with both mixes being less stiff than the HMA.
- The WMA mixtures showed less resistance to rutting than the HMA.
- The foaming WMA mixture showed high levels of permanent deformation at high temperatures.
- The WMA mixtures showed less resistance to fatigue than the HMA.

Lab testing evaluated the same performance criteria at different levels of aging. The results observed from this testing include:

- The HMA, at every aging level, was stiffer than the WMA mixtures.
- As aging increased, the stiffness of the WMA mixtures increased significantly.
- The HMA, at every aging level, had the least permanent deformation.
- The resistance to rutting increased with aging, most significantly in the foamed WMA.
- Aging had a more significant effect on WMA than HMA regarding fatigue cracking.

The evaluation of moisture effects on the WMA mixtures stated:

- HMA exhibited higher stiffness with and without moisture conditioning as compared to the WMA mixtures.
- The testing suggests that the foamed WMA had a higher sensitivity to aging than the Evotherm WMA and the HMA.
- The Evotherm WMA was the least susceptible to moisture compared to the foamed WMA and the HMA.

The final portion of the report details the use of WMA within the Pavement ME program and the modifications to the input parameters based on laboratory test results. The conclusions include:

- Adjustments to predict fatigue cracking were not needed in the Pavement ME program inputs.
- Adjustments to predict rutting were not needed in the Pavement ME program inputs. It was valid and conservative to predict rutting depths of WMA mixtures using Pavement ME.
- Using the RTFO-conditioned virgin binder resulted in better accuracy for predictions of dynamic modulus increases for HMA and WMA mixtures.
- In fatigue life predictions in Pavement ME, a parameter input method, regarding material-specific parameters, was developed which allows the software to utilize material properties of NC local materials.
- The predicted fatigue life of WMA foam mixtures should be reduced by a factor of 1.088 based on a combination of software analysis and literature.

2.32 Bonaquist, R., and Ryan, J. "Specifications for Use of WMA Technology in Delivering HMA and Non-Conventional Mixtures." Publication No. 0092-12-02. Wisconsin Department of Transportation, 2015.

The Wisconsin Highway Research Program published a brief summarizing a Wisconsin Department of Transportation (WisDOT) project on the development of guidelines and specifications for use of WMA technology in delivering HMA products inclusive of non-conventional mixtures. The objective of this research was to develop specifications for asphalt concrete covering all types of mixtures included in the Wisconsin Standard Specification, Section 460. Four laboratory experiments addressing the following issues:

1. Potential minimum temperature limits for mixtures using recycled asphalt shingles (RAS);
2. Short-term conditioning for flow number and Asphalt Thermal Cracking Analyzer (ATCA) testing;

3. Development of repeatable coating test for mix design and quality control; and
4. Initial criteria limits for the Asphalt Thermal Cracking Analyzer test

The conclusions and observations that were found included:

- RAS binders properly mixed with new binders, but a minimum production temperature of 300°F for mixtures containing RAS was in the specifications.
- A two-step process could be used on WMA mixtures to simulate construction and early in-service aging. When this was applied to WMA, the rutting resistance ranged from 60% to 90% of HMA resistance, which is reasonable considering field performance.
- Equal coating was achieved during mixing but the quality of coating was influenced by viscosity. Additionally, a relationship was observed between coating quality and tensile strength ratio similar to that of AASHTO T283.
- Thermo-volumetric properties did not appear to be related to thermal cracking resistance.

Based on these experiments, two draft specifications were developed, one with performance testing and one without performance testing. The performance testing specification uses ATCA testing and the flow number to evaluate rutting resistance and thermal cracking resistance. The specification without performance testing uses binder replacement limits to ensure an adequate resistance to thermal cracking. A sampling and testing plan was created to validate these specifications through field validation projects. The conclusions and observations drawn from the results of the field validation tests include:

- Flow number and ATCA tests could be used to evaluate mixture performance.
- Volumetric properties of lab samples compared well with samples using field-produced mixtures. The correction factor for the water injection foaming process for STH 70 was 0.7%, which was approximately half of the allowable tolerance allowed by WisDOT.
- In some cases, there were significant differences between binder contents reported in the mix designs and the binder contents measured during production. Therefore the binder content of the recycled material used in production should be measured.
- Resistance to thermal cracking was reduced when using recycled materials.
- Moisture sensitivity testing should be included on production mixtures.

The report recommended that WisDOT investigate performance related tests, other than the ATCA tests, in order to reduce testing time and increase testing frequency. Additional validation work is needed before either specification could be considered for implementation. Lastly, a wider range of projects should be considered, specifically ones with high-recycled content mixtures at lower production temperatures.

2.33 Khosla, N. P., Tayebali, A. A., Ayyala, D., and Malladi, H. "An Evaluation of Warm Mix Asphalt Technology for NCDOT Mixes." Publication FHWA/NC/2011-04. North Carolina Department of Transportation, 2015.

This North Carolina Department of Transportation report evaluated three WMA technologies (Sasobit, Advera, and The Foamer) for use in NCDOT mixes. The report consisted of a literature review; a section detailing the research approach and methodology; and an evaluation of materials and job-mix formula. This was followed by laboratory testing and an economic analysis on the use of WMA.

The Laboratory testing consisted of the Tensile Strength Ratio (TSR) test, rut depth using APA testing, E* Stiffness Ratio (ESR) test, and the Dynamic Modulus test. The TSR test results concluded:

- Sasobit mixtures performed better than the HMA (87.7%) with TSR values of 97.2% and 101.8% with 0.75% and 1.5% anti-strip agent respectively.
- Although the Sasobit mixtures had higher TSR values, the median tensile strength values for the HMA was found to be higher, so the TSR may not accurately reflect the resistance to moisture damage.
- Advera mixtures did not meet the minimum TSR value (85%), with a TSR value of 55.6% and 63.7% with 0.75% and 1.5% anti-strip agent respectively.
- Foamed mixtures did not meet the minimum TSR value (85%), with a TSR value of 78.8% and 81.4% with 0.75% and 1.5% anti-strip agent respectively.
- Although Foamed mixtures did not meet the NCDOT required 85% minimum, they did pass the minimum Superpave requirement of 75%.

The rut depth was evaluated through APA testing with these conclusions:

- All mixtures were well below the 12.5mm specification, with the highest being the Foamer mixture with 6mm of rutting.
- The APA test results contradicted the TSR results that indicate low indirect tensile strength for Advera and Foamer mixtures.
- WMA mixtures provided equivalent or better rutting resistance to the HMA mixture.

The ESR test concluded:

- All mixtures, except for the Advera mixtures, exhibited an ESR greater than 90%.
- Contradictory to the TSR test results, the ESR results showed that the effect of moisture damage on stiffness was not as significant as expected.
- There was no significant difference between E* values between any two mixes, at any temperature or frequency.

The dynamic modulus test concluded:

- The HMA mixtures had the highest stiffness of all mixtures.
- Sasobit mixtures had similar, but lower, stiffness compared to the HMA mixture.
- Advera and Foamer mixtures had very similar stiffness to each other but the stiffness was significantly lower than the HMA mixtures.
- Using M-E PDG software the approximate time of failure based on rutting and fatigue cracking were obtained:
    - HMA – No rutting or fatigue failure within 20-year design life
    - Sasobit – No rutting or fatigue failure within 20-year design life
    - Advera – Rutting failure in 15 years, fatigue failure in 15 years
    - Foamer – Rutting failure in 12 years, fatigue failure in 16 years

The last portion of the report was an economic analysis of the use of WMA. Using the performance prediction results, a life cycle cost analysis of each of the different WMA mixtures was completed. The analysis showed that constructing surface courses with Sasobit provided the most economical alternative to HMA. The use of Advera and Foamer were found to be not economically beneficial as compared to HMA.

The report recommended further studies. The TSR and APA tests results contradict each other, and suggest that the TSR test may not accurately represent the moisture susceptibility of the WMA mixtures. This should be clarified by further research. Additionally, the Sasobit mixtures performed well; testing of the mixture should be repeated without anti-stripping additives.

2.34 Tayebali, A. A., Khosla, N. P., Malladi, H., Kusam, and A. "Impact of WMA Technologies on the Use of RAP Mixtures in North Carolina." Publication FHWA/NC/2013-05. North Carolina Department of Transportation, 2015.

This North Carolina Department of Transportation (NCDOT) report details the impact of WMA technologies on the use of Reclaimed Asphalt Pavement (RAP) mixtures in North Carolina. The objective of the report was to investigate and evaluate the workability, moisture susceptibility and material performance of WMA in virgin mixes, and mixes with 20% RAP and 40% RAP content. The WMA technologies that were evaluated were Evotherm 3G and PTI Foamer.

The workability of the mixtures was evaluated using %Gmm. Each test mixture contained 0%, 20%, or 40% RAP content and using standard HMA, Evotherm 3G, or PTI Foamer. The results of the gyratory testing showed that the WMA mixtures had similar performance to the HMA at all RAP content levels. Additionally, lowering the binder grade did not have a significant effect on workability of the WMA mixtures, but did increase the workability of the HMA mixture.

The moisture susceptibility was evaluated through the Tensile Strength Ratio (TSR). As with the previous testing, each mixture was evaluated with 0%, 20%, and 40% RAP content. The results of the TSR testing showed that as RAP content increases, the TSR values decrease, meaning the susceptibility to moisture damage increases. In the 0% and 40% RAP content mixes, the HMA performed best. For the 40% RAP content HMA mix, a lower binder grade was used. All specimens, except the 40% RAP mixture with PTI Foamer met the 85% minimum required of the NCDOT.

The material performance was evaluated through the E* stiffness ratio (ESR) and the dynamic modulus test. The results of the ESR testing showed that the ratio increased as RAP content increased. ESR may not be an appropriate test to measure moisture susceptibility as it measures the aggregate structure properties more so than the adhesive properties. Additionally, although the virgin mixtures of WMA are softer than HMA, the rap mixtures show a similar E*.

The report also noted the following:

- Evotherm 3G additives worked well as WMA technology.
- Evotherm 3G also acted as an anti-stripping agent and lowers the moisture susceptibility of virgin HMA mixtures.
- Lowering the binder grade was not necessary for WMA used with up to 40% RAP content.
- For higher RAP content mixtures, an anti-strip additive should be added, even when using Evotherm 3G.
- The initial cost of production for both WMA and RAP mixtures wass more economical than HMA.

2.35 Jones, D. "Warm-Mix Asphalt Study: Summary Report on Warm-Mix Asphalt Research in California." Publication CA152385B. California Department of Transportation, 2015.

This California Department of Transportation (Caltrans) report summarized the research conducted regarding Warm-Mix Asphalt (RWMA). The following reports were included:

1. Warm-Mix Asphalt Study: Workplan for Comparison of Conventional and Warm-Mix Asphalt Performance Using HVS and Laboratory Testing (UCPRC-WP-2007-01);
2. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 1 HVS and Laboratory Testing (UCPRC-RR-2008-11);
3. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 2 HVS and Laboratory Testing and Phase 1 and Phase 2 Forensic Assessments (UCPRC-RR-2009-02);
4. Warm-Mix Asphalt Study: First-Level Analysis of Phase 2b Laboratory Testing on Laboratory Prepared Specimens (UCPRC-RR-2012-07);
5. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3a HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #1) (UCPRC-RR-2011-02);
6. Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3b HVS and Laboratory Testing (Rubberized Asphalt, Mix Design #2) (UCPRC-RR-2011-03);
7. Warm-Mix Asphalt Study: Evaluation of Rubberized Hot- and Warm-Mix Asphalt with Respect to Binder Aging (UCPRC-RR-2013-02);
8. Warm-Mix Asphalt Study: Evaluation of Rubberized Hot- and Warm-Mix Asphalt with Respect to Emissions (UCPRC-RR-2013-03);
9. Warm-Mix Asphalt Study: Field Test Performance Evaluation (UCPRC-TM-2013-08);
10. Warm-Mix Asphalt Study: Summary Report on Rubberized Warm-Mix Asphalt Research (UCPRC-SR-2013-03); and,
11. Warm-Mix Asphalt Study: Summary Report on Warm-Mix Asphalt Research in California (UCPRC-SR-2014-02).

Conclusions and observations from the review of the reports were:

Heavy Vehicle Simulator Testing: Phase 1 – Rutting Performance

- No problems were noted with production, and only minimal plant modifications were required to accommodate WMA production.
- The Sasobit additive increased the binder grade from PG64-22 to PG70-22.
- The moisture content in WMA mixes was notably higher than the control.
- Shearing under the rollers, due to tenderness, was seen on the Evotherm and Sasobit sections.
- Rut depth was higher during the embedment phase for Evotherm and Advera

Heavy Vehicle Simulator Testing: Phase 2 – Moisture Sensitivity

- The embedment duration and rut depths for the WMA were approximately half of that of the control.
- Some differences in rutting behavior were noted based on which sections were in the shade, resulting in less oxidization, vs. exposed to the sun that resulted in faster aging.
- All rutting was confined to the upper layer and no moisture damage was noted in any sections, additionally, all sections had some top-down cracking.

Heavy Vehicle Simulator Testing: Phase 3 – Rutting Performance

- The paving crew noted improved working conditions, with less smoke and odors on the WMA compared to the HMA and a better workability.
- Compaction across the test track was consistent.

Laboratory Testing: Phase 1 and Phase 2

- All mixes were found to be potentially susceptible to moisture damage, but there was no difference in susceptibility between the HMA and WMA
- All mixes performed better when subjected to additional curing, indicating similar performance on in-service pavements after aging.

Laboratory Testing: Phase 3

- In Phase 3A, only shear performance was negatively influenced by the lower temperatures used with WMA. Rutting, fatigue, and moisture sensitivity were not affected.
- In Phase 3b, the water-based WMA technologies appeared to have lower moisture resistance.
- The laboratory performance in most tests was dependent on air-void content.

Laboratory Testing: Binder Aging

- The results did not appear to be influenced by WMA technology chemistry, but the organic wax additive showed better rutting performance. This was attributed to its crystallization wax structure.
- Results were influenced by lower placement and production temperatures, indicating susceptibility to early rutting.
- Zero Shear Viscosity was a good indicator of rheological behavior of rutting performance of the asphalt binder.
- The WMA technologies did not result in grade change regarding thermal cracking properties at low temperatures.
- The rolling thin-film oven test did not always correspond to field aging.

Laboratory Testing: Emissions

- Similar observations were made in a previous review.

Laboratory Testing: Long-Term Aging

- All sections performed well, with the control and the WMA sections performing equally.
- Some early rutting was seen in some WMA sections but after 12 months the rut depths were approximately the same as the control.
- The use of WMA in open-graded friction course mixes with polymer- and asphalt rubber binders appeared to be beneficial.

The report recommended the use of WMA technologies, especially on projects using asphalt rubber, or projects with long haul distance. Care should be taken to monitor moisture sensitivity due to the lower production and placement temperature of WMA. Additionally, selecting the appropriate production temperatures was important to account for the lower initial oxidation that is associated with lower temperatures.

2.36 Bennert, T., Pezeshki, D., Shearbafan, N., and Euler, C. "Warm-Mix Asphalt Trials in New York State: Laboratory and Field Performance." Publication TRR 2575. Transportation Research Board, 2016.

This Transportation Research Record article details the laboratory and field performance of WMA trials in New York State. In total, 14 WMA specimen sets were evaluated, across 11 projects, in terms of laboratory performance and field performance and compared to a control HMA specimen set. The following observations and results were drawn from the performance evaluations:

- Laboratory
  - In terms of rutting performance, in the Repeated Load Flow Number test, the HMA performed better on average, but the Asphalt Pavement Analyzer (APA) test showed that the WMA performed the same as the HMA on average.
  - In terms of fatigue cracking, on average the WMA had higher or equal fatigue cracking resistance compared to the HMA.
  - In terms of moisture-induced damage, on average the Tensile Strength Ratio (TSR) showed that the WMA and HMA performed similarly.
  - Overall, the performances were similar, with HMA having slightly higher resistance to rutting.
- Field – After 4 years of service
  - Visual surveys showed signs of rutting, transverse and longitudinal cracking, and some slight segregation. Additionally, the in-place air voids showed that the HMA generally had lower air voids while the WMA had significantly higher air voids in some sections, suggesting the WMA did not provide the compactability needed to reach proper air voids.
  - Extracted binder tests showed that, generally, WMA had a warmer low temperature grade.
  - Field cores showed that, in terms of the APA testing and fatigue cracking resistance testing, the HMA and WMA performed similarly. In terms of TSR testing, only one sample did not meet the 80% passing requirement.

2.37 "Accelerated Innovation Deployment (AID) Demonstration Project: Pine Mountain Road – Westwood Avenue Rehabilitation." Project Report. Dickinson County Road Commission, Michigan, 2016.

This Dickinson Country Road Commission report details the rehabilitation of Westwood Avenue using Hot-in-Place Recycling (HIPR) and WMA Ultra-Thin Asphalt Overlay. The project used recycle-in-place (RIP) for the base course and WMA for the surface course. The report summarized the construction process with a focus on the HIPR process and some minor notes about the WMA. The report noted the following:

- The contractor did not reduce the temperature of the WMA from the standard HMA temperatures.
- Local contractors are reluctant to reduce temperatures and instead, treat WMA only as a compaction aid.
- An estimated savings of 0.1-0.2 gallons of fuel/ton of asphalt was achieved from using WMA.
- The WMA permissive specification will be included in all local HMA projects, similar to what Michigan Department of Transportation (MDOT) had been doing for years.

2.38 Hanson, D. I., and Jeong, M. "Evaluation of Warm Mix Technologies for Use in Asphalt Rubber – Asphaltic Concrete Friction Courses (AR-ACFC)." Publication FHWA-AZ-16-631. Arizona Department of Transportation, 2016.

This Arizona Department of Transportation (ADOT) report details the evaluation of warm mix technologies for use in asphalt rubber-asphaltic concrete friction courses (AR-ACFC). This evaluation focused on three approved WMA additives, Evotherm, Sasobit, and Advera. The objective of this study was to determine if WMA technologies could be used for the production of AR-ACFC. Specifically, the study addressed concerns about the draindown of the binder during construction, the resistance of the mixture to raveling, and raveling caused by moisture damage.

The first portion of this study was a laboratory study, in which the WMA mixes were tested against a control. The WMA mixtures were separated into three categories: below recommended dosage of additive, recommended dosage, and above recommended dosage. The laboratory study consisted of binder testing (viscosity tests, penetration tests, and dynamic shear tests) as well as mix testing (draindown testing, durability testing, and moisture susceptibility testing). Testing showed:

- Higher dosages of Sasobit increased stiffness, but Evotherm and Advera had little to no effect on stiffness;
- The WMA additives had little effect on the viscosity of asphalt rubber;
- The WMA additives had no discernable effects on the draindown characteristics of the mixtures;
- The WMA additives, at target dosage, had no negative impact on durability of the mixtures, but below-target dosage Evotherm, and above-target dosage Sasobit negatively affect durability; and,
- For moisture susceptibility the above-target dosage Sasobit mix was the only mixture with superior performance to the control.

Additionally, the laboratory testing included a test to determine if different binder grades could produce a foamed asphalt that meets industry specifications. No definite conclusions could be drawn from the data and further evaluation is required.

The second portion of this study was the field study. This consisted of a construction summary, performance testing, and a surface smoothness evaluation. The construction procedure began with a higher temperature and reduced the temperature incrementally until clumping occurred. Clumping occurred in the Sasobit and the Advera mixtures, with a mat temperature of 236°F and 257°F respectively. The Evotherm test section did not experience clumping with the low mat temperature being 263°F. The performance testing consisted of moisture susceptibility and durability. The moisture susceptibility tests showed that Advera was more susceptible to moisture damage, while Evotherm and Sasobit performed statistically the same as the control mix. In terms of durability, the Evotherm had lower durability than the control, but the Advera and Sasobit mixtures performed similarly to the control. Finally, the surface smoothness showed that the Evotherm section had a similar IRI to the control; the Advera section was significantly smoother, and the Sasobit section was significantly rougher. Some conclusions from the report included:

- The use of Sasobit would increase the stiffness of the asphalt rubber binder;
- The use of Evotherm would have no effects on the properties of the asphalt rubber binder; and

- When the additives included in this study were used at the manufacturer's suggested dosage rate, no detrimental effects were noted on the performance of an AR-ACFC.

2.39 Christensen, K. "Experimental Features Project Construction Report - Evaluation of Warm Mix Asphalt Pavement." Project MT 10-02. Montana Department of Transportation, 2017.

This Montana Department of Transportation (MDT) report details the findings from an experimental project using three WMA additives. The objective of this project was to determine the effectiveness of the WMA compared to MDT's standard HMA surfacing. The project consisted of 17.1 miles with four approximately equal length sections on Interstate I-15. These sections consisted of three WMA sections, using Evotherm, Sasobit, and foaming, as well as one HMA section as a control. The report detailed the construction phase as well as performance monitoring for a period of five years.

The construction phase was divided into each respective test section using Sasobit, Evotherm, foaming, and HMA. Observations were made during the construction of the test sections include:

- Sasobit
  - Was produced at an average plant discharge temperature of 285°F
  - Showed an excessive mat rollout to 15 feet instead of the normal 12 feet
  - Test section displayed some cracking at the beginning
  - Both observed problems were attributed to a higher plant mix temperature.
- Evotherm
  - Was produced at an average plant discharge temperature of 274°F
  - Paving started well and continued to go well throughout the test section
  - Compacted well and density tests were on target
  - Contractor was able to begin finish rolling sooner than expected
- Foaming
  - Was produced at an average plant discharge temperature of 285°F
  - Contractors noted it was the easiest to work with and worked well

Outside of the Sasobit problems at start-up, there were no issues during paving operations. In 2012 an update was added to address the reflective cracking in the HMA and WMA sections. A seal coat was applied and crack sealing was performed to address this issue.

The next portion of the report was the evaluation of the pavement by year. The following observations were made during the field inspections:

- 2013 – No visible difference between HMA and WMA, some reflective cracking present and cover material from sealing was missing
- 2014 - No visible difference between HMA and WMA, some reflective cracking present and cover material from sealing was missing
- 2015 - No visible difference between HMA and WMA, some reflective cracking present and cover material from sealing was missing
- 2016 - No visible difference between HMA and WMA, some reflective cracking present and cover material from sealing was missing, a bridge construction project was in progress in the southbound lane near the beginning of a WMA section

The report concluded that, based on this project, it is not possible to determine any performance difference between WMA and HMA. All sections, HMA and WMA, displayed reflective cracking and missing cover material. Additionally, based on performance results, the department decided to stop evaluation of this project.

2.40 Mohammad, L. N., Raghavendra, A., Medeiros, M., Hassan, M., King, W. "Evaluation of Warm Mix Asphalt Technology in Flexible Pavements." Publication FHWA/LA.15/553. Louisiana Department of Transportation and Development, 2017.

The Louisiana Department of Transportation and Development (LA DOTD) published a report in 2017 which detailed the evaluation of the use of various WMA technologies in flexible pavements. More specifically, the evaluation had the following two main objectives;

1. Evaluate the performance of WMA compared to conventional HMA through laboratory testing of plant-produced lab-compacted samples, and
2. Evaluate the environmental impacts of WMA compared to HMA.

Sample mixtures were taken from six projects throughout Louisiana which utilized different WMA technologies, providing a total of 20 mixtures (including the HMA control). The technologies used in this study were chemical (Evotherm, Sasobit, and Rediset) and foaming (Astec Double Barrel Green, and Accu-shear), each with varying percentages of Recycled Asphalt Pavement (RAP).

The first portion of the study compared laboratory measures between the WMA and HMA mixtures. This was done through seven testing procedures, with a focus on rutting, fatigue/fracture cracking, and moisture susceptibility. These performance measures were evaluated through the following tests/measures; Flow Number, Loaded Wheel Tracking Test (LWT), Indirect Tensile Strength (ITS), Dissipated Creep Strain Energy (DCSE), Semi-Circular Bend (SCB), Dynamic Modulus, and Modified Lottman test. The results were compared within the six groups, corresponding to the projects, and normalized for an overall comparison across all groups. The following conclusions were drawn regarding the laboratory testing;

- Dynamic modulus master curves for WMA showed comparable or better performance at all frequencies and temperatures.
- WMA performed similarly to HMA in LWT testing, indicating similar rutting performance.
- Flow number tests showed similar performance between WMA and HMA. It is noted that foamed WMA with higher RAP content performed better than the HMA control.
- SCB results showed similar performance between WMA and HMA, with some of each of the mixtures not meeting the specifications.
- ITS testing showed WMA has similar or better performance compared to the HMA, this is true of aged and unaged samples. Additionally, it is noted that WMA had similar or higher toughness index values.
- DCSE testing showed similar performance between WMA and HMA.

The next portion of the study was a brief comparison of production and placement practices between HMA and WMA. This section aimed to measure the following; moisture content, asphalt absorption, temperature uniformity of the mat, rate of densification and final density. The following conclusions were drawn from the data;

- The WMA generally had higher moisture content, but it was still below the 0.3% specification limit.
- WMA required less passes with the rollers to achieve the desired density compared to HMA.

The final portion of the study was an environmental evaluation of WMA compared to HMA, including a life-cycle assessment (LCA). This evaluation focuses on CO and CO_2 emissions measured during production and placement. Additionally, the LCA focuses on environmental impacts including; global warming, air pollutants, fossil fuel depletion, and smog formation. The following conclusions were drawn from the evaluation;

- Foamed WMA significantly reduced the CO emissions. The Sasobit technology also reduced CO emissions, but to a less significant extent.
- The use of foaming and chemical additives, regarding CO_2 emissions, reduced the amount of air pollutants observed.
- The other criteria were similar between HMA and WMA.

The report recommends that a permissive specification for WMA processes be developed and included in the DOTD Standard Specification for Roads and Bridges. It is also recommended that a mixture be considered WMA if the maximum plant temperature does not exceed 300ºF, and the minimum placement temperature is 250ºF. Lastly, a reduction of these temperatures may be considered when using an approved chemical additive.

3. REPORTS FROM THE U.S. ARMY CORPS OF ENGINEERS

This section summarizes several laboratory and field projects that the U.S. Army Corps of Engineers have conducted to evaluate WMA. In the laboratory, WMA was observed to have better workability but increased susceptibility to moisture and higher rutting than HMA. Production for airfield pavements showed better workability in the field with WMA, similar moisture contents during production and no differences in volumetric properties between WMA and HMA. Initially, more rutting was observed with the WMA materials but the performance was rated as good or better than HMA after some field curing time.

These studies identify gaps in documented long-term performance of WMA mixtures and evaluation of cracking properties of WMA mixtures.

3.1 Mejias-Santiago, M., Doyle, J., Brown, E., and Howard, I. "Evaluation of Warm-Mix Asphalt Technologies for Use on Airfield Pavements." Publication ERDC/GSL TR-12-3. United States Army Corps of Engineers, February 2012.

This United States Army Corps of Engineers report is an evaluation of WMA technologies for use on airfield pavements. The purpose of this report was to evaluate and assess the different WMA technologies available and their applicability for used in airfield pavements. The three technologies tested were Evotherm™ 3G; Sasobit®; and, foamed asphalt. A HMA control section was used to compare the results. Each technology was performance tested in five categories: permanent deformation, durability, non-load associated cracking (thermal cracking), moisture susceptibility, and workability.

The results of the testing led the researchers to a variety of conclusions. The results of the permanent deformation testing showed that an increase in RAP content in the WMA and HMA mixes improved rut resistance due to the increase in binder stiffness. In the durability testing, it was observed that there was no statistical difference between the HMA and WMA mixes, but increases in RAP content led to an increase in mass loss (decreased durability). The results of the thermal cracking testing show that increasing RAP content increases the susceptibility to thermal cracking, but without RAP, thermal cracking is not a concern for WMA. Regarding moisture susceptibility, WMA mixes are generally susceptible to water damage, but increasing the RAP content significantly reduces the susceptibility. Finally, the workability testing showed that WMA is potentially more workable than HMA based on laboratory testing, but the researchers caution that the ability to achieve the desired density during construction is still unknown.

Based on these results, the recommendation of the researchers is that the use of WMA for airfield asphalt pavements is acceptable. They recommend at least one project with WMA technology be constructed per year within each Air Force Command, and the data be collected to characterize these technologies and performance under aircraft loading. It is also recommended that more research should be conducted to further evaluate WMA for airfields, including both laboratory and construction tests.

3.2 Mejias-Santiago, M., Doyle, J., and Rushing, J. "Comparing Production and Placement of Warm-Mix Asphalt to Traditional Hot-Mix Asphalt for Constructing Airfield Pavements." Publication ERDC/GSL TR-13-35. United States Army Corps of Engineers, August 2013.

This United States Army Corps of Engineers report compared the production and placement of WMA technologies to HMA mixtures for constructing airfield pavements. The purpose of the report was to present observations made during construction of full-scale test sections of WMA, as well as comparing the procedures for production and construction of WMA to those of HMA. The data collected to quantify the production and construction details were: temperature, moisture content, time from production to laydown, and special equipment required. Four test sections were created, one HMA section and three WMA sections (Sasobit, Foamed Asphalt, and Evotherm).

The test sections being constructed consisted of a 4-in.-thick asphalt concrete surface layer placed on top of a 10-in.-thick crushed limestone base, a 12-in.-thick clay-gravel sub-base, and 24-in.-thick high-plasticity clay subgrade, over an existing silt foundation. The procedures for placing and compacting the WMA were the same as for the HMA, but the WMA additives provided additional workability. In terms of compactability, the WMA and HMA were similar; the exception to this was the foamed asphalt being slightly more difficult to compact due to the lower temperature.

The production side of the WMA mixes was similar to those of the HMA mix. All moisture contents of the asphalt mixtures were below the 0.5% maximum. Except for the foam, which was slightly higher than average, the WMA and HMA has similar moisture content. Even when rain preceded construction, the WMA additives did not cause excessive moisture to be retained in the mixture. In general, the WMA did not cause any difference in measured volumetric properties compared to the HMA.

The researchers recommend further evaluation of full-scale production and placement of WMA. It was noted that nothing found in this study would preclude the use of WMA for airfield pavements. Finally, the researchers noted that with only a few modifications to construction specifications WMA would be allowed to be used in place of HMA.

3.3 Mejias-Santiago, M., Doyle, J., Rushing, J., McCaffrey, T., Warnock, L., and Taylor, M. "Laboratory Performance Testing of Warm-Mix Asphalt Technologies for Airfield Pavements." Publication ERDC/GSL TR-13-41. United States Army Corps of Engineers. December 2013.

This United States Army Corps of Engineers report detailed the laboratory performance of WMA technologies for airfield pavements. The laboratory testing addressed the susceptibility of WMA to permanent deformation and moisture damage compared to HMA produced using the same aggregate blend. Additionally, durability and cracking resistance were assessed through binder testing only. Previous research had concluded that WMA will perform similarly or better than HMA. The study evaluated the three main categories of WMA technology, specifically: chemical additives; organic waxes; and, foaming agents or processes. The testing was divided into two phases. Phase One consisted of 11 technologies and an HMA control investigated in the laboratory. In Phase Two, three of those 11 were chosen based on performance to be produced and tested at full-scale.

The results of the binder testing show that the low temperature binder performance was similar to HMA or slightly reduced when using WMA, but the high temperature binder performance was not significantly affected. The tensile strength ratio test (TSR) shows that for all laboratory produced samples, WMA samples performed significantly worse than HMA samples, specifically in the wet tensile strength category. It is noted that for the reheated plant-produced samples, the WMA performed similarly to HMA in the TSR testing. The overall results of the moisture testing show that WMA has a potentially increased susceptibility to moisture damage compared to HMA. However, the research suggests that adequate testing during mix design with the addition of anti-strip additives, if necessary, will reduce the moisture susceptibility to acceptable levels. In terms of rutting, the performance of WMA samples generally was worse than HMA samples. This was consistent across all WMA technologies and rutting tests. In terms of mixture stiffness, the plant-produced WMA mixtures generally had similar rutting performance and stiffness to that of HMA. The researchers note that overall, initially the field-compacted WMA mixtures had worse rutting performance but suggest that the WMA will match or exceed the performance of HMA after a reasonably short curing period. In general, the reheating of plant-produced mixtures improved the results of rutting tests and moisture susceptibility. This is due to the increased binder aging provided by the reheating process.

The recommendations based on the results of this study are that WMA is a suitable alternative to HMA for wearing surfaces on airfields. That recommendation's caveat is that it is based on limited laboratory test data. Further traffic testing is recommended to validate rutting performance of WMA compared to HMA. It is also recommended to investigate the use of anti-strip agents with WMA to test their effects on moisture susceptibility. Additionally, a long-term performance test section should be constructed on an active airfield to compare relative performance between HMA and WMA. Lastly, the researchers recommend investigating the performance of WMA regarding environmental cracking and long-term durability to determine benefits compared to HMA.

3.4 Mejias-Santiago, M., Doyle, J., and Rushing, J. “”Full-Scale Accelerated Pavement Testing of Warm-Mix Asphalt (WMA) for Airfield Pavements.” Publication ERDC/GSL TR-14-3. United States Army Corps of Engineers, January 2014.

This United States Army Corps of Engineers report details the results from a full-scale accelerated pavement testing of WMA mixtures designed for airfield pavements. In addition, surface grooving on WMA compared to conventional HMA is evaluated. The evaluation was done on three WMA test sections, using Sasobit, Foamed Asphalt, and Evotherm, along with one HMA control section using a HVS (HVS-A) to recreate the traffic loading of an F-15E aircraft. The failure criterion was defined at 1 inch of permanent deformation. Collected data were: temperature, permanent deformation, asphalt strains, pavement stiffness, and soil stresses and deflections.

The main objective of this research was to assess the failure of the asphalt layer in order to compare the field rutting performance of the three WMA technologies to the HMA control. Therefore, worst-case loading and high pavement temperature conditions were applied to induce failure in the asphalt layer. The results of the simulated traffic evaluated performance the four test sections in the following order (best to worst): 1. Foamed Asphalt; 2. HMA; 3. Sasobit; and, 4. Evotherm. The report notes that the suspected reason Foamed Asphalt performed so well was due to the lower average pavement temperature during testing. It suggests that if the temperature had been closer to that of the HMA, the foamed asphalt would have been less stiff and had higher deformations. With that caveat, the WMA mixtures had slightly lower resistance to rutting compared to the HMA mixture. Additionally, the report notes that the WMA sections were tested before the HMA section; additional in-place curing time may have played a role in the performance of the HMA.

As noted in previous studies, WMA initially has greater propensity for rutting, but allowing the pavement to cure adequately can alleviate the problem. Lastly, the report suggests that if a more rut resistant aggregate gradation or a polymer-modified binder were used, the tenderness from using WMA would be less of a concern. In terms of the grooving evaluation, the WMA and HMA performed similarly. The report suggests that given proper curing time before grooving, the WMA should not exhibit groove closure during normal traffic, unless there are other mixture issues contributing to the problem.

The combination of the falling weight deflectometer (FWD) testing and the forensic evaluation confirmed that the deformations were limited to the asphalt layer only. This further reinforces the validity of the testing, ensuring that the results only reflect the performance of the WMA mixtures and not the pavement structure.

The report recommends that WMA is a viable alternative to HMA for wearing surfaces on airfields. In addition to this, it recommends long-term performance should be documented through trial sections placed on active military airfields, comparing both HMA and WMA sections using the same source material.

4. FEDERAL HIGHWAY ADMINISTRATION RESEARCH AND TECHNOLOGY: LONG-TERM PAVEMENT PERFORMANCE, SPECIFIC PAVEMENT STUDIES

The following documents provide a summary of the experimental design plans, selection of candidate projects, construction documentation, sampling and testing, and performance monitoring requirements for the LTPP SPS-10 WMA Overlay of Asphalt Pavement Study. These documents provide insight on the parameters that are important for the evaluation of WMA.

4.1 Appendix A "Specific Pavement Studies Experimental Design and Research Plan Experiment SPS-10 Warm Mix Asphalt Overlay of Asphalt Pavement Study." United States Department of Transportation, Federal Highway Administration, 2014.

This United States Department of Transportation, Federal Highway Administration (FHWA) report documents the research plan and experimental design for Specific Pavement Studies – 10 (SPS-10) experiment for the Long Term Pavement Performance (LTPP) program. The goals of the experiment were to gather information regarding short- and long-term performance of WMA compared to HMA. This report details the specific conditions that must be met for an experimental design to be admitted into the LTPP database. All experimental conditions must be met and are presented in a bulleted list below:

- Each project location must contain a minimum of three test sections (core test sections) each 500 feet in length constructed continuously along a section of highway.
  - One HMA section
  - One WMA section using a Foaming Process
  - One WMA section using a Chemical Additive
- The only variation in core test sections is the WMA Technology (all other factors are constant).
- The experiment will only include new Asphalt Concrete (AC) overlays, between two- and four-inches, over flexible pavements (HMA).
- The pavement thickness as well as depth of milling, or other surface preparation, should remain constant across all test sections.
- Existing pavement condition should be consistent across all test sections.
- Tack coats are required prior to placement of all WMA and HMA lifts constructed.
- Mix design must be developed by the Highway Agency in accordance with standard practice, and must be identical to the mix design of the HMA control.
- Binder used in the mixture must be selected using the Highway Agency's normal practice, and the source, grade, and modification of the binder must be consistent across all test sections.
- Aggregate type, source, and gradation must be consistent across all core test sections.
- The test section layout must include one 100-ft sampling area followed by a 50-ft buffer area before the test section followed by a 50-ft buffer area and 100-ft sampling area.

- Between each test section, including sampling and buffer areas, a minimum of 800-ft of transition zone must be provided.
- Constant densities should be a goal across all test sections, and the same compaction equipment should be used for all sections.

The goal of all the above criteria is to provide data that will allow the direct comparison of WMA to HMA while keeping the other variables constant.

4.2 Appendix B – "Specific Pavement Studies Nomination Guidelines Experiment SPS-10 Warm Mix Asphalt Overlay of Asphalt Pavement Study." United States Department of Transportation, Federal Highway Administration, 2014.

This FHWA report provides guidelines and information for nominating candidate projects for the Specific Pavement Studies experiment 10 (SPS-10) WMA study. This report explains the project nomination process and forms, as well as the details of the experimental design and study factors. The report outlines the required activities:

1. Construct the test sections as described in the experimental design document.
2. Provide traffic information; continuous data is preferred but not required. A minimum of two continuous weeks four times per year is required.
3. Perform and/or provide for drilling, coring and sampling of in-place pavement materials used in test sections, at the expense of the participating agency. LTPP Regional Support Contractor (RSC) staff will be on site to perform sample logging and sample shipment.
4. Prepare plans, specifications, quantities, and all other documents necessary as part of the participating agency's contracting procedure. In addition, the agency must provide construction control, inspection and management as is required by their standard quality control and assurance procedures.
5. Provide periodic traffic control for on-site data collection activities.
6. Coordinate maintenance activities on the test section.
7. Notify FHWA LTPP RSC prior to the application of overlays or other such treatments when any of the test sections reach an unsafe condition or become a candidate for rehabilitation.
8. Provide and maintain signing and marking of test sites.

The report details the project selection criteria; this is a review of the information provided in experimental design document. In summary, the project reported that it should minimize the differences and variables across test sections to identify the relative performance of the WMA sections to the HMA section. It is noted that projects containing all desirable qualities are not readily available and each candidate site will be individually evaluated to determine the usefulness to the experiment. Finally, the document provides nomination forms and instructions that include forms detailing:

- General Project Information;
- Pavement Design Information, Resurfacing;
- Mix Information;

- Test Section Layout;
- Traffic Data Collection Guidelines; and,
- Material Type Classification Code Tables.

4.3 Appendix C – "Specific Pavement Studies Materials Sampling and Testing Requirements Experiment SPS-10 Warm Mix Asphalt Overlay of Asphalt Pavement Study." United States Department of Transportation, Federal Highway Administration, 2014.

This FHWA report documents the guidelines for the development and implementation of a materials sampling and testing program for Specific Pavement Studies– 10 (SPS-10) experiment for the Long Term Pavement Performance (LTPP) program. The report provides a detailed description of all sampling and testing procedures to be used for SPS-10, including the material sampling and testing requirements, field material sampling, and laboratory material sampling. The document provides the following general procedure for materials sampling and testing:

1. Review project site layout and soil profile logs. Identify any variations in the subgrade material, embankments, or other materials related to pavement features.
2. Formulate a field materials sampling and test plan that accounts for site conditions and laboratory material testing requirements, assuring an adequate number of samples for laboratory material characterization tests to be performed need to collected, as well as to providing additional samples for storage in the Materials Reference Library (MRL).
3. Develop and submit a field sampling plan report to the FHWA for review prior to implementation specifying sampling area locations, type and number of material samples from each location, and include a tracking table that specifies all tests and testing sequence to be performed on each sample.
4. Conduct field sampling and testing of materials, in accordance with LTPP test protocols and report on standard LTPP data forms. Any adjustments to the sampling and testing plan made in the field must be recorded and a modified sampling and testing report produced and entered into the Materials Tracking System (MTS).
5. Conduct laboratory testing of material samples, in accordance with LTPP test protocols and report on standard LTPP data forms.
6. Compile and store data, including field sampling, field testing, and laboratory material test data. All data must be entered into the Pavement Performance Database (PPDB).

The specific procedures/protocols of each of these general steps can be found in more detail throughout the document. The report states that guidelines are provided to protect the integrity of the material samples as much as possible, as these materials are important to the success of the LTPP program. Cooperation from all participants is needed to ensure that specimens are shipped between entities with minimal damage.

4.4 Appendix G - "Specific Pavement Studies SPS-10 Performance Monitoring Guide Experiment SPS-10 Warm Mix Asphalt Overlay of Asphalt Pavement Study". United States Department of Transportation, Federal Highway Administration, 2014.

This FHWA publication documents the guidelines for the development and implementation of a monitoring program for Specific Pavement Studies – 10 (SPS-10) experiment test sections. The report provides guidelines for the performance monitoring on the test sections. These sections can be divided into three time frames; pre-overlay monitoring, short-term performance monitoring, and long-term performance monitoring. The document briefly reviews the SPS-10 experiment and objectives, noting that a key component to achieve these objectives is developing and executing a performance monitoring plan capable of tracking and collecting long-term data of WMA.

Pre-overlay monitoring includes the following testing: manual distress surveys, Falling Weight Deflectometer (FWD) testing, transverse and longitudinal profiles, and texture measurements. These tests are to be performed in accordance to the Long Term Pavement Performance (LTPP) standards, and should be performed approximately six months prior to the overlay and again six months after the overlay. It is noted that these time frames may need to be shifted to account for late season paving.

Short-term performance monitoring includes the following testing: manual distress surveys, FWD testing, transverse and longitudinal profiles, and texture measurements. The testing would occur within the following time periods; zero months (within 30 days), between three and six months, 12 months (± 30 days), and 18 months (± 30 days). The report states that the increased testing frequency will capture early rutting concerns and moisture susceptibility issues.

Long-term performance monitoring includes the following testing: deflection measurements, surface distress evaluations, transverse and longitudinal profile, and texture measurements. Table A14 summarizes the LTPP performance monitoring intervals (FHWA 2014).

The report states that these guidelines are to be used in all SPS-10 experiments for LTPP, unless otherwise noted in the current LTPP Directives. It is also noted that it is in the interest of the LTPP that cored sections receive priority in terms of performance monitoring.

Table A14: Information on LTPP SPS-10 Site Performance Monitoring (LTPP Appendix G, 2014)

Performance Measure	LTPP Experiment	Desired Level	Maximum Allowable Interval Period
Longitudinal Profile/Texture	GPS-1, 2,3	Annual	Every 3 years
	SPS-1, 2,10	***Annual***	***Every 2 years***
	SPS-8	Annual	Every 3 years
	Others	Annual	Every 3 years
Distress/ Transverse Profile	GPS-1, 2,3	Annual	Every 4 years
	SPS-1, 2,10	***Annual***	***Every 2 years***
	SPS-8	Annual	Every 3 years
	Others	Every 2 years	Every 4 years
FWD	GPS-1, 2,3	Every 3 years	Every 5 years
	SPS-1, 2,10	***Every 3 years***	***Every 5 years***
	SPS-8	Every 3 years	Every 5 years
	Others	Every 3 years	Every 5 years

4.5 Appendix H – "Specific Pavement Studies SPS-10 Construction Documentation Guide Experiment SPS-10 Warm Mix Asphalt Overlay of Asphalt Pavement Study." United States Department of Transportation, Federal Highway Administration, 2014.

This FHWA report documents the guidelines and information for documenting construction activities for the Specific Pavement Studies–10 (SPS-10) experiment for WMA study. The report provides guidelines for the proper documentation of construction activities in order to facilitate future analysis efforts. The report consists of a brief summary of SPS-10 and its experimental objectives, construction report requirements, and data collection and recording procedures.

The construction report section gives an overview of the recommended elements of each SPS-10 construction report. The recommended construction report consists of these elements:

- Cover page
- Table of Contents, List of Tables and List of Figures
- Introduction
- Project Description
- Construction
- Summary
- Key Observations
- Appendix A: Construction Photographs
- Appendix B: Mix Designs
- Appendix C: Materials Sampling and Testing Layouts
- Appendix D: Other Construction Documents
- Appendix E: SPS-10 Data Sheets
- Appendix F: SPS-10 Deviation Report

The report describes the minimum information required in each of the sections listed above, and recommendations to populate these sections.

The data collection and recording section contains all the SPS-10 data sheets required for recording data activities during construction. The data sheets have a broad array of data elements and not all of these elements will be applicable. All data sheets include an explanation of each item in the data sheet, as well as details about how to populate it.

5. MISCELLANEOUS DOCUMENTS

This section summarizes the information available in brochures and on various websites. The information generally covers basic information about WMA including definitions and descriptions of the various types of WMA technologies. This section also summarizes surveys that have been conducted and work plans that have been developed.

5.1 "Best Management Practices to Minimize Emissions During HMA Construction." Association of Modified Asphalt Producers, 2004.

This presentation was created to address the problems created by Superpave technology, rising emissions across the country, as well as asphalt fumes becoming a problem for workers. The new Superpave thicknesses, coupled with poor designs, make it harder to achieve target densities. To extend the compaction times, contractors use a higher temperature, which leads to more emissions and fumes. Additionally, when the temperature increases, the mix was reported to exhibit more tenderness and excessive aging occurs during construction. The presentation goes on to note that research is underway to address these issues but interim guidelines will need to be used until conclusions are drawn from the research. Generally, it is advised to find the lowest possible laydown temperature that allows for the target density to be reached. The presentation suggests using the "Best Management Practices to Minimize Emissions During HMA Construction" guide from the Asphalt Pavement Environmental Council to minimize emissions.

5.2 NCAT Report 13-02: Physical and Structural Characterization of Sustainable Asphalt Pavement Sections at the NCAT Test Track, 2013.

The National Center for Asphalt Technology reconstructed the test track during the summer of 2009, as part of the new experiment. WMA mixtures, high RAP mixtures, and porous friction courses (PFC) were included in the new track. The WMA sections included a foam-based and an additive-based technology. Pavement sections were instrumented and the pavement responses and performance were monitored over time. Laboratory tests were performed on plant-produced mixtures.

The measured pavement responses changed significantly from the control sections for the high RAP and PFC sections, but not for the WMA sections. The modulus of high RAP and PFC mixes was less sensitive to changes in pavement temperature than the control sections. There were no differences with the WMA sections. WMA sections had lower AC moduli than the control. The pavement responses (strain and stress) were not affected significantly by the use of WMA technologies. The factors of material type and production temperature and their interaction significantly affected the AC modulus, longitudinal strain and vertical stress of the sections. However, the use of high RAP had a greater impact than the reduction in production temperature.

The laboratory tests performed on the plant-produced mixtures generally indicated that the WMA materials were more susceptible to rutting. However, different test methods had varied results and overall the laboratory results did not correlate with the observed field performance.

Field performance showed no cracking or moisture damage over the two-year test cycle. All sections showed similar rutting accumulation through the first 3 million ESALs. By the end of the loading, the WMA sections had similar or higher rut depths than the control section, though all sections had acceptable performance overall with less than 12.5mm of rutting after 10 million ESALs.

5.3 Prowell, B. D., Hurley, G. C., and Frank, B." Quality Improvement Publication 125 - Warm-Mix Asphalt: BestPractices." Publication QIP-125. National Asphalt Pavement Association, 2012.

The National Asphalt Pavement Association (NAPA) published QIP 125 – Warm-Mix Asphalt (WMA): Best Practices to detail the various types of WMA technology, the benefits of WMA, and the best practices regarding mix design, production, and placement in the U.S. as of 2012. The benefits noted in this report include the following:

- WMA can be used as a compaction aid.
- WMA can be used to extend the paving season in colder climates.

- Longer haul distances can be obtained with WMA.
- Increased levels of RAP can be used, as the WMA will potentially rejuvenate the RAP binder resulting in better low-temperature cracking resistance.
- Reduced fuel usage resulting in lower emissions, including fumes during paving.

The best practices suggested include, but are not limited to, the following:

- Use NHCRP Project 9-43 as a guide for mix design
- Maintain adequate baghouse temperatures to prevent condensation
- Dry aggregate, and increase aggregate retention time
- Insulating the dryer shell to improve aggregate heating
- Reduce stockpile moisture content to prevent moisture susceptibility
- Optimize burner performance for WMA temperatures
- Introduce RAP to aid in the drying of virgin aggregate
- Place and compact in the same manner as HMA

The report suggested further research needs to be conducted but does not state specific research efforts.

5.4 Hansen, K., and Copeland, A. "Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Usage: 2014." 5th Annual Asphalt Pavement Industry Survey, IS-138, 2015.

This survey covered the production methods of asphalt in the US between 2009 and 2014, particularly the introduction of WMA. The introduction of WMA has been a largely beneficial and sustainable paving practice. It reduces the production and compaction temperatures for asphalt mixtures (which reduces the energy required), reduces the emissions produced in production, improves the compaction process, and lengthens the paving season. As a result, there has been tremendous growth in the industry for WMA. Tracked in tonnage, the use of WMA has increased approximately 577% between 2009 and 2014.

WMA comprised one-third of all asphalt mixtures in 2014, or about 113.8 million tons. With the exception of Nevada and Rhode Island, all states have reported using WMA in 2014. However, of the states that have utilized WMA, almost 27% of them reported a decrease of 5% or greater in WMA usage between 2013 and 2014, while almost 42%of these states showed an increase of 5% or greater in WMA usage in the same time period. The reasons for this disparity were largely inconclusive, as there were no clear links between the states that have reduced their WMA usage. Despite this, WMA is expected to continually grow as agencies and contractors gain more exposure to the production method, encouraging states to implement updated WMA specifications.

5.5 Tabib, S., Marks, P., Bashir, I., and Brown, A. S. "Successful Implementation of Warm Mix Asphalt in Ontario." Ministry of Transportation of Ontario, 2014

The Ministry of Transportation of Ontario (MTO) published this paper to detail the laboratory results, the pavement condition data of the test sections, and the quality assurance and emissions data collected during construction of the WMA projects. This paper evaluates the following criteria: emissions, rutting, compactability, moisture sensitivity, cost, pavement roughness, cracking, and macro-texture. The conclusions from the evaluation of the WMA pavement sections include:

- WMA could be paved at temperatures between 10-30°C lower than HMA without any negative effect on mixture properties or compaction.
- Emissions savings at the plant were not achievable without proper tuning of the plant burner. Additionally, the lower production temperatures result in significant reduction of asphalt fumes and visible smoke at the paving site.
- WMA performed similarly to HMA in the Hamburg wheel track test (rutting performance).
- WMA had increased compactability compared to the HMA control section.
- Tensile Strength Ratio (TSR) tests were variable, but no moisture damage was observed on the WMA sections or from the wheel track rut testing. It was recommended that monitoring of the WMA pavements continue until they are at least 5-7 years old.
- The environmental benefits and potential performance improvements suggested the life cycle cost of WMA be equivalent to HMA.

The report stated that MTO would continue monitoring the performance of the WMA pavements. The MTO, in collaboration with Industry WMA Task group, would continue to provide recommendations for improvements to the WMA specifications. Lastly, MTO is participating in the Federal Highway Administration Specific Pavement Study-10 (SPS-10), which involves construction of WMA test sections for long term pavement performance monitoring.

5.6 Rahman, M., Burchett, T., Kargah-Ostadi, N., and Sassin, J. "Long-Term Pavement Performance: A Preliminary Analysis of the Constructed Warm Mix Asphalt Overlay Projects" 95th Annual Meeting of the Transportation Research Board, 2016.

This paper summarized the preliminary analysis of the Long-Term Pavement Performance (LTPP) program Specific Pavement Study (SPS-10) sections. The LTPP SPS-10 experiment was designed to compare the long-term field performance of pavement constructed with WMA technologies to the performance of sections paved with conventional HMA. The objectives of the report were to:

- Report on the WMA overlay construction experience;
- Evaluate the overlay compaction temperatures, and compaction quality data; and,
- Utilize the preliminary analysis of the Falling Weight Deflectometer (FWD) testing to investigate stiffness differences in HMA and WMA overlays.

The paper identified construction practices that require significant attention. The accurate collections of temperature, at laydown and production, and compaction information are essential to producing correct conclusions from the SPS-10 experiments. Recording the compactive effort was also reported to be potentially challenging, but also important in reducing variability. This report suggested that video-recording the entire compaction process could aid in gathering compaction information. Additionally, construction practices must be consistent. For example, when switching between HMA and WMA, the plant needs to reach steady state temperatures and contractors need to produce consistent lift heights. These construction considerations will ensure that errors do not significantly impact the experiment's results.

The final portion of this paper addressed the analysis of the initial FWD deflection measurements taken before and after the overlay construction two SPS-10 sites (New Mexico and Texas). The data showed that the post-overlay construction deflections were significantly smaller than the pre-overlay deflections. This observation was true across all test sections. An overall pavement stiffness estimate, before and after overlays, was also performed. In the New Mexico site, the HMA gained the most stiffness of all the test sections in that location, but in the Texas site the WMA (Evotherm) gained a higher stiffness than the other sections in the Texas location. Due to the variability, no trends were identified from the FWD deflections or pavement stiffness estimates. The results shown are only preliminary, and compaction from further traffic loading will likely reduce the differences in densities between the test sections.

5.7 NTPEP Committee, "NTPEP Committee for Work plan for Evaluation of Warm Mix Asphalt Technologies." AASHTO – National Transportation Product Evaluation Program, 2015.

The National Transportation Product Evaluation Program (NTPEP) released a detailed work plan regarding the evaluation of WMA technologies. This work plan covered the requirements and testing criteria for the evaluation of WMA technologies. The document goes into detail on specific sample submittal procedures, manufacturer participation, test methods and reporting, material criteria, testing facility criteria, and laboratory evaluations. The goal of the testing will be to determine the performance of WMA relative to the performance of a HMA control sample with all variables the same across both materials. The testing is divided into four categories; Binder Properties, Aggregates, Mixture Volumetric, and Mixture Performance.

The binder category addresses the following properties: continuous grade of asphalt binder, continuous grade of WMA-modified asphalt binder, and continuous grade of extracted binder.

The aggregate category addresses the following properties: gradation, bulk specific gravity and AIMS method, sand equivalent, stockpile moisture content, coarse aggregate angularity, fine aggregate uncompacted voids, geologic type, soundness, and LA abrasion or MicroDeval test.

The mixture volumetric category addresses the following: theoretical maximum specific gravity and density of HMA, density of HMA specimens by means of Superpave gyratory compactor, and practice for Superpave volumetric design for HMA.

Lastly, the mixture performance category addresses the following performance criteria: mixture design verification with 150-mm diameter specimen, rutting, dynamic modulus, compactability, and moisture susceptibility. All of the testing criteria have a referenced AASHTO testing standard that should be used to determine the property in question.

5.8 AMAP "Asphalt Modifiers Brochure." http://modifiedasphalt.org/wp/wp-content/uploads/Brochure-Asphalt-Modifiers-Tools-That-Work-lowres.pdf, 2016.

The Association of Modified Asphalt Pavement (AMAP) brochure details the benefits of various asphalt modifiers. The brochure explains that WMA additives include technologies that allow better compaction at lower than normal temperatures. This means a reduction in energy costs while allowing longer haul distances and less compaction effort. The main application that is listed for the WMA additives is the reduction in mixing and compaction temperatures.

5.9 Bower N., Wen, H., Wu, S., Willoughby, K., Weston, J., and DeVol, J. (2016) "Evaluation of the Performance of Warm Mix Asphalt in Washington State." International Journal of Pavement Engineering, 17:5, 423-434, DOI: 10.1080/10298436. 2014. 993199.

This article detailed the comparative performance of WMA to HMA control sections obtained at field sites Washington state. The WMA technologies reviewed include three water-foaming technologies, Gencor, Aquablack, and ALMix Water injection, as well as the organic additive, Sasobit. Four projects, consisting of an HMA control section and a WMA test section, were selected for this study. Cores were taken from each of these four projects and were used to conduct mixture performance tests and asphalt binder tests. Additionally, field performance data for the four study projects was obtained from the Washington State Pavement Management System. The following conclusions were drawn from the testing and field data:

1. Laboratory binder testing
    - WMA binders showed consistently lower complex shear modulus and less rutting resistance and fatigue resistance.
    - Water-based foaming WMA binders showed no difference in thermal cracking resistance compared to the HMA control, but the Sasobit binder showed better thermal cracking resistance.
2. Laboratory mixture testing
    - Stiffness of the WMA mixtures was comparable to the HMA except for the Aquablack mixture. The Aquablack had a lower stiffness. This is likely due to the shorted period from time of production (1-year) compared to the other projects (2+ years).
    - Fatigue resistance of the WMA mixtures was comparable to the HMA except for the Sasobit mixture The Sasobit mixture showed higher resistance to bottom-up fatigue.
    - The Sasobit and Aquablack WMA mixtures showed comparable thermal cracking resistance to the HMA control. The Gencor and Water Injection WMA mixtures showed better resistance to thermal cracking, most likely due to the lower production temperatures
    - The Sasobit and Aquablack WMA mixtures showed comparable rutting resistance to the HMA control. The Gencor and Water Injection WMA mixtures showed less resistance to rutting.
    - All WMA mixtures performed similarly to the HMA control in terms of moisture susceptibility.
3. Field performance
    - WMA pavements were comparable to their corresponding HMA control sections in terms of early-age rutting.

- No moisture damage was observed in the field, which matches the results from the mixture moisture susceptibility tests.
- The Sasobit WMA section showed more reflective transverse cracking than the HMA control section.

The article recommended further research into the effects of crystallization of Sasobit on the binder properties. Additionally, further research is recommended into the presence of Recycle Asphalt Pavement (RAP) and complete blending between RAP binder and original binder during extraction and recover process. Lastly, the long-term performance of WMA pavements compared to HMA pavements should be researched further.

5.10 Tran, N., Turner, P., and Shambley, J. "Enhanced Compaction to Improve Durability and Extend Pavement Service Life: A Literature Review." Publication NCAT 16-02R. National Center for Asphalt Technology, Auburn University, 2016.

A literature review was completed to provide information to support the Federal Highway Administration (FHWA) Asphalt Pavement Technology Program strategic direction on extending pavement service life through enhanced field compaction. In the literature review, the effects of air voids on laboratory and field performance of asphalt mixtures are discussed, as well as a summary of best practices for achieving higher in-place densities.

The effects of reducing in-place air voids were variable, but beneficial. It was noted that with a 1% decrease in air voids, fatigue performance improves by between 8.2 and 43.8%, and rutting resistance improves by between 7.3 and 66.3%. Additionally, the estimated extension in service life is 10%. Using this estimation, a life cycle cost assessment estimated a NPV savings of $88,000 on a $1,000,000 paving project.

The article noted that WMA could also be considered a compaction aid. WMA could be used to reach similar in-place densities at much lower compaction temperatures (as compared to HMA). This is especially relevant for cold weather and long haul projects. Finally, the review stated that since in-place density had a significant impact on performance of asphalt pavements, agencies might consider implementing a higher in-place density requirement. Following best practices and utilizing new technologies and knowledge gained from research could achieve this requirement.

5.11 Springer, Jack. LTPP WMA Project SPS-10. NCHRP Project 20-44(01) Workshop, May 2017.

This presentation was created to provide updates regarding the Long-Term Pavement Performance (LTPP) WMA project Specific Pavement Study 10 (SPS-10). The presentation gives a brief overview of the project including the following; the objectives, the experiment design, the recommended testing and sampling, as well as the documentation and performance monitoring.

The updates provided in this presentation are regarding the performance monitoring of the ongoing projects. According to the presentation, most test sites are not showing any distress, but there are three sites (Washington, Manitoba, and New Mexico) that are showing distress. The Washington site consists of four test sections; two HMA control sections, WMA (Foaming w/ 2% water), and WMA (Chemical – 1% Evotherm). All four sections show signs of longitudinal cracking within the two-year test period, with the HMA sections performing worse than both WMA sections. The Manitoba site consists of three test sections; a HMA control section, WMA (Foaming w/ 1% water), and WMA (Chemical – 0.3% Evotherm). All three test sections show similar performance with signs of longitudinal and transverse cracking within a one-year period, with the Evotherm section having the poorest performance. Lastly, the New Mexico site consists of five test sections; a HMA control section, WMA (Foaming), WMA (Chemical – Evotherm), and two WMA (Chemical - Cecabase). The test sections all showed signs of longitudinal cracking, with the HMA control performing best and the Cecabase sections performing worst.

5.12 Hansen, K., and Copeland, A. "Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Usage: 2015." 6th Annual Asphalt Pavement Industry Survey, IS-138, 2017.

This survey covered the production methods of asphalt in the US between 2009 and 2015, particularly the introduction of WMA. The estimated total production of WMA for the 2015 construction season was 119.8 million tons, which represented approximately a 5 percent increase from the 2014 estimated tonnage. WMA was estimated to comprise 30% of the total estimated asphalt mixture market in 2015. Plant foaming was reported to be the most commonly-used WMA technology (72% of the market), while chemical additive technologies represented approximately 25% of the market.

The report indicated that from 2014 to 2015, 18 states reported an increase of 5% or more in WMA production, while 14 states reported a decrease of 5% or more in WMA production. Three states (Georgia, Michigan, and South Carolina) were reported to have increased WMA production by more than 25%. Six of the states (Arkansas, Colorado, Idaho, Mississippi, Montana, and Nebraska) were reported to have decreased WMA production by 25%.

5.13 City Usage of WMA: Various Websites

New York City http://www.nyc.gov/html/dot/html/motorist/sustainablepaving.shtml
The New York City DOT implemented WMA for its sustainable street resurfacing. The WMA is heated to 200 degrees Fahrenheit, as opposed to the traditional 300 to 325 degree Fahrenheit typical of HMA pavements. This results in decreases emissions, fumes, and odors both at the asphalt plants and at work sites. It reduces the energy requirements for asphalt production. The temperature range allows it to be laid even in the winter seasons. WMA has an estimated potential of 75% of asphalt used in NYC.

San Jose, California http://www.sanjoseca.gov/documentcenter/view/6561
The City of San Jose used WMA for construction of the Highway 237 Bikeway. The aim of this project was primarily environmental. The project used WMA (heated at 200 degrees versus 300 degrees Fahrenheit for HMA), a less viscous oil to bind stone, and recycled stone material from existing asphalt found at the project site. This allowed for less energy to be used and fewer hydrocarbons/fumes to be produced.

District of Columbia DOT https://comp.ddot.dc.gov/Documents/Energy Savings Initiatives.pdf

The District of Columbia DOT considers WMA as the better alternative over conventional asphalt for both emissions and energy savings. WMA can be produced between 215°F and 275°F, as opposed to 280°F to 340°F for HMA. While these temperatures are noticeably more conservative compared to other cities, an estimated 30% reduction in carbon dioxide emissions can still be achieved.

5.14 Warm Mix Asphalt Website, http://www.warmmixasphalt.org/Default.aspx

The website *www.warmmixasphalt.org/* consists of six tabs: Home, About Us, About WMA, Publications, WMA technologies, and a Submission form. The site has not been maintained for several years.

The *About Us* and *About WMA* pages provide similar links to the Warm Mix Asphalt Technical Working Group (WMA TWG) and notes from several of their meetings and documents published during 2007 through 2010. These two pages list several benefits of WMA (cutting fuel consumption and decreasing greenhouse gases).

5.15 U.S. Department of Transportation, Federal Highway Administration Website, https://www.fhwa.dot.gov/pavement/asphalt/wma.cfm

The FHWA website primarily addresses WMA under the sustainability tab of the Pavement Section of the website. The article gives an overview of WMA and five WMA Technologies. Additionally, two projects from the Warm Mix Asphalt Technical Working Group (WMA TWG), NCHRP Projects 09-43 and 09-47 (addressed under NCHRP reports), are introduced. Three WMA demonstration projects in Missouri, Colorado and Western Lands are mentioned.

Several of the links provided for The U.S. Department of Transportation, Federal Highway Administration's website, https://www.fhwa.dot.gov/ are no longer operational.

These include links to a searchable reference on state specifications, state specification websites, and state construction manual websites (http://www.specs.fhwa.dot.gov/nhswp/, http://www.specs.fhwa.dot.gov/nhswp/stateSpecificationWebsites.jsp), http://www.specs.fhwa.dot.gov/nhswp/stateConstructionManualWebsites.jsp).

The link https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=30 links to Construction of Pavement Subsurface Drainage Systems (Instructor's Manual) and does not include information on WMA.

5.16 The National Center for Asphalt Technology at Auburn University, http://eng.auburn.edu/research/centers/ncat/

The National Center for Asphalt Technology (NCAT) website focuses on Education & Training, Research, and Publications. While most of the training and education is outside of the scope of this project, it is noted that NCAT offers pavement courses on WMA at the professional and academic level. An introductory webinar on WMA is available for viewing by the public, although it is aimed at asphalt plant and roadway personal.

Reports and Publications available via the website include newsletters, technical reports, case studies, and referred publications. The research and reports from this website are both current and ongoing. NCAT reports are included in this literature review under Section 2.

5.17 The FHWA Warm Mix Asphalt Website: Asphalt, http://www.fhwa.dot.gov/innovation/everydaycounts/edc-1/wma.cfm

The Federal Highway Administration website focus on the advantages and benefits of WMA. The resources include brochures, FAQs, along with various articles and documents.

5.18 State DOT Asphalt Specifications: Various Websites

As previously stated, there are many research studies and documents available that discuss WMA; however, the topical bibliography is focused primarily on implementation studies and field performance. Since there is no one site which compiles all of the state DOT reference specifications for HMA nor WMA, a search was conducted for the topical bibliography and the websites (if available) as well as a cursory comparison of the specifications are presented in Table A15.

Table A15: Inventory of State DOT Specifications Related to WMA

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are <u>different</u> than those required for HMA	Sou (sp
Alabama	WMA is defined as the use of an approved warm mix technology in the plant mix at the time of production (within the range of 215°F to 280°F).	All approved JMFs approved with an increased amount of RAP (25%), or RAP with RAS blend (total of 35%), shall be produced as WMA only. WMA layers of 200 lb/yd^2 or less shall not be placed when the surface or air temperature is below 32 ºF; air temperature shall be 32ºF before the spreading operation is started. Spreading operations shall be stopped when air temperature is below 35ºF and falling. WMA layers of greater than 200 lb/yd^2 can be placed at temperatures 27ºF and above. Polymer-modified WMA of 200 lb/yd^2 or less shall not be placed when the surface or air temperature is below 50ºF. Polymer-modified WMA layers of greater than 200 lb/yd^2 can be placed at temperatures 40ºF and above.	http /pd FT
Alaska	N/A	No details on differences between WMA and HMA.	http /dcs 201
Arizona	WMA is defined as asphaltic concrete that is produced within the temperature range of 215 to 275 °F.	To be approved, the WMA must have been constructed successfully in other projects nationally (at least 100,000 tons) and the manufacturer must submit documentation from at least three construction projects, such as test results that show the effects on the rheological properties of virgin asphalt binders. A contractor must construct a test section of 1000 to 2000 tons. The moisture content of the asphaltic concrete tested immediately behind the paver cannot exceed 0.5 percent, and additional moisture content testing shall be performed when using WMA technologies. Additionally, the WMA mix must be inspected at the plant and on the grade to ensure that aggregate is fully coated during production.	http ss/2 for- con http ls-n Dir
Arkansas	N/A	N/A	http /sta
California	WMA is defined as asphalt produced at temperatures of 45°F or less than HMA.	No differences in requirements from HMA.	http nstr spe cs.p
Colorado	Warm mix technology is an additive that the contractor may elect to use.	No differences in requirements from HMA.	http sign -co 400 http sign geo fmr
Connecticut	N/A	N/A	http mer mar 1.pc
Delaware	N/A	No differences in requirements from HMA.	http _fo ual/ part

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are <u>different</u> than those required for HMA	Sou (sp
Florida	N/A	During construction, WMA can be placed in ambient temperatures that are 5°F lower than temperatures specified for HMA. WMA technologies on the approved product list can be used in the production of Superpave Asphalt Concrete pavement. The target mixing temperature is to be established by the Contractor and may be reduced when using warm mix technology. When the asphalt binder will be used with a foaming warm mix technology, the addition of silicone will be determined by the technology supplier's guidance.	Rep WM http inis atio 09- Ma http mar http gen uly
Georgia	WMA is a term used to describe the lower production, placement and compaction temperatures required in conjunction with the application of one of several approved WMA technologies.	WMA must be produced at least 30°F less than the JMF temperature in the Asphalt Cement Mixture Control Temperature Chart for PG Binder published by the Office of Materials. An unapproved WMA technology can be used if a 500-ton test section is constructed for evaluation for compliance with all specified requirements. Additional quality acceptance is required and additional testing samples provided from the mixture production.	DE TR STA SPI Sec Cor Rev
Hawaii	N/A	N/A	http 200 stan
Idaho	N/A	N/A	http ubli 201
Illinois	N/A	Compaction temp should be 270+/-5 F for both QC and QA testing. WMA additives shall be interlocked with the aggregate feed of weigh system to maintain correct proportions for all rates of production and batch sizes. The WMA Technology approval process is based on the following criteria: 1. Initial screening by the Department. 2. Testing of mainline surface mixture produced at an approved asphalt plant on two field trial projects. 3. Or reciprocity with other states.	Illin Tra Spe Asp Jan
Indiana	N/A	Water-injection foaming is mentioned in sections 401.04, 402.05 and 410.04.	http s/st
Iowa	N/A	The Iowa method for WMA design is in IM 510. (https://iowadot.gov/erl/current/IM/content/510.htm) uses an Aging Index IM 510A.2 to determine binder grade. Acceptance is per Standard Specification 2303 Flexible Pavement: "No differences in requirements from HMA" as reported for other states.	http /CM (htt /cor
Kansas	WMA is defined as a warm mix additive added to a binder. This changes the general name from HMA to WMA.	Acceptance is based on prequalification as specified in subsection 1207.4 and field observations of WMA production.	http ksd nne Cor Par
Kentucky	N/A	N/A	http ctio spe

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are <u>different</u> than those required for HMA	Sou (sp
Louisiana	Warm mix is defined as asphalt concrete that is at a temperature of at least 245°F.	No differences in requirements from HMA.	http aDO nda Spe 20S %2 20(%2 %2 %2 0(c
Maine	WMA is defined as asphalt produced at temperatures that are 35°F lower than those of HMA.	No differences in requirements from HMA.	http pub 4/S
Maryland	WMA is defined as an asphalt mixture that utilizes a warm mix temperature decrease.	Any new warm mix additives must be submitted and approved through Maryland Products Evaluation List (MPEL) before use.	See Cor http d/fr
Massachusetts	WMA is defined as additive that lowers the mixture production temperature to below 260°F.	The WMA additives will be used as a compaction aid for bridge pavements, produced at HMA temperatures. The WMA additive equipment must be fully automated and integrated into the plant controls and must record actual dosage rates. A QC plan must address WMA metering requirements, tolerances and other QC measures.	Ma *Mix*
Michigan	WMA is asphalt mixture produced at temperatures that are 50°F to 70°F lower than typical HMA.	No differences in requirements from HMA.	http mi. Wa
Minnesota	WMA is defined as a mix produced at temperatures that are 30°F or lower than typical HMA.	No differences in requirements from HMA.	http letti f
Mississippi	WMA is defined as an asphalt mixture at a range of temperatures, based on the technology type and presence of polymer modification.	For WMA, the ambient air and pavement temperature at the time of placement shall equal or exceed 40ºF, regardless of compacted lift thickness. Temperature ranges of non-polymer modified, WMA produced by foaming the asphalt binder at the plant are typically 270ºF to 295ºF. With polymer modifications, the temperature ranges is 280ºF to 305ºF and the addition of a terminal blended additive may allow the producer to reduce the temperatures below 270ºF, as long as all mixture quality and field density requirements are met	http ot% es/4
Missouri	N/A	Rollers shall not be used in the vibratory mode when the mixture temperature is below 200^0F.	http nda Spe f

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are <u>different</u> than those required for HMA	Sou (sp
Montana	WMA is defined as a plant mix surfacing that has been modified with additives or processes that allow a reduction in the temperature at which plant mix surfacing is produced and placed. Warm mix defined at a minimum temperature of 220°F and within the range recommended by the manufacturer and approved by the MDOT.	Comply with manufacturer's recommendations regarding receiving, storage, and delivery of warm mix additives. Additionally, provide the following information at least 30 calendar days before warm mix production: 1. Warm mix technology and/or warm mix additives information; 2. Manufacturer's established recommendations for usage; 3. Manufacturer's established target rate for water and additives, the acceptable variation for production, and documentation showing the impact of excessive production variation; 4. Warm mix technology material safety data sheets; 5. Temperature ranges for mixing and compacting; 6. Asphalt binder performance grade test data over the range of warm mix additive percentages proposed for use; 7. The warm mix design and testing sample preparation may differ from conventional HMA. Provide manufacturer's sample preparation recommendations for warm mix design and testing; and, 8. Include the binder supplier's recommendations for warm mix additive content, methods for incorporating warm mix additive into mix design samples and mixing and compaction temperature ranges.	http data 014 401 201
Nebraska	WMA is defined as a HMA mixture modified to be produced, placed, and compacted at temperatures between 20^0F to 100^0F less than those of HMA.	No differences in requirements from HMA.	http dia/ csu
Nevada	N/A	N/A	
New Hampshire	WMA is defined as asphalt produced at a temperature less than 260°F and that meets the specific warm mix technology specification.	No differences in requirements from HMA, unless used with rubber.	http dev icat
New Jersey	WMA is defined as mixing and compaction temperatures at 30°F or lower than HMA.	WMA surface temperature must be less than 120°F before the road is opened to traffic or to convey construction equipment. Storage bins must be held to 10°F above the manufacturer's recommended temperature.	http n/er 00_ http n/er http n/er 7-2(
New Mexico	WMA is defined as asphalt mix at temperatures in the range of 215°F to 275°F from mixer to transport vehicle	Limit RAP to 15% when used in WMA without a grade adjustment. WMA used with between 15 to 25% RAP requires that the high and low grade must be reduced by one grade, or extract and recover and combine the RAP's asphalt binder with a virgin asphalt binder per AASHTO M 323, Appendix A. WMA used with between 25 to 35% RAP requires extraction and recovery and combining the RAP's asphalt binder with a virgin asphalt binder per AASHTO M 323, Appendix A. Place WMA when the "Chill Factor" is at least 35 °F and rising. If the ambient air temperature is 55°F or warmer, do not consider the Chill Factor for WMA placement. Construct a maximum 1,000 ton test strip for each WMA mix design with a minimum of three (3) contractor and three (3) agency samples to evaluate the JMF, process control, and placement operations.	http nmo 4_S ge_ Sec

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are <u>different</u> than those required for HMA	Sou (sp
New York	WMA is defined as a mixing temperature of 240°F to 260°F for asphalt with less than 20% RAP.	No differences in requirements from HMA.	http ngi serv repo
North Carolina	WMA incorporates use of an additive to allow a reduction in the temperatures at which asphalt mixes are produced and placed.	No differences in requirements from HMA.	http /Ma S%
North Dakota	WMA is produced at temperatures 35°F to 100°F lower than typical HMA.	No differences in requirements from HMA.	http ater 2fir
Ohio	WMA is defined as asphalt produced at temperatures 35°F to 70°F lower than HMA.	Compaction of WMA is permitted at temperatures 30°F less than that for HMA (i.e., JMF Lab Compaction) with +/- 5°F compaction temperature tolerance.	http ns/C pec S_0 df
Oklahoma	AASHTO R35 unless otherwise specified.	N/A	http mar 9-70
Oregon	WMA is defined as asphalt produced at temperatures 25°F to 75°F lower than HMA.	Compaction temperature minimum is 260°F.	http WY AN f
Pennsylvania	WMA is defined as asphalt produced at 215°F to 330°F depending on the binder type.	No differences in requirements from HMA.	http ubs 08_ .pdf
Rhode Island	WMA is defined as the use of warm mix additive(s) in a HMA design.	N/A	http oing 20A
South Carolina	WMA is defined as asphalt produced at 220°F to 285°F.	No differences in requirements from HMA.	http alP 408
South Dakota	N/A	N/A	http ntra 5_S
Tennessee	WMA is defined as asphalt with a mixing temp of 275ºF or lower.	Additive supplier must show a project where the additive was used and successful in the U.S. The project must have been subjected to traffic for more than one year and exhibit the following: 1. No visible cracking, rutting or deformation; 2. No measurable rutting greater than 0.25 inch; 3. Demonstration of successful ability to reduce mixture temperatures without reducing roadway density; and, 4. Demonstration on a TDOT project with documentation of the mixture's ability to resist moisture damage according to TDOT specifications.	http dot/ _Bo http dot/

State	Definition of WMA in Spec	Details related to Acceptance of Warm Mix (density, compaction, gradation limits, etc.) that are **different** than those required for HMA	Sou (sp
Texas	WMA is asphalt produced at 30° to 100°F below HMA temperatures.	No differences in requirements from HMA.	http otm onc
Utah	N/A	No differences in requirements from HMA.	http onc
Vermont	WMA is defined as modified HMA design using a warm mix technology.	N/A	http /vtr Pro ach AL
Virginia	WMA is defined as asphalt produced at 250ºF to 290ºF.	Acceptance of WMA is decided through laboratory and field testing. Laboratory tests must show that binder grade remains the same, and include the Warm Mix Asphalt design and VTM 13 test if an anti-stripping agent is used. The field testing must comply to the following criteria: 1. Minimum TSR 80%; 2. Lab volumetrics consistent with the HMA JMF; 3. Binder sampled from production meets specified PG Binder Grade; 4. Full roller pattern and control strip conducted to verify density; and, 5. Temperature monitored and reported to VDOT at the plant and behind the screed.	Vi Ap
Washington	WMA is defined as asphalt produced at 250ºF to 275ºF.	No differences in requirements from HMA.	http apw
West Virginia	N/A	Temperature difference previously approved through trial production.	http high ons enta
Wisconsin	N/A	According to additive supplier recommended mixing and compaction temperatures.	http pec
Wyoming	N/A	Comply with manufacturer's recommendations	ftp: file on/ s/S 400 0an ant %2
Puerto Rico	WMA can be used through Special Provision Specification 964	N/A	http et_
District of Columbia	WMA is defined as asphalt produced at 215ºF to 275ºF.	N/A	http s/do ents sHi

APPENDIX B

Agency Survey Questions and Results

Survey Questionnaire for State Transportation Agencies and Other Public Agencies

INTRODUCTION/BACKGROUND

The purpose of this appendix is to present the survey questions distributed to all fifty states, the District of Columbia, the Canadian provincial transportation agencies, and other public agencies through Survey Gizmo® and to present a summary of the results.

Question 1: "Please provide your contact information."

TABLE B1 Survey response to Question 1: "Please provide your contact information"

State Departments of Transportation	State Departments of Transportation
Alabama	Ohio
Alaska	Oklahoma
Arizona	Oregon
California	Pennsylvania
Colorado	Rhode Island
Connecticut	South Carolina
Delaware	South Dakota
District of Columbia	Tennessee
Florida	Texas
Georgia	Utah
Idaho	Vermont
Indiana	Virginia
Iowa	Washington
Kansas	Wisconsin
Louisiana	
Maine	**Local Public Agencies**
Maryland	City of Bellingham, Washington
Massachusetts	City of Santa Rosa, California
Michigan	Dickinson County, Michigan
Minnesota	Lake County, Illinois
Mississippi	Orange County, California
Missouri	
Montana	**Federal Agencies**
Nevada	FHWA – Federal Lands Division
New Hampshire	
New Jersey	**Canadian Agencies**
New Mexico	British Columbia (Canada) DOT
New York	
North Carolina	**Other Agencies**
North Dakota	Pennsylvania Turnpike Authority

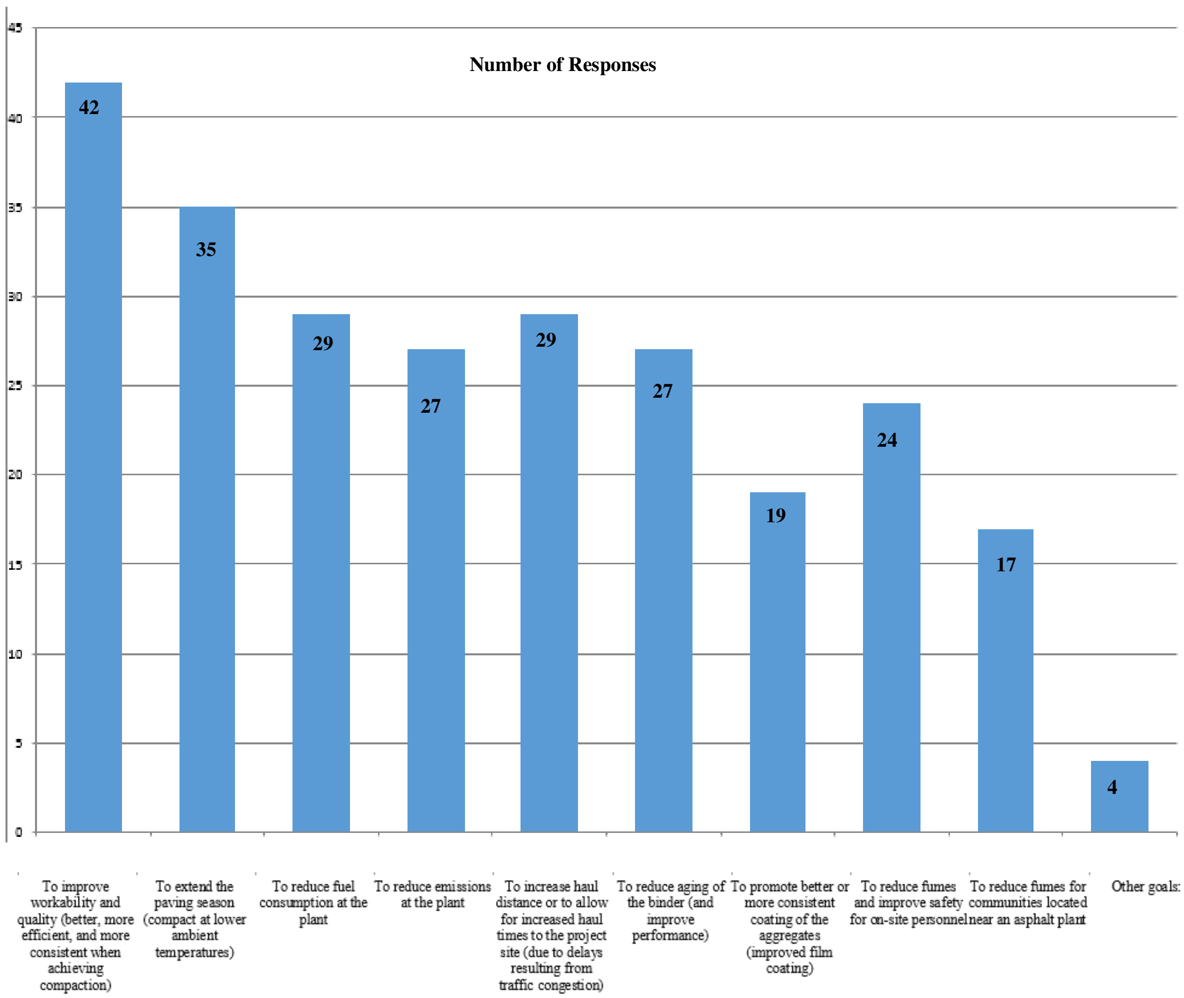
Question 2: “How does your agency define Warm Mix Asphalt?”

TABLE B2 Survey response to Question 2: “How does your agency define Warm Mix Asphalt?”

00745.02 Definitions: Warm Mix Asphalt Concrete - An asphalt concrete mix following all requirements of HMAC, except that through use of approved additives or processes, it is mixed, placed, and compacted at lower temperatures.
2. According to our specifications, "Warm mix asphalt is defined as a plant produced asphalt mixture that can be produced and constructed at lower temperatures than typical hot mix asphalt. Typical temperature ranges of non-polymer modified, WMA produced by foaming the asphalt binder at the plant are typically 270ºF to 295ºF at the point of discharge of the plant. Typical temperature ranges of polymer modified, WMA produced by foaming the asphalt binder at the plant are typically 280ºF to 305ºF at the point of discharge of the plant. WMA produced by addition of a terminal blended additive may allow the producer to reduce the temperatures below 270ºF as long as all mixture quality and field density requirements are met.
A plant mixed asphalt produced at a lower temperature and placed at a lower temperature without loss of workability or the ability to properly compact the mixture.
An alteration to traditional Hot Mix Asphalt, through either foaming or additives that allow the mix to be produced at lower temperatures with the benefit of reducing energy consumption, emissions and worker exposure, while improving field compaction, extending the paving season and increasing haul distances. CDOT requires WMA be documented with equal or better performance compared to HMA. CDOT considers asphalt mixtures intentionally produced at HMA temperatures, but intended for compaction in cold conditions (or long haul), to be WMA.
An asphalt with a mixing temp less than 350F
An warm mix additive or process which lowers the pavement production temperature and enhance the workability and performance of the warm mix asphalt
Any technology including foaming or chemicals used are called WMA, regardless of temperature reduction. Most of WMA so far was produced by using water foaming at plant.
Any technology that allows HMA to be placed at a cooler temperature than would be otherwise required.
Asphalt Mix produced either by chemical or plant modification that is produced at temperatures less than or equal to 300 F.
Asphalt cement mix that uses additives to achieve compaction at lower temperatures.
Asphalt mixture produced at temperature of 275^ or less by the use of additives, a water foaming process, or a combination of both.
Asphalt that has a different working temperature than traditional asphalt (Typically cooler, but may be higher). This is achieved through chemical additive or water foaming.
Asphalt with water injection foaming, water additive foaming, or warm mix chemical additive
Asphaltic Concrete produced at a temperature at least 30 degrees F lower than conventional Hot Mix Asphaltic Concrete.
Asphaltic concrete batched at a temperature of 350 degrees F or lower.
By AASHTO R 35 Appendix X2.
HMA that is produced at 275 degrees or less and using a WMA additive or process
Hot Mix Asphalt Pavement produced with an accepted WMA technology (no drop in temperature required)
If a warm mix additive is used in the mix.
Mix must have plant discharge temperature range of 215 to 275 F.
Mix produced and placed below 275F and above 215F
MnDOT defines WMA as "Any mix that is produced at temperatures 30F or lower than typical HMA mixing temperature of the asphalt binder, as defined by the asphalt producer.
NCDOT defines "Warm mix asphalt (WMA)" as additives or processes that allow a reduction in the temperature at which asphalt mixtures are produced and placed.
No
No definition, technically. Our specs simply say, "QC/QA HMA may be produced using a water-injecting foaming device."
No formal definition has been drafted at this time.
No formal definition. Closes definition we have was prior to 2015 for mixes that contained 26-40% RAP that required a grade bump for HMA. If they used WMA and kept temperatures below 275 deg F they didn't have to do the grade bump.
No official but our specification reads. A volumetric asphalt mixture design developed with the Superpave Gyratory Compactor (SGC), using prescribed manufactured additives or modifiers, and/or plant process modifications.
Not specifically defined in our state specifications. A product or process that lowers the production temperature Hot Mix Asphalt.
Organic additives, chemical additives and foaming
Per SC-M-408 Spec. 220 -285 Degrees F.
Plant mix surfacing which has been modified with additives or processes that allow a reduction in the temperature at which plant mix surfacing is produced and placed.

Technology that can decreases the mix temperature of HMA that is either added by chemical, solid or foamed at the manufacturing plant and aides in the compaction process during cooler weather.
There is no official definition in our specs. However it is understood that WMA are mixes that are produced at temperatures about 50F (28C) or more cooler that used in HMA production. We have a permissive WMA specification that allows the contractor to choose (from a pre-approved WMA list in our specs.) if WMA will be used in their mix. The mix design is typically done by the DOT. The contractor proposes the materials/ingredients to be used in the mix and submits these ingredients to the state for determining Job Mix Design.
To be considered a WMA, the HMA must be modified with an approved additive that is capable of reducing production temperatures to below 260F.
Using WMA technologies such as foaming, chemical additives.
Utilizing a WMA additive or technology
WMA Technology allow a reduction in the temperatures at which asphalt mixes are produced and placed. With the decreased production temperature comes the additional benefit of reduced emissions from burning fuels, fumes, and odors generated at the plant and the paving site. It also extends the Paving Season.
WMA additives or processes that are used and certified according to the mix design process in AASHTO R 35 for consideration and practices for using WMA.
WMA are technology to reduce HMA production temperature range of 240 to 325 degree F.
WMA at 30 F or lower mixing and compaction temperature than HMA.
WMA is asphalt mix produced and paved at lower temperatures than conventional hot mix with an approved warm mix additive or process.
WMA is asphalt mix produced with special technologies at temperatures 30 to 70 F lower than typical HMA
WMA is defined as a mixture produced at lower production temperatures than the conventional mixture. The minimum production temperature is 275°F
WMA is defined as asphaltic concrete that is produced within the temperature range of 215 to 275 °F.
WMA is standard HMA produced using a WMA technology typically resulting in a production mixture temperature of 275°F or lower.
Warm Mix Asphalt (WMA) Technology: A qualified additive or technology that may be used to produce a bituminous concrete at reduced temperatures and/or increase workability of the mixture.
Warm Mix Asphalt (WMA) is defined as an asphalt binder and aggregate mixture which, by additive or process, can be produced and placed at a reduced temperature from normal HMA temperatures. WMA requirements are the same as for HMA except where noted.
Warm Mix Asphalt (WMA) refers to asphalt concrete mixtures produced at temperatures approximately 50 degrees F or more below those typically used in production of hot mix asphalt (HMA).
We don't have our own definition. Most of our contractors have the foaming equipment for warm mix. They have also used different chemical methods.
We have no set definition, although we regard it as a compaction aid.

Question 3: “What are/would be the primary goals of your agency in terms of encouraging the use of WMA technologies in your state? (check all that apply)”



Other goals: (open-ended question)	Agency
Help achieve compliance with Commonwealth of Massachusetts \"Global Warming Solutions Act of 2008\"	MA
Lower costs, increase competition (we typically only have 1 contractor for all paving)	Dickinson County, MI
No current goals	NV
To reduce segregation	NH

FIGURE B1 Survey response to Question 3: “What are/would be the primary goals of your agency in terms of encouraging the use of WMA technologies in your state? (check all that apply)”

Question 4: “Has your agency implemented any WMA technologies to date on any paving projects?”

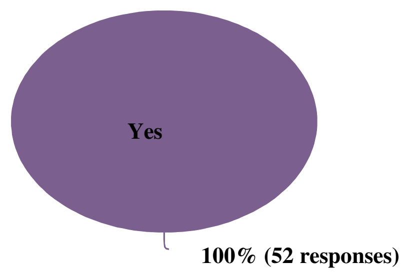


FIGURE B2 Survey response to Question 4: “Has your agency implemented any WMA technologies to date on any paving projects?”

Question 5: **“**Which types of WMA technologies has your agency implemented in paving projects to date? (check all that apply)”

TABLE B3 Survey response to Question 5: “Which types of WMA technologies has your agency implemented in paving projects to date? (check all that apply)”

Value	Percent	Count
Material Processing (e.g., LEA, hot-coated coarse aggreg. + moist fine aggreg.+ additives)	3.9%	2
Organic Additives (e.g., waxes, Zeolite)	51.0%	26
Chemical Additives (e.g., surfactants)	80.4%	41
Foaming Processing (e.g., water injection, Zeolite)	94.1%	48
Hybrid Systems (e.g., water injection and surfactant)	3.9%	2
Hybrid Systems (e.g., water injection and organic additive)	2.0%	1
Other type:	9.8%	5

Other type: (open-ended to the response "Other" in previous question)	Agency
Evotherm	MN, DC
A number of WMA technologies and processes are pre-approve in our specifications, however we have seen the majority of our WMA using Evotherm (chemical additive).	Alaska
We let a WMA project but did not direct the contractor as to what technology to use.	GA
We've had Evotherm used a limited amount by one contractor from 2012 to current but are water injection foamed.	OH

Question 6: “Which types of mix variations have been combined with WMA in your state/jurisdiction? (check all that apply): For each type of WMA mix variation, indicate what you have observed to be the impact on performance (as compared to those used with HMA)?”

TABLE B4 Survey response to Question 6: “Which types of mix variations have been combined with WMA in your state/jurisdiction? (check all that apply): For each type of WMA mix variation, indicate what you have observed to be the impact on performance (as compared to those used with HMA)?”

	Haven't used	No difference in performance	Worse performance	Better performance
	Count	Count	Count	Count
Polymer-modified (SBS, etc.)	4	36	1	7
RAP	4	41	2	3
Rubber	31	7	0	2
SMA	27	12	0	2
Polyphosphuric acid (PPA) binders	22	16	3	0
TLA	37	0	0	0
Recycled shingles	22	13	3	1
Recycled ceramics or glass	36	1	0	0
Antistrip additives (lime, etc.)	10	28	0	3
COMMENT: we did a WMA Ultra thin overlay	0	1	0	0

Question 7: “Was a control section used when your organization built a WMA project?”

TABLE B5 Survey response to Question 7: “Was a control section used when your organization built a WMA project?”

Was a control section used when your organization built a WMA project?		
Value	**Percent**	**Count**
Yes	58.0%	29
No	42.0%	21
	Total	50

Question 8: "Briefly describe how you documented any noticeable differences in performance (e.g., amount of distress, timing to first distress, etc.) between the control and WMA sections?"

TABLE B6 Survey response to Question 8: "Briefly describe how you documented any noticeable differences in performance (e.g., amount of distress, timing to first distress, etc.) between the control and WMA sections?"

Agency	Survey Response
SCDOT	We have a 12.5mm OGFC with WMA (Evotherm and no fibers) against same mix with GTR (no fibers) and SBS with Fibers on I-20...5 years old no issues with any mix yet.
FHWA Western Federal Lands Highway Division	This project was annually monitored by WRI as part of a WMA study. Samples and data were obtained through the course of evaluation.
TN DOT	Field observation during paving, limited monitoring afterward has shown no significant difference in distress.
FDOT	A report was produced documenting the construction and performance of the first three WMA projects in Florida. The report (09-527) can be found at this link: http://www.fdot.gov/materials/administration/resources/library/publications/researchreports/2006-2010.shtm
NJDOT	Differences were documented during construction that resulted in better workability, reduced emissions on asphalt-rubber mixtures, increased compaction, cool weather paving which allowed increased time for compaction. Field performance is being monitored by the Pavement Management unit, but no noticeable differences in field performance have been realized. Based on field performance observed up to this point in time, WMA performs as well as HMA.
MassDOT	Distress and rutting comparison.
Colorado Dept of Transportation	The performance data documents rutting, cracking and raveling / weathering as measured by established field performance data gathering methods. HMA Control sections or similar HMA comparison sections are required prior to approving new WMA technologies.
Georgia Department of Transportation	We are continuing to inspect the project and rate it is performance using GDOT's Pavement Condition Survey.
Montana Department of Transportation State Materials Engineer	Two were studied through national NCHRP studies and initial performance documented through the studies. One of these was also evaluated as an experimental project internally. No differences between sections were identified.
South Dakota DOT Bituminous engineer	Cores taken every year for 4 years and test results show some difference vs. control section
TxDOT	Performance testing - HWT and OT, Color of Mix, Distress measurements
NMDOT	We built the first SPS-10 Test Project on I-40 in October of 2014. We built 5 test sections. One HMA Control Section with 4 WMA Test sections using Evotherm, Foaming & Ceca base with PG 70-28 & Ceca base with PG 70-28+). Fugro BRE is monitoring and keeping records of testing. UNM did some testing using the mix placed on those sections and Ceca base sections seems to be performing better than other sections.
City of Santa Rosa CA	City of Santa Rosa back in 2008 paved Hoen Ave. We had the contractor use typical HMA on the Southern portion of the project and used a Foaming Technology WMA on the Northern portion. Both mixes are performing extremely well with very little/none thermal or load related cracking. Visually, you cannot tell the difference.

Agency	Survey Response
Lake County Division of Transportation	Via informal field inspection, not noticeable difference in WMA and HMA in first 3 years. After 5 years, WMA had less longitudinal cracking. Via laser road surface testing, rutting and smoothness are slightly better for WMA, but cracking and overall condition are same for WMA and HMA.
WashDOT	Described in the report provided http://www.wsdot.wa.gov/Research/Reports/700/723.2.htm
Ohio DOT	We did 7 trial projects with control sections in 2008 with some having stack testing. Other than the initial report, no further documentation. In general, there have been no visual performance issue differences.
Caltrans	WMA evaluations were based on early pilot projects. Majority of observations were made up during construction.
State Pavement Engineer - Alaska DOT&PF	Please see TRB paper here: https://trid.trb.org/View/1107750
Vermont AOT	Feedback from crew, review of compaction data and visual observations.
NY DOT	The evaluation was done visually to account for the distress, mostly cracking and rutting, and the results were documented for at least two years.

Question 9: "Have you observed the development of any distresses in the WMA pavements, which have not been observed to the same extent in HMA pavements? (check all that apply)"

TABLE B7 Survey response to Question 9: "Have you observed the development of any distresses in the WMA pavements, which have not been observed to the same extent in HMA pavements? (check all that apply)"

Value	Percent	Count
No differences in distress levels observed between WMA and HMA pavements	93.9%	46
Rutting	2.0%	1
Fatigue cracking (top down, reflective, or bottom up)	2.0%	1
Other distress:	4.1%	2
Other distress: (open-ended comment for Other from previous question)	**Agency**	
Seeing transverse cracking, but coring makes us believe reflective from below. Not 100 % confident all of the cracking is reflective	Dickinson County, MI	
WMA allows contractors to place asphalt mixes at colder and windy conditions which may lead to a shortened pavement life	DC	

Question 10: "Does your agency track WMA usage, construction properties, or post-installation performance?"

TABLE B8 Survey response to Question 10: "Does your agency track WMA usage, construction properties, or post-installation performance?"

Value	Percent	Count
Yes	52.9%	27
No	47.1%	24
	Total	51

Question 11: “Which approaches are used for tracking? (check all that apply)”

TABLE B9 Survey response to Question 11: “Which approaches are used for tracking? (check all that apply)”

Value	Percent	Count
State DOT centralized database (through PMS, asset management, construction, maintenance, etc.)	66.7%	18
State DOT regional or district-level data entry (through construction, etc.)	18.5%	5
FHWA Every Day Counts (EDC) initiative for tracking WMA	3.7%	1
State Asphalt Pavement Association (SAPA) portal	3.7%	1
Other approach used for tracking WMA	33.3%	9

Other approach used for tracking WMA: (Open-ended from Other in previous question)	Agency
Microsoft ACCESS-based lab system tracking HMA/WMA	City of Santa Rosa, CA
Job tickets and plant reports used to track usage	Lake County, IL
Records of tonnage of WMA used vs. HMA	DC
State Research Project	SD
Track usage of individual approved mix designs. This is done by giving WMA mix design numbers a unique identifier and then tracking tonnage placed based on the mix design number/identifier.	NC
TxDOT Site Manager	TX
We have one Research Project with University of NM (UNM) and they are doing some tracking of WMA Projects.	NM
We intend to populate our new PMS with WMA projects.	Alaska
Local agency database	Dickinson County, MI

Question 12: “Does your agency’s pavement management system (PMS) include any data elements that allow for tracking the performance of pavements constructed with WMA specifically?”

TABLE B10 Survey response to Question 12: “Does your agency’s pavement management system (PMS) include any data elements that allow for tracking the performance of pavements constructed with WMA specifically?”

Value	Percent	Count
Yes	14.0%	7
No	86.0%	43
	Total	50

Question 13: “Which design methodology does your agency follow in determining the optimum asphalt content when using WMA mixtures?”

TABLE B11 Survey response to Question 13: “Which design methodology does your agency follow in determining the optimum asphalt content when using WMA mixtures?”

Value	Percent	Count
Follow the agency’s HMA mix design and then "drop in" the WMA additive	66.7%	34
Determine the optimum asphalt content with the WMA included	13.7%	7
Other approach:	19.6%	10
	Total	51
Other approach: (open-ended response to Other in previous question)	**Agency**	
Contractor follows Agency HMA specification and optimizes the asphalt content through an end product performance specification.	British Columbia (Canada)	
Depends, if foaming without additive standard HMA mix design process and require HMA production before WMA production; if chemical additive design in the lab with WMA included	OR	
FDOT uses a hybrid approach of these two methods. Additives are included during the WMA mix design process. Foaming technologies are not used during the mix design process.	FL	
Follow agency's HMA mix design and then reduce mixing and compaction temperature by 30 degrees F. Specify no grade bump if between 26 to 40% RAP.	OH	
For water injection technology use "drop in": For additive technology, include additives at mix design	CA	
None	City of Bellingham, WA	
The WMA additive is \"dropped in\" when foaming is used. Other methods of modification require the WMA to be included when the design is developed.	MT	
We allow the use of a GDOT approved mix design if using a mechanical foaming device at the asphalt plant, but require new mix designs for WMA additives.	GA	
We test the WMA mix design at the producer's predetermined optimum binder content	DC	
Both: drop in method for foaming designs, additives use the WMA blended in the design to set opt. binder content.	SC	

Question 14: "Does your agency perform any of the following laboratory tests on WMA binders or mixtures, which are not done on HMA mixtures?"

TABLE B12 Survey response to Question 14: "Does your agency perform any of the following laboratory tests on WMA binders or mixtures, which are not done on HMA mixtures?"

Value	Percent	Count
Moisture content	20.0%	4
Gyratory compaction	25.0%	5
Volumetric properties	35.0%	7
Absorption (by calculation)	15.0%	3
Theoretical maximum specific gravity	35.0%	7
Thermal stress restrained specimen test (TSRST)	5.0%	1
Tensile strength ratio (TSR)	40.0%	8
Hamburg test for moisture susceptibility	15.0%	3
Dynamic Modulus (AMPT or IDT)	5.0%	1
Rutting potential	15.0%	3
Other laboratory test	65.0%	13

Other laboratory test: (open-ended to Other response in previous question)	Agency
One test on first day's production, and every 30 days afterwards for TSR.	SC
All WMA must follow NEAUPG protocol which lists test requirements for both the WMA and HMA	NJ
Arizona Test Method 802 Immersion Compression Testing	AZ
Hveem design/testing	City of Santa Rosa, CA
None	CO, Dickinson Co. (MI), DC, TX, VA
Performance testing required for all mixtures (HMA or WMA)	LA
RTFO DSR @ 135C and 163C to assure the binder characteristic does not change under lower temperature production.	NY
We are in the process of developing Hamburg Test for WMA as well as HMA. Mix Designs are developed by Private Testing Labs and they try to run Hamburg on WMA as recommended by AASHTO, but it is still not a requirement in NM.	NM
We do require tensile strength testing on HMA, but require more frequent for WMA.	GA

Question 15: "Does your organization employ different conditioning methods for short-term aging or long-term aging of WMA than for HMA?"

TABLE B13 Survey response to Question 15: "Does your organization employ different conditioning methods for short-term aging or long-term aging of WMA than for HMA?"

Value	Percent	Count
Yes	9.8%	5
No	90.2%	46
	Total	51

Question 16: "Please provide some details on how the conditioning temperature and time are selected and who makes the decision on what these parameters should be?"

TABLE B14 Survey response to Question 16: "Please provide some details on how the conditioning temperature and time are selected and who makes the decision on what these parameters should be?"

Response (for agencies who answered Yes in previous question)	Agency
Follow AASHTO and Caltrans test Methods, usually 3+ hours of stabilization prior to testing.	City of Santa Rosa, CA
HWT used with a 4-hour cure instead of 2-hour cure	TX
Not in mix design, but during QC we require the contractor to compact at 30 deg F lower than HMA per ODOT Construction and Materials Specification 441.09.C (conditioning for short term is one hour for QC at compaction temperature for both HMA and WMA).	OH
Specification language: For HMA with WMA additive technology, produce HMA mix samples for your mix design using your methodology for inclusion of WMA admixture in laboratory-produced HMA. Cure the samples in a forced-air draft oven at 275 degrees F for 4 hours ± 10 minutes.	CA
We do not allow additional aging for WMA.	GA

Question 17: "Does your organization perform any of these field performance tests, specifically on pavements constructed using WMA, but not on HMA pavements? (check all that apply)"

TABLE B15 Survey response to Question 17: "Does your organization perform any of these field performance tests, specifically on pavements constructed using WMA, but not on HMA pavements? (check all that apply)"

Value	Percent	Count
Smoothness	20.0%	2
Rut depth profile	10.0%	1
Visual distress survey	20.0%	2
ASTM "sand patch" test	10.0%	1
Bond strength between layers at construction	10.0%	1
In place thickness and density	20.0%	2
Bulk specific gravity	20.0%	2
Maximum theoretical specific gravity	20.0%	2
Other	80.0%	8

Other: (open-ended response to Other in previous question)	Agency
No	AZ, CO, DC, NM, TX, UT, VA
No special tests other than to waive temperature requirements	Dickinson Cty (MI)

Question 18: "Does your agency specification require the use of WMA?"

TABLE B16 Survey response to Question 18: "Does your agency specification require the use of WMA?"

Value	Percent	Count
Yes	12.2%	6
No	87.8%	43
	Total	49

Question 19: "Is there a certification process or qualification program used by your agency regarding WMA?"

TABLE B17 Survey response to Question 19: "Is there a certification process or qualification program used by your agency regarding WMA?"

Value	Percent	Count
Yes - a state process	52.0%	26
Yes - the AASHTO NTPEP on WMA	6.0%	3
No	42.0%	21
	Total	50

Question 20: "Please provide a copy of your WMA specification to wmaproject.20.44@gmail.com or insert a weblink."

TABLE B18 Survey response to Question 20: "Please provide a copy of your WMA specification to wmaproject.20.44@gmail.com or insert a weblink."

Response	Agency
A test section is required to be placed and monitored for two months before the specific WMA technology is allowed for further use.	NV
Approved list, looking to transition to AASHTO NTPEP on WMA	OR
California Transportation Dept. approved WMA technology.	City of Santa Rosa (CA)
For water injection no. For other technologies, we have to approve each by individual basis but this is not in the spec as we only allow water injection.	OH
IDOT WMA spec emailed to above address.	Lake County (IL)
Link to spec.: http://www.state.nj.us/transportation/eng/specs/2007/pdf/StandardSpecificationsforRoadandBridgeConstruction200720170223.pdf Link to NEAUPG process: http://www.neaupg.uconn.edu/pdf/NEAUPG%20WMA%20Qualification%20Process%206-24-2011.pdf	NJ
MassDOT Special Provision for WMA forwarded to gmail address.	MA
NETTCP approval.	RI
No formal written process but WMA products are tested to determine detrimental effects on binders before being approved for use in our product listing.	PA
Section 334-3.2.1 of the 2017 specifications at this link: http://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm	FL
Section 610 of Standard Specifications: https://connect.ncdot.gov/resources/Specifications/Pages/2012StandSpecsMan.aspx?Order=SM-06-610 Approved listing of WMA technologies showing Tiered system approach based on tonnage placed on DOT projects: https://connect.ncdot.gov/resources/Materials/MaterialsResources/Warm%20Mix%20Asphalt%20Approved%20List.pdf	NC
The approval process used by NY is similar to the one used by the NE States. http://www.neaupg.uconn.edu/pdf/NEAUPG%20WMA%20Qualification%20Process%206-24-2011.pdf	NY
VTrans follows NY DOT's approval process. Technologies approved by NY DOT are accepted by VTrans.	VT
Will copy to the above email in terms of our approval procedure. -Need to prove volumetric properties are same as HMA w/o WMA technology. -for foaming: need VDOT personnel to see the process and evaluate system at the plant to approve the plant. -Field Evaluation with test section: TSR, volumetric properties, binder check, temperature check, etc.	VA
http://apps.azdot.gov/files/materials-manuals/Policy-Procedure-Directives/ppd23.pdf	AZ
http://www.in.gov/indot/div/mt/itm/pubs/583_testing-b.pdf No specific requirements other than listing it in the QCP as part of the Certified Producer Program. (12.2.8) Basically just have the option to turn it on and off.	IN
http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/1207.pdf	KS

Response	Agency
http://www.mdt.mt.gov/business/contracting/ MDT's specification regarding Warm Mix can be found under Subsection 401.02.4 of the Standard Specifications which can be found at the link about. Also, there is a link to MDT's qualified products list on the same page. MDT's approval process is outlined there.	MT
http://www.neaupg.uconn.edu/pdf/NEAUPG%20WMA%20Qualification%20Process%206-24-2011.pdf	NH
http://www.odot.org/materials/pdfs-mcpubs/L_qual028.pdf	OK
http://www.scdot.org/doing/technicalPDFs/supTechSpecs/SC-M-408-(04-15).pdf	SC
https://www.tn.gov/assets/entities/tdot/attachments/List_39.pdf	TN
No real specs, just allow it http://wisconsindot.gov/rdwy/stndspec/ss-04-60.pdf#ss460	WI
www.codot.gov/business/designsupport/materials-and-geotechnical/manuals/2017-fmm/cps/CP-50s/13-cp-59-17/view	CO

Question 21: "What is a Contractor required to do to become pre-qualified for paving WMA on your projects?"

TABLE B19 Survey response to Question 21: "What is a Contractor required to do to become pre-qualified for paving WMA on your projects?"

Value	Percent	Count
Nothing is required beyond what is normally done to pave with HMA	88.0%	44
A separate process exists	12.0%	6
	Total	50

Question 22: "Please describe or provide a link to the online document that explains the process."

TABLE B20 Survey response to Question 22: "Please describe or provide a link to the online document that explains the process."

Response (open-ended response to Separate Process in previous question)	Agency
A QC Plan is required that outlines which process is being used. Main objective - set compaction temperature for volumetric testing (reheat if necessary), etc.	SC
As detailed in the specification I have emailed, we require 3 acceptable tests sections using WMA.	GA
No formal written process but WMA products are tested to determine detrimental effects on binders before being approved for use in our product listing.	PA
The process is outlined at this link: http://www.fdot.gov/materials/mac/production/warmmixasphalt/index.shtm	FL
www.codot.gov/business/designsupport/materials-and-geotechnical/manuals/2017-fmm/cps/CP-50s/13-cp-59-17/view	CO

Question 23: “How is cold weather paving (at temperatures less than 40^{0}F) specified?”

TABLE B21 Survey response to Question 23: “How is cold weather paving (at temperatures less than 40^{0}F) specified?”

Value	Percent	Count
Not specified	38.0%	19
By a method specification (i.e., if certain conditions exist, then must do “x”)	14.0%	7
By a required cold weather quality control plan (i.e., a mutual agreement between the contractor and owner)	18.0%	9
Other	30.0%	15
	Total	50

Other: (open-ended response to Other in previous question)	Agency
Contractors may place an unmodified binder mix at thicknesses greater than 1.0" when using a warm mix technology at 35 degrees F and rising. See section 330-3.2.2 of the 2017 FDOT specifications for details.	FL
Discuss with contractor, but no hard spec.	Dickinson County Road Commission
IDOT does not currently give any waiver on temps if using WMA. But LCDOT believes that late year required paving regardless of temperature benefits from using WMA.	Lake County Division of Transportation
In general, no paving below 40°F	VA
In our regular specs.	TX
Must be 50°F and rising to pave.	LA
Not allowed	OK
Our specs state "Do not place HMA leveling course when the roadway surface temperature is colder than 40° F."	State Pavement Engineer- AK
Paving is not allowed below 40°F on surface lifts. On sub-surface lifts between 1.5" - 4.0" lift thickness, paving is allowed below 40°F to varying temperatures depending if HMA or WMA.	KS
Same temperature requirements apply whether WMA or HMA	OH
The base or subgrade upon which asphaltic concrete is to be placed shall be prepared and maintained in a firm condition until asphaltic concrete is placed. It shall not be frozen or excessively wet.	AZ
We do not allow any paving below 40° F	MD
Not allowed below 35°F	DC
On a project by project basis using predetermined specifications	BC MOT
Using warm mix additive as compaction aid.	WI

Question 24: “Please estimate the total asphalt tonnage (tons) produced for your state/jurisdiction in 2016.”

TABLE B22 Survey response to Question 24: “Please estimate the total asphalt tonnage (tons) produced for your state/jurisdiction in 2016”

Value	Percent	Count
Less than 50,000 tons	22.4%	11
50,000 to 100,000 tons	12.2%	6
100,000 to 500,000 tons	6.1%	3
500,000 to 1 million tons	12.2%	6
1.5 to 5 million tons	44.9%	22
6 to 20 million tons	2.0%	1

Question 25: “Please estimate the proportion of WMA (relative to all of the asphalt produced) for your agency’s paving jobs in 2016 (%).”

TABLE B23 Survey response to Question 25: “Please estimate the proportion of WMA (relative to all of the asphalt produced) for your agency’s paving jobs in 2016 (%)”

Response	Agency
10%	FHWA WFL
10%	NC
10%	MI
10%	WI
1%	NV
1%	OR
3%	CO
3%	NY
5%	City of Santa Rosa CA
5%	SD
50%	City of Bellingham, WA
50%	UT
0%	Dickinson County Road Commission
0%	WA
0% Very few contractors have been interested, some use WMA Additives for compaction aid, I do not know of any projects built as WMA last year.	TN
0.5%	FL
14%	DE
15%	ME
20%	MO
20-35	AL
25 - 26%	CT
25%	MS
30%	DC
35%	TX
37%	MD
40%	IA
41%	Lake County Division of Transportation
5 %	AZ
5-10%	BC MOT
5.0%	RI
50%	OK
50-55%	OH
54%	NH
56%	VT
60%	KS
75%	PA
80%	LA
91.19%	MA
< 10%	SC
> 1%	GA
It depends on the Region/District; average use is about 20%.	AK
Less than 1%	MT
Less than 10%	ID
Not Possible. We currently have 110 approved HMA plants in Indiana. 42 of them are reported to have water-injection foaming capability. May or may not be used.	IN

Response	Agency
Unknown: Contractor options	CA
About 95% of production of HMA uses foam, but the temperature is not lowered by the producer.	MN
Between 30-35%	VA
Less than 5%	NJ

Question 26: "Have you observed that the amount of WMA usage over time has decreased (e.g., once the DOT required WMA on 50% of the projects in the state, but now WMA accounts for approximately 20% of the paving projects)?"

TABLE B24 Survey response to Question 26: "Have you observed that the amount of WMA usage over time has decreased (e.g., once the DOT required WMA on 50% of the projects in the state, but now WMA accounts for approximately 20% of the paving projects)?"

Value	Percent	Count
Yes	36.0%	18
No	64.0%	32
	Total	50

Question 27: "What do you believe the reasons to be? (check all that apply)"

TABLE B25 Survey response to Question 27: "What do you believe the reasons to be? (check all that apply)"

Value	Percent	Count
Environmental concerns are not monitored as closely (e.g., in non-attainment areas with air quality issues)	22.2%	4
No tracking mechanisms in place for monitoring how much or little WMA is being placed	16.7%	3
No standard specification directly related to WMA (e.g., permissive spec is used)	50.0%	9
No contractual incentives provided to encourage the Contractors to use WMA	66.7%	12
No observed benefits in bid pricing (e.g., use of WMA vs. HMA results in lower bid prices for paving jobs)	61.1%	11
Other reasons	55.6%	10

Other reasons: (open-ended response for Other in previous question)	Agency
Contractors are more interested in use of RAP than WMA	WA
Contractors do not see any benefit from WMA	DE
Contractors going away from foaming technology, additives cost extra and will only use it when absolutely necessary	ME
Contractors have not indicated interest, even when given the choice.	AK
In 2015, we removed the "No grade bump is needed for 26-40% RAP." See our 2013 spec book section 401.04 for extended RAP.	OH
Most of the contractors were just using water foaming and didn't see real benefit of it. So kind of went down after first two years and came back up in 2016. Maintenance of water foaming process at plant could also be a reason for this.	MD
No cost savings for the contractor	AL
Some local agencies do not allow WMA. Producers don't want to switch between HMA and WMA.	FL
WMA in Indiana really only entails dropping the temp to around 285F compared to 300 or 315F. It was less about the environmental concerns/heating costs and more about the improvement in mix workability and density achievement. WMA had higher interest when fuel prices (heating) were high and it resulted in more significant savings.	IN
If Contractors temperature drop is 10 degrees F or less, still called HMA	OR

Question 28: "How has your agency made progress in furthering the use of WMA technologies? (check all that apply)"

TABLE B26 Survey response to Question 28: "How has your agency made progress in furthering the use of WMA technologies? (check all that apply)"

Value	Percent	Count	Agencies
No progress has been made	31.3%	15	Multiple
Providing incentive clause in paving contracts that encourage the use of WMA technologies (e.g., through higher density, reduced number of working days, improved ride quality or texture)	4.2%	2	SC, FHWA WFL
Establishing specific environmental goals for the agency (e.g., mandate use of WMA technologies, etc.)	2.1%	1	MA
Customizing the Approved Product List to include WMA technologies that are classified according to their intended use (i.e., technologies that are used to produce at lower temperatures vs. technologies that are used as additives to aid compaction)	14.6%	7	WI, MD, MI, TX, CA, LA, City of Santa Rosa
Tracking the placement location and tonnage of asphalt mixtures using WMA technologies	22.9%	11	WI, CO, MD, MI, SD, NY, TX, WA, City of Santa Rosa, Lake County, City of Bellingham
Monitoring the field performance of pavements constructed using WMA technologies over time, as part of pavement management system (in conjunction with DOT Maintenance)	20.8%	10	PA, CT, KS, MI, SD, WA, LA, NY, Dickinson County, City of Bellingham
Use of end result specifications for asphalt mixtures including those with WMA technologies	31.3%	15	BC, NY, CA, WA, IA, SD, MI, MT, GA, MD, CT, MA, SC, WI, PA
Use of performance specifications for asphalt mixtures including those with WMA technologies	18.8%	9	WI, MT, KS, MI, SD, TX, LA, BC, City of Santa Rosa
Contract provisions requiring use of WMA technologies for certain times of the year or below certain ambient temperatures	16.7%	8	BC, CA, RI, SC, WI, ME, PA, City of Bellingham
Contract provisions requiring use of WMA technologies for longer haul distances or increased haul duration (due to congestion)	6.3%	3	RI, TX, BC
Encourage or require use of WMA technologies for projects in urban settings with reduced emissions requirements or in areas with local environmental permitting issues or concerns	6.3%	3	TX, MA, City of Bellingham
Providing training related to WMA technologies to the local agencies and members of the paving industry	14.6%	7	TN, ME, MA, CO, SD, TX, IA
Other	27.1%	13	

Other	Agency
Allowing the contractor to use it.	UT
Contractor option WMA	CA
Early pilot projects requiring WMA use. Requiring WMA in AARG mix. Requiring WMA between Oct. 1 and May 1.	NH
FDOT allows the minimum ambient temperature to be reduced by 5 degrees F when using a warm mix technology. See section 330-3.2.2 of the 2017 FDOT specifications	FL
Permissive Specification	OK
Put a spec in every paving job saying WMA is a contractor option. Mich DOT says we should not mandate WMA but let contractors choose to use it.	Dickinson County, MI
Requiring the use of WMA in order to capture the higher compaction potential of WMA mixes.	PA
Research	VA
There was a lot of progress between 2008 to 2010 but not much since then.	OH
WMA is permitted in NJDOT specs. but usage is up to contractor/supplier	NJ

WMA is required when PG 76-22 (64E-22) is specified.	CT
We have a permissive WMA spec (preapproved list), as seen in Table 702-3 here: http://www.dot.state.ak.us/stwddes/dcsspecs/assets/pdf/hwyspecs/sshc2015.pdf	AK
None	DC

Question 29: "Which material properties do you believe are the most critical to WMA performance? (check all that apply)"

TABLE B27 Survey response to Question 29: "Which material properties do you believe are the most critical to WMA performance? (check all that apply)"

Value	Percent	Count
In situ air voids	71.4%	35
Binder content	63.3%	31
Dust-to-asphalt ratio	38.8%	19
Mixture stiffness	32.7%	16
Mixture tensile strength	38.8%	19
Mixture compactability	71.4%	35
Other properties:	14.3%	7
Other		**Agency**
All the same properties as normal HMA		ME
Laboratory air voids		FL
I believe the moisture damage test is critical for WMA mixtures in addition to routine ones above		MD
Film Thickness		IA
Moisture Susceptibility		WA
Same for HMA		OH
VMA		VT

Question 30: "Which field performance properties do you believe are the most critical in WMA pavements? (check all that apply)"

TABLE B28 Survey response to Question 30: "Which field performance properties do you believe are the most critical in WMA pavements? (check all that apply)"

Value	Percent	Count
Rutting	64.6%	31
Moisture damage (e.g. stripping, raveling, potholes)	85.4%	41
Transverse low-temperature cracking	35.4%	17
Bottom-up or top-down cracking	45.8%	22
Ride quality	27.1%	13
Texture (skid resistance)	10.4%	5
Other distress:	8.3%	4
Other		**Agency**
Density		AL
Loss of temperature or lack of enough heat to properly compact the mixture		DC
Fatigue and longitudinal joint cracking		NY
All - same for HMA		OH

Question 31: “Has your agency funded research on WMA in the past 10 years in order to assist with its implementation in your state?”

TABLE B29 Survey response to Question 31: “Has your agency funded research on WMA in the past 10 years in order to assist with its implementation in your state”

Value	Percent	Count
Yes, university research	26.0%	13
Yes, in-house research	14.0%	7
Yes, consultant contracts	2.0%	1
Yes, a combination of above	12.0%	6
No	46.0%	23
	Total	50

Question 32: “Please provide a link to the state DOT reports related to WMA research.”

TABLE B30 Survey response to Question 32: “Please provide a link to the state DOT reports related to WMA research.”

Response	Agency
Another VTRC Final Report will be available soon	VA
For a paper in a presentation of our use of WMA at a CTAA conference	BC (Canada)
I will forward an email that has the links, 2008 trials summary, Colorado DOT peer exchange questions and answers, plus our usage up to 2014.	OH
LTPP SPS-10 Site	OK
Not available at this time. Research in progress.	NV
SD2008-03	SD
http://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/SPR631.pdf	AZ
http://tundra.ine.uaf.edu/wp-content/uploads/2013/07/207086.Final-report_WMA.Liu-ineautc1109.pdf TRB-LVR paper at: https://trid.trb.org/View/1107750	AK
http://wisconsindot.gov/documents2/research/final-reports-proj-briefs/WisDOT-WHRP-project-0092-12-02-brief.pdf	WI
http://www.mdt.mt.gov/other/webdata/external/research/docs/research_proj/warmmix/final_report and http://www.mdt.mt.gov/research/projects/warm_mix	MT
http://www.scdot.org.scltap/projects/completed/completed-page-2 SPR 680 "Investigation of WMA Technologies and Increased Percentage of RAP in Asphalt Mixtures"	SC
http://www.state.nj.us/transportation/refdata/research/reports/FHWA-NJ-2011-005.pdf	NJ
http://www.ucprc.ucdavis.edu/PublicationsPage.aspx	CA
https://connect.ncdot.gov/projects/planning/Pages/ProjectSearch.aspx	NC
https://minds.wisconsin.edu/handle/1793/53405	WI
https://trid.trb.org/view.aspx?id=1394386	NY
https://www.fhwa.dot.gov/innovation/grants/projects/mi_dickinson_finalreport.pdf	Dickinson County (MI)
Not published. Simply confirmed it was a viable option to use	IN
www.codot.gov/programs/research/experimentalfeatures/wma.pdf/view	CO

Question 33: "What are some best management practices that your agency has employed to effectively use WMA in your state/jurisdiction?"

TABLE B31 Survey response to Question 33: "What are some best management practices that your agency has employed to effectively use WMA in your state/jurisdiction?"

Best Management Practices	Agency
A permissive specifications that allows its use at any time.	OK
Allow contractors to innovative.	VT
Allow producers to use at will, when it is beneficial.	IN
Allow the Contractor to choose the WMA technology they want to use rather than specifying one.	ID
Allow the technology to be used and let the economics of it provide the incentive for it to be used.	UT
Allowing more flexibility for paving in cold weather	DC
Allowing producers to use it in a manner that suits them the best to obtain specified material properties and in-place density. Not specifying specific temperature reduction.	CT
Approved WMA technology. Same end result/performance specifications as HMA. Presence and input of WMA representative on project sites.	CA
Back in 2008: 1. Meetings with industry and ODOT districts 2. Extensive review of equipment and plant set-up 3. Have trial sections with controls to start out. 4. Educate contractors and placement crews on what to expect different/same compared to HMA	OH
Contractors have the option to use either WMA or HMA on a project. Once either is selected, the contractor will have to stay with that mix for the duration of the project.	MS
Discussion with contractors on the benefits and barriers to the use of the technologies. Many of our contractors are equipped with foaming devices and use them regularly.	LA
Encouraged its use on long hauls, polymer-modified binders, and touch placements	ME
Established an APL procedure for both WMA Technologies and contractors.	CO
Follow MnDOT HMA specification.	MN
IDOT special provision is required for all paving contracts that allows use of WMA at Contractors' decision.	Lake County
Implementing a permissive specification which allow contractors and producers to have the option to use WMA technology to produce asphalt mixture even when the contract specifies HMA.	NY
KDOT does not require a temperature drop if WMA additives are used so the additives are being used to aid with compaction and as anti-stripping agents.	KS
Keep trying to improve field density. Contractors probably use WMA as compaction aids to get better density and workability also at cold season.	VA
Leave this up to industry to make the decision for change to WMA. If they are sold on HMA, then let them continue. If there is a cost savings (low bid) and improvement then both parties win.	SC
MDT has simply adhered to existing production requirements. This has forced contractors to identify any modifications to their operations that are necessary due to the use of warm mix additives.	MT
Minimal use of WMA in Nevada.	NV
Moisture content of mixture Close monitoring of density by QC during temperature reduction to WMA	OR
Nothing that sets us apart from any local agency here in CA	City of Santa Rosa
Our permissive WMA spec (preapproved list), as seen in Table 702-3 here: http://www.dot.state.ak.us/stwddes/dcsspecs/assets/pdf/hwyspecs/sshc2015.pdf	AK
Permissive spec.	NJ
Put specs in every paving job telling contractors we will accept it.	Dickinson County
QC Specifications Incentives/Penalties Informally changed all HMA to WMA in all projects.	MA
Report 09-527 at this link: http://www.fdot.gov/materials/administration/resources/library/publications/researchreports/2006-2010.shtm	FL
Require minimum anti-strip additive addition to foamed asphalt mixtures to counter the negative effects of the foaming process on moisture susceptibility. This coupled with the increased density potential make WMA slightly better than HMA.	PA
Requiring WMA early and late in the season. Removing the ambient temperature restrictions, allowing contractor to proceed if he can achieve compaction.	NH
Specifications call for an either/or when using WMA and HMA.	AL

Best Management Practices	Agency
Specified its use during cold weather.	RI
Track location and use of WMA technology and compare performance compared to HMA.	WA
Use an additive for cold weather paving though not at lower production temps.	WI
Use of WMA is entirely optional. Contractors only need to submit a WMA mix design, with documentation, to use on highway and airport projects.	AK
Using approved product lists from multiple states to evaluate WMA products.	FHWA WFL
We do not prescribe any specific BMP's for use with WMA. Its use is at the option of the contractor. The contractor is expected to implement BMP's with help from the WMA Technology supplier.	NC
We have a permissive spec. We approve various products through our approval process and contractors could use any of approved products to produce WMA on any project.	MD
We have little experience with the process, but using proper mixture production and placement procedures are vital for all asphaltic concrete materials.	GA
We use it primarily for long haul distances, cooler paving seasons, in urban areas that are in non-attainment areas, as a compaction aid for stiffer mixtures.	TX
Working on tracking usage with tickets, including dosage rate. Will implement NTPEP WMA when it is ready. Allowed use at the contractor's choice, which saves all money.	WI
Allow WMA if meet current specifications.	SD
For use in late season paving contracts, workability and better asphalt pavement.	BC
Arizona DOT http://apps.azdot.gov/files/materials-manuals/Policy-Procedure-Directives/ppd23.pdf	AZ
Monitoring locations where it has been used. Developing specification: http://mdotcf.state.mi.us/public/dessssp/spss_source/12SP-501Z-04.pdf	MI

Question 34: “List some ideas regarding how to overcome the barriers that agencies face in increasing the implementation of WMA.”

TABLE B32 Survey response to Question 34: “List some ideas regarding how to overcome the barriers that agencies face in increasing the implementation of WMA.”

Response (open-ended question responses)	Agency
Discuss benefits of increase use of recycled materials and discuss environmental benefits and worker safety	DC
1. Conduct trials & open houses using some of the more common WMA technologies (with known successes). 2. Conduct workshops, speak at agency/industry meetings, etc., to promote the "green" aspects of WMA, as well as the potential cost savings due to reduced burner fuel requirements. Also, emphasize improvements in working environment due to reductions in heat and fumes produced versus HMA.	IA
1. For most mixes, there should not be restrictions on whether to use HMA versus WMA. Allow both and economics will decide. 2. Require WMA in areas like extending the season (but not with water injection) and reducing highly polymerized, thin lift pavement temperatures below X temperature. You do see better coating with foamed mixes so could include that drier mixes use WMA.	OH
1. Require WMA technology, both foaming and chemical, be used for all mixture production. 2. Make a clear distinction if it's WMA additive and require temperature limitation or use it as a compaction aid. In that case it will not be a WMA.	NY
A permissive specifications that allows its use at any time.	OK
Allowing the contractors to produce WMA in lieu of HMA on non-specified projects.	GA
Better define specifically what needs to be done by (or required of) contractors when using WMA. WMA has been "sold" to agencies and industry as the fix-all for asphalt: better coating, better mixing, lower fuel costs, less emissions, higher recycle content, better compaction -- the list goes on and on. However, no one has forced the contractors to change how they operate their plants when they switch to WMA - mixing cycle times are the same, recycle materials are introduced into the mixer at the same point (but with lower mixing temperatures, but the same mixing times), etc. No one has forced contractors to slow production or change how their plants are set up to produce same-level quality of mix, but at lower temperatures. At the same time, all of the above are difficult to enforce for an agency when we are trying to use much less prescriptive specifications than ever before. The Industry should lead the way in implementing best practices for the use of WMA.	NC

Response (open-ended question responses)	Agency
Better understanding and methods to employ application of WMA with RAP to ensure performance	WA
Continue education and training programs. Incorporating WMA into HMA specifications and procedures to show it is not that different.	ID
Contractor education. Performance comparisons between HMA and WMA.	KS
Contractors are used to using HMA and are slow to come around to change. Incentive plans could be implemented to encourage the contractors to switch over to WMA.	MS
Contractors have not expressed a desire to use it more. Normal hot mix asphalt paving is providing the desired performance.	NV
Cost savings for contractors in using WMA instead of HMA.	AL
Define WMA and the intended benefits (i.e. lower temperatures, reduced emissions, improved compaction, extended haul distances, etc.). Establish an APL process.	CO
Don't specify temperature reduction.	CT
Due to proliferation of WMA additives / processes, it would be good to have an established evaluation process that manufacturers would provide to bring new products into the market place.	FHWA WFL
Educating the contracting community about the economic (compactibility, density pay bonus, less plant fuel usage) and environmental (reduced emissions, fumes) benefits of WMA usage.	AK
Employ pilot projects to demonstrate the advantages of WMA.	CA
I plan to have a local agency meeting hosted by us to discuss "WMA Day" paving options throughout the year.	City of Santa Rosa
Illinois DOT currently gives no benefit to contractor for using WMA (no lower paving temp allowed). Indirectly get benefit of ISTHA requiring contractors to produce WMA to be eligible to bid on ISTHA projects. This is good for big suppliers, but some smaller non-tollway pavers exist in our area.	Lake County
MichDOT says it must be an option, and should not say it must be done.	Dickinson County
Mandate WMA additives with temperature reductions. Encourage temperature reductions via incentives. Determine if the use of foaming with its limited temperature reductions is adversely impacting the rollout of WMA.	MA
Marketing to producers of HMA.	MN
Mixture testing that shows it to be as durable as HMA.	RI
NJDEP will need to require the usage of WMA by HMA plants to reduce emissions. Industry will only use WMA when it is in their best interest (financial).	NJ
None	DE, FL, IN, OR, VT
Offer cost incentives. Provide mix design assistance.	AK
Performance testing of mixes will help. It will define which products really do perform.	WI
New technology [and want to carefully consider] the risk to taxpayers' funds to do a research project that may fail.	SC
Specifications are permissive and not encouraging industry to use WMA technologies.	AZ
Specifying maximum temperatures in demonstration projects to show that compaction is attainable at lower temps.	NH
Start addressing the moisture susceptibility issue and gather large amounts of compaction data on a both HMA and WMA mixtures to show that WMA has a benefit (even just slightly) for the compaction of asphalt mixtures. This makes WMA better than HMA and then agencies will be more likely to embrace WMA.	PA
The Montana contracting community does not believe there is a monetary benefit to using warm mix technologies. The Department required the use of WMA technologies on roughly a half a dozen projects in order to introduce the technologies to the local contracting community but only one contractor appears to be actively using WMA on MDT projects.	MT
Training for contractors	ME
Use with recycled materials is challenging	TX
We may have to incentivize the WMA usage by showing some merit to contractor, or mandate the use of it under certain circumstances in order to get real benefits of it.	MD
We're not sure why there should be any barriers. Simply modify expectations of what production and laydown temperature ranges should be.	MO

Response (open-ended question responses)	Agency
With the emergence of performance testing, it seems a lot of avenues will open regarding the freedom to try (or increase the use of) new technologies.	LA
Work with your batch plants to become comfortable with the technologies available. Agencies need to just go for it and test a few small installations.	City of Bellingham
Cost of chemical additives	MI
Just need to specify the WMA pavement	BC
Improvement of field density.	VA
Need to show benefit to Contractor incentive to use	SD
There are no barriers yet voluntary use is low	WI

APPENDIX C

Industry Survey Questions and Results

Survey Questionnaire for Industry

INTRODUCTION/BACKGROUND

The purpose of this appendix is to present the survey questions distributed to both asphalt paving contractors and producers of WMA to capture the views of the industry on the current usage and impacts of WMA technologies through Survey Gizmo® and to present a summary of the results.

Question 1: “How does your organization define Warm Mix Asphalt?”

TABLE C1 Survey response to Question 1: “How does your organization define Warm Mix Asphalt?”

Response
1. Reducing mixing temperature, 2. Compaction Aid
Admixture or Foaming technology that allows mixing temperature of 30 degrees F less than traditional HMA.
Any HMA incorporating a WMA technology
Any effort towards reducing the temperature of an asphalt mix
Any mix produced at a reduced temperature. (roughly 240 degrees F)
Any mix that is produced at temperatures 30 degrees Fahrenheit or lower than typical HMA mixing temperature of the asphalt binder, as defined by the asphalt supplier. The WMA can be manufactured through use of foamed asphalt and/or chemical additive processes.
Any mix under 285 degrees F
Asphalt produced under 300 degrees F
Basically an HNA built with a reduction of production, paving and compaction temperatures, achieved by either using a foaming method or using an additive, such as Evotherm
By Process or Additive
Chemical additive or process that allows 15 degrees F or more reduction in production and placement temperature
Defined by technology type
FLDOT specifies it as made at 285°F or less. I think the definition of WMA needs to be re-evaluated.

Response
Hot mix asphalt that uses an additive to do one or more of the following: decrease temperature, increase compaction, decrease emissions.
If using the foaming method 275ºF and if using the additives 235ºF.
It is open for discussion currently. As a membership organization our members us WMA as warm mix and to reduce temperatures, while others simply as a compaction aid.
Mix discharged below 275 degrees F
Mix enhancer and additive which meets the Northeast requirements as an Approved Warm Mix Technology
Mixtures produced using a recognized WMA technology which is produced at a temperature lower than conventional temperatures (must be at least 10 degrees F cooler).
Most typically by mix that has been foamed. "Warm" mix term is subjective, and difficult to manage out of batch plants, as hot bin aggregate temperatures can't be varied, and private customers often want "Hot" mix.
NEAUPG defines Warm Mix Asphalt as a material produced utilizing technology that allows for a reduction in production temperature to 275ºF or less. Allowable technologies include organic and chemical additives, foaming (water), or a combination of additive and foaming. MassDOT defines Warm Mix Asphalt as a material produced utilizing technology "capable" of reducing production temperatures to 260ºF. Allowed are organic and chemical additives. Foaming by water or steam is not allowed.
Production of WMA at 35 to 100 degrees F lower than that HMA
Reduced mixing temperature and Compaction aid
Reduction of hot max asphalt production temperatures, as defined by the temperature-viscosity curve for a given asphalt binder, by 15 degrees F below the low end of the temperature-viscosity curve production temperature
Target temperature 275 degrees F with field production tolerance of ± 25 degrees F
Temperature reduction and compaction aid.
The production of asphalt pavement with technologies that allow for production at reduced temperatures.
Use of WMA technologies to reduce the temperature at which asphalt mixes are produced and/or compacted (as with HMA, there isn't a set temperature).
Utilization of a WMA Technology
Utilizing either a water foaming device or additive to aid in performance or constructability of the asphalt mixture. If temperatures can be lowered that is fine but it is not the main goal. Most of the time we foam hot - we don't utilize additives often.
WMA is defined within PennDOT through the use of an additive and/or asphalt foaming process. In addition, a lower, defined temperature range must be documented, prior to production.
WMA is hot mix asphalt that can be mixed and placed at lower temperatures. Foaming and chemical technologies can modify mixes to meet this goal.

Response
Warm Mix Asphalt: a term used to describe the lower production, placement and compaction temperatures required in conjunction with the application of one of several approved warm mix asphalt technologies.
Water injected asphalt
We define WMA as an asphalt mix that utilizes technology that Improves asphalt mix compaction density and Improves asphalt film thickness of the mix aggregate.
We define it based on contractual definitions from the DOT.
We do not "define" WMA...we use technologies to enhance characteristics and/or maximize benefits (extend hauling distance, cold weather paving, etc.). The NYSDOT does define WMA, and they accept based on any reduction in production temperature.
We suffer from an overall lack of a national WMA definition. Generally for reporting we would look at least a 10 degrees F delta relative to the standard production temperature. Most all of our WMA mixes are within 30F of the production temperature of the conventional mix.
Any asphalt that uses a WMA technology
Any process that allows a reduction in temp and increases time to finish

Question 2: “How many asphalt plants does your paving company currently operate?”

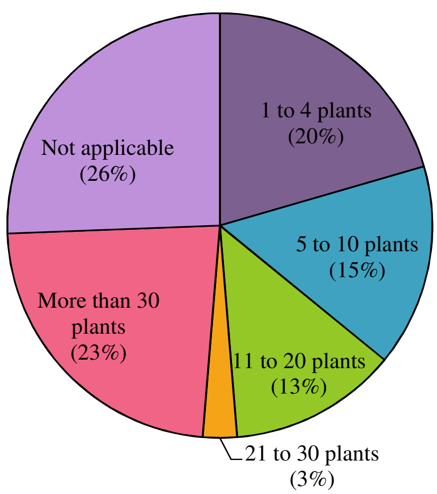


FIGURE C1 Survey response to Question 2: “How many asphalt plants does your paving company currently operate?”

Question 3: “Please estimate the total asphalt tonnage (tons) your organization produced for your state DOT clients in 2016.”

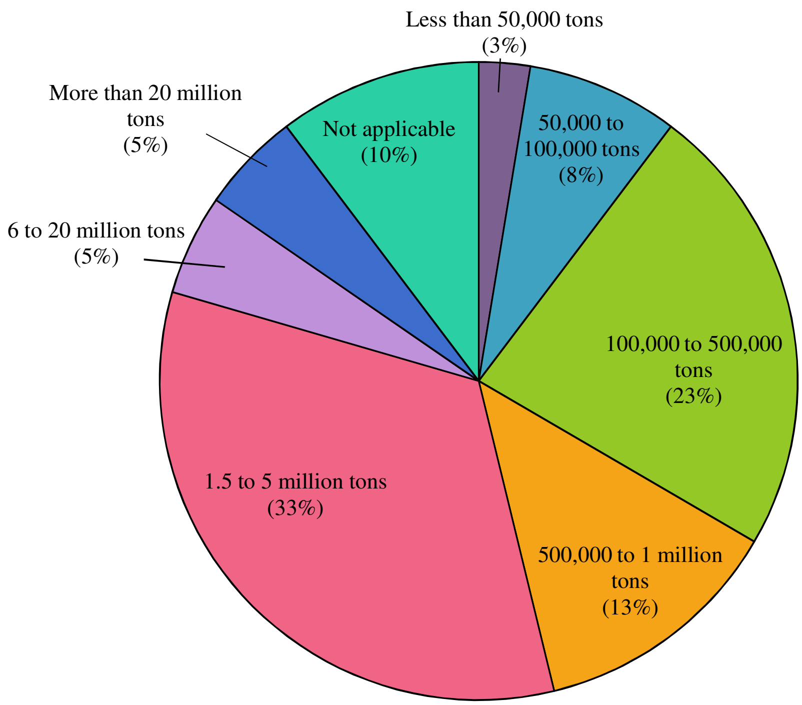


FIGURE C2 Survey response to Question 3: "Please estimate the total asphalt tonnage (tons) your organization produced for your state DOT clients in 2016."

Question 4: "Please estimate the relative proportion of WMA that your organization produced for your state DOT clients in 2016."

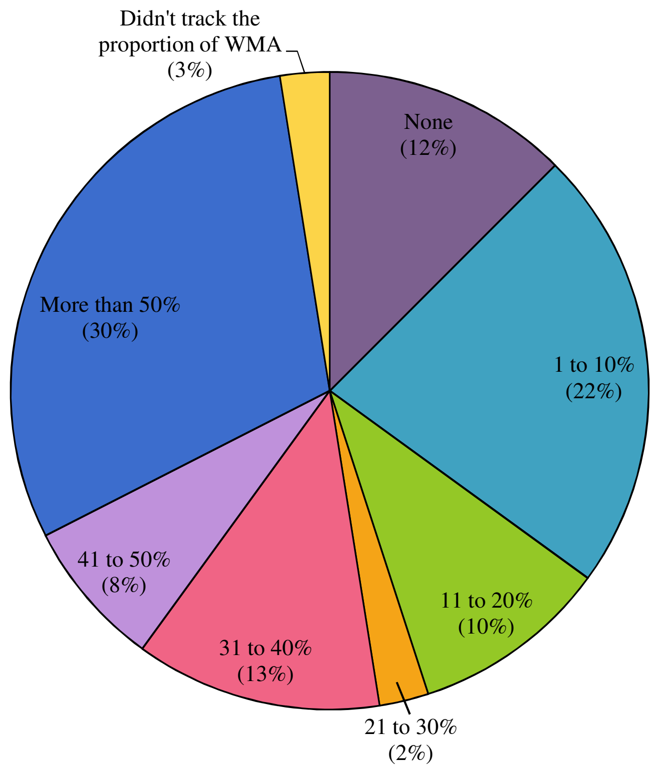


FIGURE C3 Survey response to Question 4: "Please estimate the relative proportion of WMA that your organization produced for your state DOT clients in 2016."

Question 5: "Please estimate the total asphalt tonnage that your organization produced for other entities that you do business with (e.g., cities, counties, municipalities, private/commercial customers, turnpike or expressway authorities, port authorities, airports, etc.) in 2016."

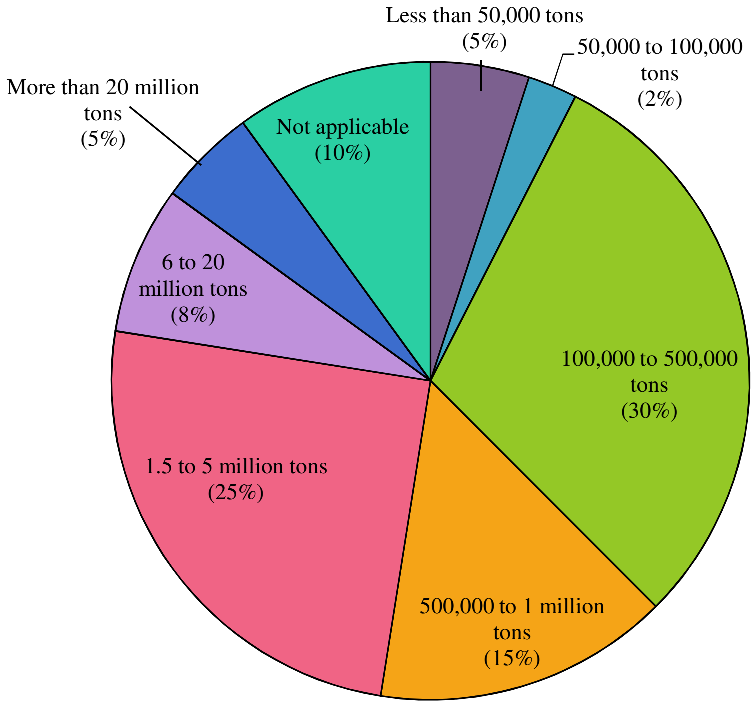


FIGURE C4 Survey response to Question 5: "Please estimate the total asphalt tonnage that your organization produced for other entities that you do business with (e.g., cities, counties, municipalities, private/commercial customers, turnpike or expressway authorities, port authorities, airports, etc.) in 2016."

Question 6: "Please estimate the relative proportion of WMA that your organization produced for other entities that you do business with (e.g., cities, counties, municipalities, private/commercial customers, turnpike or expressway authorities, port authorities, airports, etc.) in 2016."

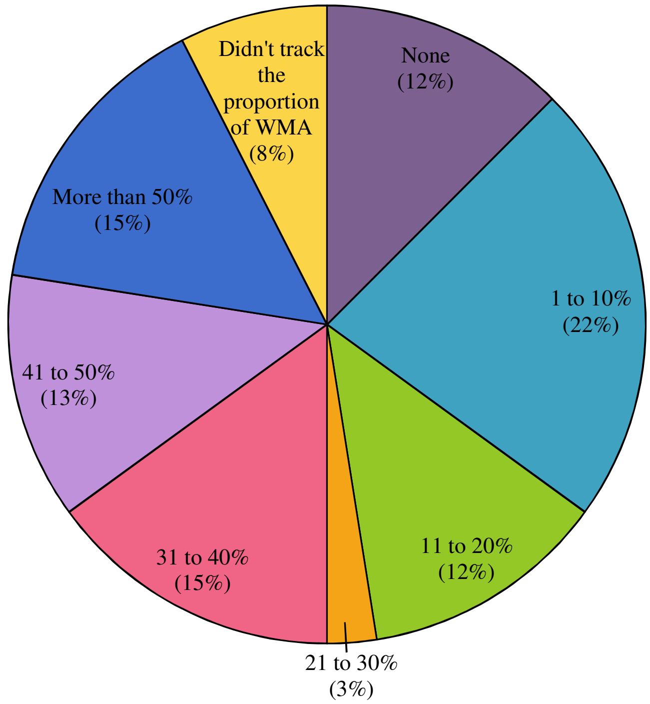


FIGURE C5 Survey response to Question 6: “Please estimate the relative proportion of WMA that your organization produced for other entities that you do business with (e.g., cities, counties, municipalities, private/commercial customers, turnpike or expressway authorities, port authorities, airports, etc.) in 2016.”

Question 7: “Have you observed a reduced demand for WMA in the past few years (e.g., once the DOT required WMA on 50% of the projects in the state, but now WMA accounts for approximately 20% of the paving projects)?”

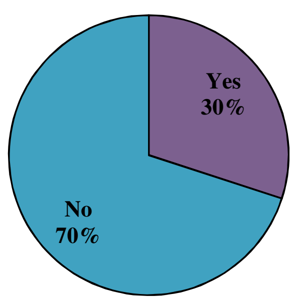


FIGURE C6 Survey response to Question 7: “Have you observed a reduced demand for WMA in the past few years (e.g., once the DOT required WMA on 50% of the projects in the state, but now WMA accounts for approximately 20% of the paving projects)?”

Question 8: “What do you believe the reasons to be for the reduced demand for WMA? (check all that apply)”

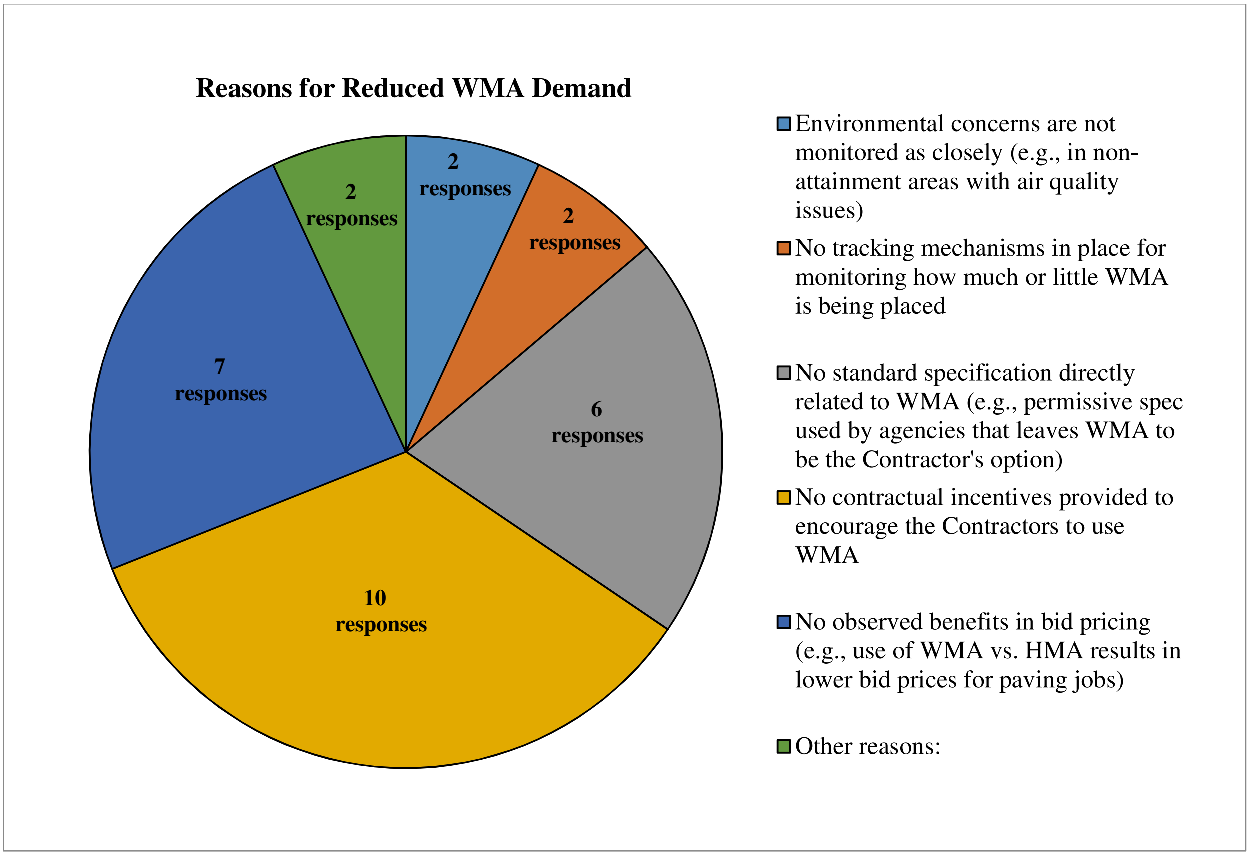


FIGURE C7 Survey response to Question 8: “What do you believe the reasons to be for the reduced demand for WMA? (check all that apply)”

Question 9: "Please indicate the reasons why your organization has used each of the various categories of WMA technologies (check all that apply)"

TABLE C2 Survey response to Question 9: "Please indicate the reasons why your organization has used each of the various categories of WMA technologies (check all that apply)"

	Material Processing (e.g., LEA, hot-coated coarse aggreg. + moist fine aggreg.+ additives)	**Organic Additives (e.g., waxes, Zeolite)**	**Chemical Additives (e.g., surfactants)**	**Foaming Processing (e.g., water injection, Zeolite)**	**Hybrid Systems (e.g., water injection and surfactant)**	**Hybrid Systems (e.g., water injection and organic additive)**
Reasons for Various WMA Technologies	Count	Count	Count	Count	Count	Count
Not used to date	22	12	9	7	15	16
Used to achieve better compaction	1	8	30	28	10	3
Used to maintain temperature for longer haul distances or haul durations (due to congestion delays)	0	3	22	20	6	1
Used to target lower production or placement temperature for emissions or energy savings	1	5	25	21	7	2
Used to extend paving season or to allow paving at night (at ambient temperatures less than 40^0F)	0	7	26	19	5	2
State Demonstration Project	2	2	1	2	0	0
Can place mixture in thicker lifts in reconstruction projects	0	0	1	0	0	0
Handwork or workability	0	0	1	1	0	0
Increase use of recycled materials	0	0	1	1	1	0

Question 10: "Which types of mix variations has your organization tried with WMA, and to what extent? (check all that apply)"

TABLE C3 Survey response to Question 10: "Which types of mix variations has your organization tried with WMA, and to what extent? (check all that apply)"

	Not Used to Date	Tried It Once	Use Occasionally	Use Regularly
Types of Mix Variations Tried with WMA	Count	Count	Count	Count
Polymer-modified (SBS, PPA, etc.)	4	0	13	16
RAP	2	1	5	31
Rubber	18	1	8	4
SMA	14	0	10	9
TLA	26	1	2	0
Recycled asphalt shingles	8	3	10	10
Recycled ceramics or glass	29	1	0	0
Antistrip additives (lime, cementitious materials, etc.)	6	2	7	16
Open Graded Friction Course	0	0	0	1

Question 11: "Do you find that it is easier to reach field compaction targets when constructing your projects with WMA?"

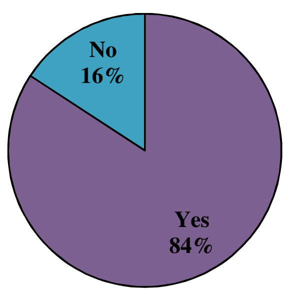
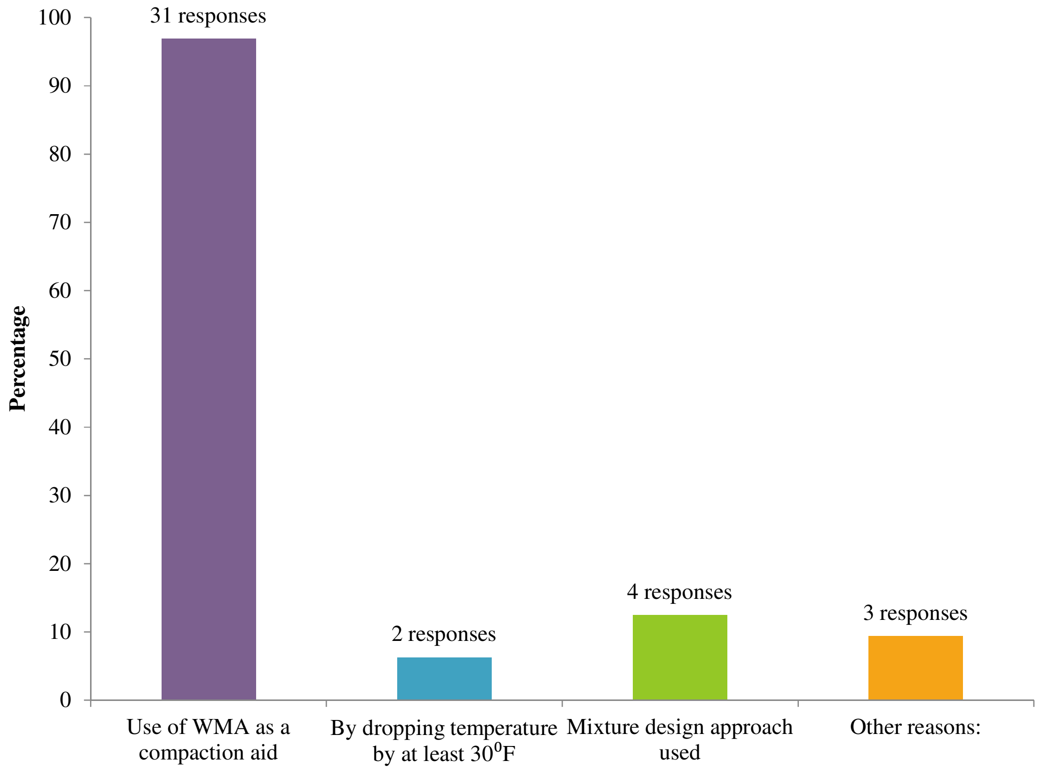


FIGURE C8 Survey response to Question 11: "Do you find that it is easier to reach field compaction targets when constructing your projects with WMA?"

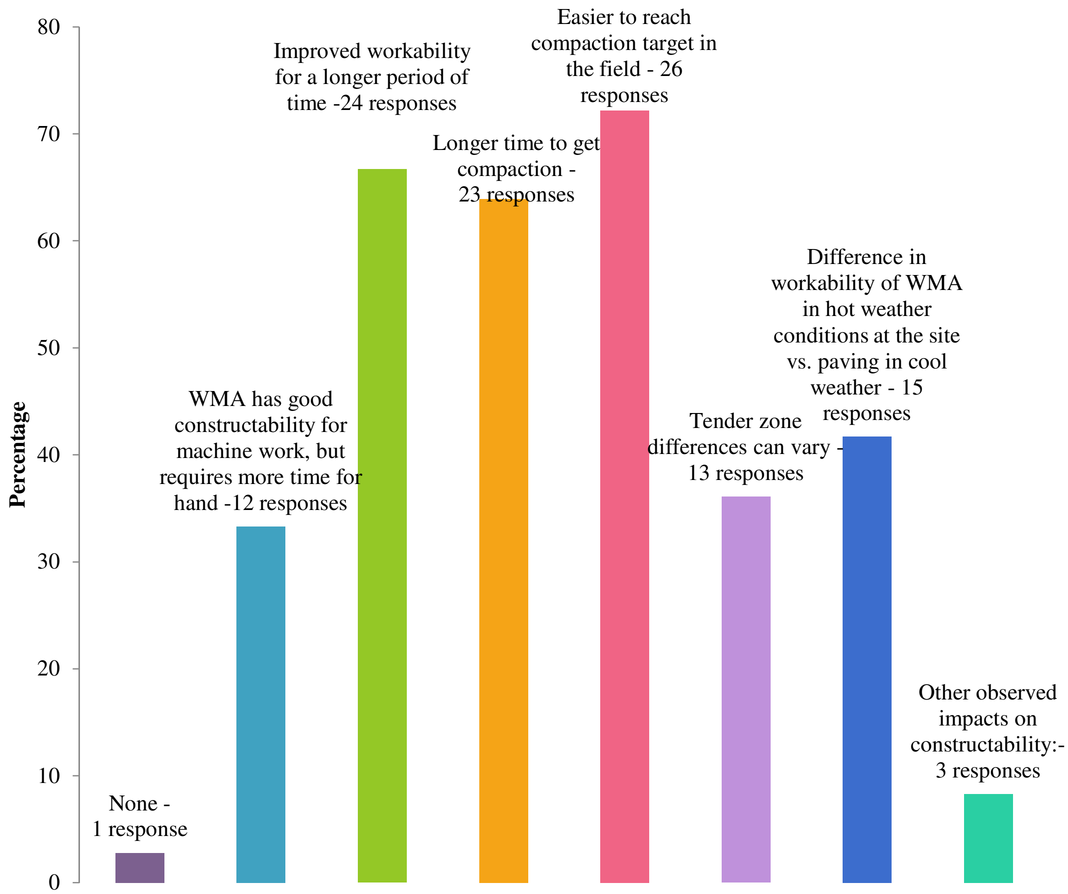
Question 12: "What do you believe the better field compactability was a function of? (check all that apply)"



Other reasons:
Change in Pbe of the mix, which led to increase in the total asphalt content
Foaming
Temperatures typically lowered less than 30^0F

FIGURE C9 Survey response to Question 12: "What do you believe the better field compactability was a function of? (check all that apply)"

Question 13: "What are some of the observed impacts of using WMA on the constructability of flexible pavements? (check all that apply)"



Other observed impacts on constructability:
Handwork is more forgiving
Results have varied, mostly produce warm mix when required, and mostly use foaming.
Surface texture varies with different WMA additives

FIGURE C10 Survey response to Question 13: "What are some of the observed impacts of using WMA on the constructability of flexible pavements? (check all that apply)"

Question 14: "Does your organization run any different laboratory or field tests on WMA as compared to HMA?"

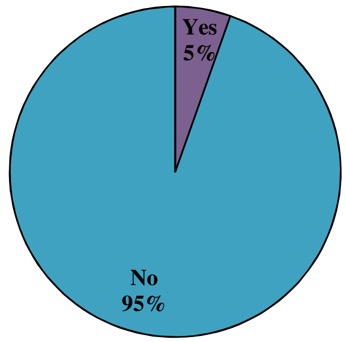


FIGURE C11 Survey response to Question 14: “Does your organization run any different laboratory or field tests on WMA as compared to HMA?”

Question 15: “Please describe the laboratory or field tests that you run on WMA specifically (not required for HMA).”

TABLE C4 Survey response to Question 15: “Please describe the laboratory or field tests that you run on WMA specifically (not required for HMA).”

Response
Conditioning of the mix for 2 hours before molding for lab molded properties.
Mixes must meet Indirect Tensile Strength when you first use it, then it is tested once every 30 days.

Question 16: "Have you observed that any of the conditions listed significantly affect the short term or long term field performance of WMA, as compared to HMA pavements? (check all that apply)"

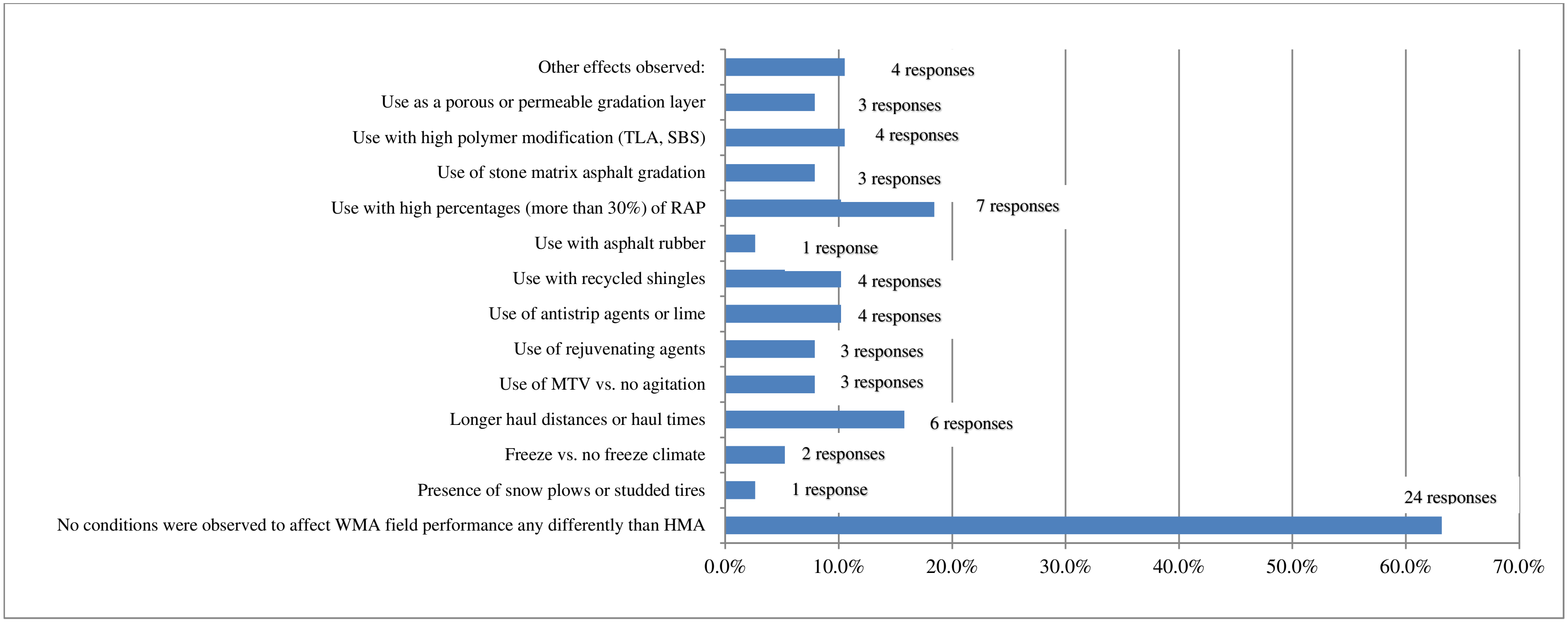


FIGURE C12 Survey response to Question 16: "Have you observed that any of the conditions listed significantly affect the short term or long term field performance of WMA, as compared to HMA pavements? (check all that apply)"

TABLE C5 Other effects observed in response to Question 16: “Have you observed that any of the conditions listed significantly affect the short term or long term field performance of WMA, as compared to HMA pavements?”

Other effects observed:
Liquid deicing agents, such as potassium chloride
Placing traffic on WMA pavement at or slightly above 140°F. Sometimes a sheen develops which may or may not be slippery.
Some tenderness in summer months.
We waited until the next day to fill in core holes and noticed that the edges of the core holes had curled into the hole - for SonneWarmix at 0.75% of AC. It is possible that this higher dosage caused this to occur, July 2015, no known pavement problems to date. Also, crews like the decrease in higher temperature fumes.

Question 17: “Have you observed any of these benefits with the use of WMA? (check all that apply)”

TABLE C6 Survey response to Question 17: “Have you observed any of these benefits with the use of WMA? (check all that apply)”

Benefits	Percent	Count
Reduced emissions from mixture production or paving operations	67.6%	25
Improved workability in the field over a longer period of time	64.9%	24
Asphalt temperatures held constant for increased haul distances or haul duration (due to congestion delays)	59.5%	22
Improved worker conditions (less fumes, reduced smoke)	59.5%	22
Extended paving season (at temperatures lower than 40°F)	54.1%	20
Energy conservation at the plant (e.g., reduced fuel usage)	51.4%	19
Helps to prevent stripping of the mix	27.0%	10
Energy conservation in the field (e.g., reduced fuel usage by being able to remove one or more compaction rollers)	21.6%	8
Less time needed to construct and compact pavement	21.6%	8
Improved pavement durability and longer service life	18.9%	7
Lower optimum asphalt content than will HMA mix designs	16.2%	6
Other benefits:	10.8%	4

Other benefits:
Increased film thickness and less effective binder content differential in comparison to HMA effective binder contents
Replaces lime as the antistrip in asphalt mixtures
Drain down of porous mixes

Question 18: “What are some best management practices that your organization has used to effectively use WMA on paving jobs?”

TABLE C7 Survey response to Question 18: “What are some best management practices that your organization has used to effectively use WMA on paving jobs?”

Response
1.8% better compaction without any change in process
As a compaction aid
Communicate the type of mixture (HMA vs WMA) to the end user. Use foaming equipment for all mixes to ensure consistency of mixes being produced.
Communicate with the plant to know the production temperature. Roll as aggressively as in HMA to attain compaction earlier when possible or extend compaction window
Constant delivery and the use of Material Transfer Vehicles and Material Transfer Devices
Foam everything
Focus on constructability(compaction aid) with temperature reduction (fuel use/emissions) secondary
Generally best practices same as HMA
It is primarily used on OGFC mixes, which it has helped with workability on those mixes.
Maintain a consistent paving speed; set-up delivery speeds to your paving speeds. In addition, change roller patterns several times/day, based upon ambient temp., to achieve best possible densification.
Maintain mixing temperatures over 300 degrees F.
Monitor production temp versus compaction on the grade. This is impacted by haul time, lift thickness and ambient temperature.
Pavers with good "screed assist" to help reduce screed bumps. Increase WMA temp. by 30 deg. F when doing hand work.
Proper truck management and education of those involved in the laydown process
Same BMPs
Treat every warm mix method and mix design differently. Reduce temperature as mix, process, and conditions allow. Not a cookie cutter approach.
Treat it like asphalt. All best mgmt. practices apply.
Typically ordered pre-blended in the asphalt.

Use similar paving practices for both WMA and HMA.
WMA best practices really fall in line with conventional mix best practices. Must be careful with handwork when using WMA.
WMA is, generally, not used in GA. One project is upcoming, but it's an FHWA test project, which is something of a different animal.
WMA mixed at Binder facility for better quality.
Warm up plant at conventional temperatures and then back temperature down.
We always try and use the driest material available so that the recycle products in the mix do not steam too much and drastically reduce the mix temperature by the time it arrives on the job.
We are not a contractor.
We have been fortunate to try various types of WMA technology, all additions to either AC or mix. We have not invested in any mechanical foaming equipment. BM practices, currently to have the WMA technology incorporated into the asphalt at the terminal (but we are considering adding a tank and injection system to be able to utilize different WMA additives as prices change). We also do not try to drastically lower the final mix temperature, producing mixes with PG64-22 at 285°F to 290°F and PG76-22 at 305°F to 310°F most of the time. When we do utilize WMA at lower temperatures, we begin higher in the AM and slowly lower the mix temperature throughout the morning.
Working with Oklahoma DOT and the Oklahoma Turnpike Authority, to educate them on the benefits.
Would foaming system we prefer to foam hot.
Major temp reduction with porous mixes
Providing education to the DOT on the benefits and usage of WMA
We run our WMA system all the time. we use water mostly, but do use chemicals at times
With the chemical additive you really need to watch your temps

Question 19: “What types of difficulties has your company had to overcome in implementing WMA? (check all that apply)”

TABLE C8 Survey response to Question 19: “What types of difficulties has your company had to overcome in implementing WMA? (check all that apply)”

Types of difficulties	Percent	Count
Cost of WMA technology additives	67.6%	25
Inconsistent demand for WMA technologies among different customers (DOT vs. local agencies vs. airports vs. private)	56.8%	21
Lack of familiarity with WMA among different customers (local agencies, airports, private vs. DOT)	56.8%	21
Prescriptive specifications that require minimum production temperatures or that restrict tonnage	45.9%	17

Meeting agency specifications or approved product list (e.g., restrictions on approved WMA products by agency)	40.5%	15
Contractual issues with customers (e.g., no incentive clauses, last-minute switches from WMA to HMA, etc.)	37.8%	14
Maintenance and upkeep of equipment at the plant (e.g., foaming tips get clogged and have to be constantly cleaned; clogged bags in bag house; replacing bags in bag house, reflighting the bags, etc.)	32.4%	12
Cost of equipment to produce the WMA technology	24.3%	9
Lack of quantification of the cost benefits of using WMA technologies	24.3%	9
Lack of information on the impacts of combining WMA technologies with other mix elements like PPA, lime, fibers, SMA, etc.	21.6%	8
Batch vs. drum plant gives different (or insignificant) fuel cost savings	18.9%	7
Initial installation, set-up, and logistics to continue use of WMA	13.5%	5
Other challenges:	13.5%	5
Convincing upper management to run WMA jobs on a more frequent basis (for better operation of equipment over time, greater cost savings, more competitive bid pricing, etc.)	8.1%	3
None	8.1%	3

Other challenges:
Asphalt cement storage at HMA facilities
DOT needs to limit the number of ESAL ranges, so more consistent mix can be produced; less is more. This vast range of available mixes has handicapped operations, due to not being able to set-up plants for a more fixed temperature range. Ex. adjusting flighting to keep baghouse temperatures above dew point
Employee complaints (fumes) when using amine based chemical WMA additives
Hard temperature restrictions by agencies. For example, defining WMA as maximum of 270F without regard to the conventional mix being modified.
Incorporation of 0.5% antistrip additive into WMA.

Question 20: “Name one barrier that you have observed which prevents the more widespread use of WMA by paving contractors.”

TABLE C9 Survey response to Question 20: “Name one barrier that you have observed which prevents the more widespread use of WMA by paving contractors.”

Response
Cost
As AC cost and plant burner fuel has come down, it has affected the cost savings for WMA. Need to educate that even if a little higher cost, use of Evotherm produces a superior, more durable product.
CDOT approval and Mix Design process

Response
Calling it Warm Mix. See below.
Caltrans Non Standard Specification allow the Districts to disallow the use of foamed asphalt technologies. This is a common practice in California.
Change
City, Local Specifications that are resistant to WMA. PennDOT's restrictive specification to foaming.
Cost to purchase chemical WMA additives
Cost/benefit in a low bid environment.
Customers do not like change (hot mix)
DOT will not accept foaming on Highway projects.
Does not work well for smaller projects requiring a lot of hand work
DOT restrictions and no state endorsement.
Full implementation of performance testing; let the contractors design mixes based upon performance, not merely fixed specifications.
Inconsistent definition of what is "Warm Mix", and unnecessary restrictions by DOT.
It is mandated that any chemical modification must be terminally blended. This allows liquid producers to control market.
Knowledge....
Laborers complain of stiffer mix making it difficult to work with.
Lack of acceptance by some paving contractors who purchase mixture FOB.
Lack of knowledge of WMA by specifying agencies. Generally non State DOT agencies.
Lack of understanding by the customer of the merits of WMA when proposed.
Lack of understanding of the process of warm mix and extended workability
Little to no fuel savings
Old thinking. Scared of change
PennDOT is now 100% WMA. Effort now is to bring PA Turnpike Commission, municipal and commercial markets into using WMA

Response
Roller Patterns / Compaction Process
Running multiple projects on a daily basis in which one requires WMA and the others do not.
State agencies setting a maximum temperature limit on WMA. There needs to be consideration as to what the conventional mix is that is being run as WMA. For example a conventional mix with a production temperature of 340°F could see benefit from a production temperature of 300°F. However if the specification was set to 270°F maximum, the WMA could not be practically used.
The greatest barrier would be that we still make HMA as well.
The requirement of anti-strip when using a limestone/dolomite aggregate
There is no financial reason to use WMA. Fuel costs are low, liquid anti-strips are not allowed, and whether an up-front foamer cost or an ongoing additive cost, WMA represents an increased cost that a competitor does not have.
When the producer isn't the contractor as is the case in NYS very often, producer doesn't want the expense of WMA. State is permissive so producers don't always have to use it.
In regards to comment above, education towards the difference aside from the temperature to the Owner
Lack of knowledge
The state agency is not willing to use plant-injected chemical additives

Question 21: “List some ideas regarding how to overcome the barriers that Contractors face and to increase the implementation of WMA.”

TABLE C10 Survey response to Question 21: “List some ideas regarding how to overcome the barriers that Contractors face and to increase the implementation of WMA.”

Response
-Township/Muninicpal Meetings regarding WMA vs. HMA performance -WMA marketing to the public as "green" technology -LEED credits and/or Engineering credits on commercial projects that encourage the use of WMA -Mandatory implementation of WMA
Agency incentives
Allow WMA to be used in lieu of lime as an antistrip additive.
Allow contractors to meter chemicals at plant, similar to hydrated lime.
As contractors are seeing the difference, they are slowly converting.
Better "Tech Note" literature (short summaries) explaining WMA to customers by an authoritative association.
Continue to educate specifying agencies on WMA
Drop the distinction between warm mix and hot mix. Let it be asphalt mix and let the contractors sort it out based on their market and other factors. If it is a truly good idea and brings cost and performance benefits, the contracting community will endorse it or tweak it and use it. As mentioned earlier, we see the technology being used, just not at the designated temperature drop recommended. Please don't try and mandate it.
Educate customers.
Educate municipalities on the potential longevity benefits of WMA.
Education / QC Representation
Education of the specification writers
Education on the differences in WMA vs. HMA, need to overcome the cultural bias of hotter is always better.
Educational discussions regarding the impact of the lower temperatures
Eliminate HMA from PA DGS Bituminous ITQ Contract. Municipalities procure asphalt mix from this contract. Promote through LTAP, PSATS, Boroughs Association, etc. Eliminate HMA from PennDOT Pub 408.
Encourage agencies to see the value in 1) any temperature reduction from the conventional and 2) improved/more consistent compaction of the WMA mat.

Response
In our state a lot is dictated by FHWA, a more concise description of what they want and expect out of WMA would help
Less prescriptive specifications.
“Lunch and Learn” presentations are good tools to implement with different agencies in order to convince them to give WMA a try.
Mandate WMA with no temperature reduction for agency work.
More research on how WMA improves pavement performance, LCCA, how it works with the new performance tests, how to deal with the cost at bid time.
None available for DOT work
Require it for all night paving, early and late season paving.
Specify WMA, make people use it. It seems in our industry, this is the best approach for change.
The selection of WMA technology should be based on production and placement temperatures not a bias against foamed asphalt technology.
There are several benefits associated with the use of WMA. Which are actually the most important, and what tools can we use to approach our industry partners with the goal being increased implementation?
Training
Training and Education of local specification writers. County, City, and Township Officials.
More education
Proven technologies need to show cost savings
Simplify the acceptance criteria
We need to get the smaller outside customers used to the idea of WMA and get them on board with the benefits

Appendix D
Workshop Proceedings

2-Day National Workshop NCHRP 20-44(01) WMA Implementation, Irvine, California – May 8 and 9, 2017

Overview of 2-Day National Workshop, Providence, Rhode Island – September 20, 2017

TRB Straight to Recording for All: Increasing Warm Mix Asphalt Implementation (online) – November 28, 2017

Pennsylvania Asphalt Pavement Conference, Harrisburg, Pennsylvania – January 30, 2018

MidAtlantic Quality Assurance Workshop, Dover, Delaware – February 14, 2018

NCHRP Project 20-44(01)

Increasing WMA Implementation by Leveraging the State-of-the-Knowledge

Leslie A. McCarthy, Ph.D, P.E.
Jo Sias Daniel, Ph.D, P.E.
Lee Friess

National Cooperative Highway Research Program

Transportation Research Board
National Research Council

NCHRP Project 20-44(01)

Workshop Proceedings: Increasing Warm Mix Asphalt Implementation Leveraging the State-of-the-Knowledge

Myers McCarthy Consulting Engineers, LLC

May 8 and 9, 2017

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RESEARCH SCOPE

WMA technology and deployment were largely driven by the asphalt industry. Implementation progressed while a number of technological questions were identified for research. Research was performed at both the state and national levels as well as by private industry, and the FHWA WMA TWG was responsible for developing key research needs statements. WMA later became a focus area for the FHWA in its Every Day Counts (EDC) initiative, which encouraged state agencies to allow WMA in their specifications and to track its usage.

A number of WMA technologies were developed and marketed during the mid to late 2000s. These technologies included the use of foam (water), waxes, and other specialty chemicals. A large number of demonstration sections were placed in the late 2000s by many states and contractor groups and performed favorably. This resulted in the continued and more rapid acceptance of WMA as the benefits gained more prominence. These benefits included lower production temperatures, reduced emissions and energy consumption, extended construction day and season, and additional opportunities for more uniform and higher density construction. In the 2014 construction season, over 32 percent of the asphalt mixture tonnage placed in the United States was produced with WMA technology.

A review of contemporary information indicated that gaps continue to exist concerning knowledge of WMA technology and performance. As additive technologies have continued to change and evolve, agencies and industry are scrutinizing production and performance to freshly assess whether WMA—as well as other technologies such as polymers, RAP, RAS, and recycling agents—provides the benefits originally envisioned. Lead States have widely adopted WMA and now well over 75% of all states have a standard WMA specification rather than a special provision. However, details on how those WMA specifications affect the characteristics of the WMA that is placed on roadways is difficult to capture. WMA represents less than half of total state DOT tonnage with anecdotal evidence of WMA tonnage dropping in some areas. Research is needed to identify impediments to the wider use of WMA and develop strategies to foster its expanded implementation by the state DOTs.

The National Cooperative Highway Research Program (NCHRP) Project 20-44(01) was initiated to (1) identify the barriers encountered by those state DOTs where WMA specifications remain to be implemented and proportional WMA tonnage has lagged, and (2) establish and update implementation performance indicators that better measure WMA implementation as its usage is increased nationwide.

Workshop Development

The *Dialogue on Warm Mix Asphalt Implementation: Present and Future* workshop, developed as part of NCHRP Project 20-44(01), brought together federal, state, and industry representatives along with academics and researchers. A survey was sent to agency and industry representatives, which included questions on the WMA definition, tonnage, and experiences. Participants were identified through the industry and agency surveys. Those attending were requested to view a series of webinars covering the background, current research, and industry experiences with warm mix asphalt. The webinars provided a common knowledge base for all participants.

The workshop was structured as a two-day event. Topics were divided into four broad areas, plus conclusions. Each section began with an introduction of the subject matter, followed by a presentation. The participants were divided into subgroups for a moderated discussion of the issues. After this, each group presented their findings to the whole group and a plenary discussion ensued.

Workshop Proceedings: Irvine, California

Summary of Breakout Session 1: WMA Definition

Introduction

The survey results regarding how the agency and industry respondents currently define WMA were presented to the participants.

Objectives

Participants in each breakout group were tasked with reaching consensus definition(s) for WMA and describing the logic the group used in reaching that consensus. If consensus was not reached sticking points and issues were to be explained. Participants were asked to consider the following in their discussions:

- Producing at lower warm temperatures for energy/environmental benefits;
- Producing at HMA temperatures for late season paving compaction aid; and,
- Producing at warm temperatures when used to extend haul distances (or haul durations).

Outcomes

Following a one-hour discussion in breakout sessions, the entire group reconvened to hear reports from each breakout group and engage in an overall group discussion. This discussion continued with several participant emails to the research team, following the conclusion of the workshop.

Group A

The discussion in this group focused around several topics:

- Defining the appropriate temperature range for WMA: should it be a hard temperature range or a specific reduction amount/percentage of a comparable HMA (to account for the different production temperatures used with different types of binder);
- Defining WMA so that all different types of technologies are included; and,
- How individual states may specify WMA versus the definition of WMA.

At the end of the discussion, the suggested definition for WMA was recommended as an additive or process that is used to achieve or allow one or more of the following aspects:

- Produce mix at [85 to 95%] of HMA temperatures;
- Achieve compaction at normal temperatures;
- Allow for longer haul distances;
- Allow for paving at lower ambient temperatures; and,
- Results in equal to or better performance than HMA.

Group B

The discussion in this group led to a recommended change in the name to workability mix additive/asphalt mix enhancement. This change would remove "Warm" from the term and definition. However, the fuel economy that can be realized by using these processes and/or additives, the positive environmental impacts, and the health and safety benefits would be inadvertently lost if using the new definition.

Another point discussed by this group was that existing specifications are challenging for local agencies to follow in using WMA.

Group C

This group discussed the potential need to not only define WMA, but to define a WMA technology. Technology, and the applications of the technology, should be defined to help make the distinction between the different applications/uses of these processes/additives. WMA technology could be used for other reasons (compaction aid, etc.) in lieu of a temperature reduction.

The suggested definition from this group was:

- Technology used for reducing asphalt production temperatures which potentially enhances mixture performance and provides greater flexibility during placement.

Group D

Industry members of this group observed that a rigid definition for WMA might limit their ability to use the product. As in the previous group, members of Group D suggested that the word "warm" should be removed from the definition.

The definition suggested by this group was:

- An additive or process used with asphalt mixtures that allows a reduction in production temperature, if desired. WMA improves workability and compaction and may provide other environmental benefits.

Group E

The discussion in this group centered on the importance of the temperature (should it really be called warm mix?) and whether the definition for WMA should be specification-driven. The group suggested a multifaceted definition that included hot mix asphalt with additives, and WMA at specific temperatures, as shown in Table D1.

TABLE D1
Defining WMA in Matrix Format Based on Placement and Production Temperatures

		Production Temperature		
		Cool/Warm	Warm/Hot	Hot
Placement Temperature	Cool / Warm	Air Quality Management (Urban)	Sustainability initiatives Late season	Haul (Rural) Late season
	Warm/Hot/Regular	Rubber used in the mix	Stone matrix SMA Fibers, specialty mix enhancement	

Plenary Discussion

The plenary discussion first focused on defining the audience for the WMA definition: Agency, Industry, Public? All need to be included in some fashion.

There was significant discussion about the continued use of "warm" as there are both positive and negative associations with the term. Additionally, different customers may or may not want specific terms based on the intended use of the mix. There was also a general discussion about removing references to temperature (e.g., "warm" or "hot") in specifications and instead simply using "asphalt mix" (particularly since ASTM International is moving in this direction).

Suggestions were made to use terms or phrases that relate to the benefits that are realized in using these technologies, such as:

- Workability additive/tool;
- Aid production/distribution/laydown/compaction;
- A tiered approach to the definition was also suggested that distinguishes the reason the technology is being used in a particular situation and for perception/marketing;
- Construction/performance – defining usage;
- Public perception/environmental benefits; and,
- Marketing approach (compaction aid/warm mix).

Post-Workshop Email Discussion

A definition that summarized the discussion at the workshop was proposed:

- "Warm Mix Asphalt: Modified asphalt mixes produced with various technologies—including water foaming, chemical additives, and organic waxes—to achieve improved compatibility, in-place density, and sustainability over an expanded range of working temperature and haul distance and without a diminution of short- and long-term performance."

Other email discussion reinforced the various opinion that temperature should be kept as part of the WMA definition and that it could be related to a reduction in emissions or tied to some maximum temperature (300°F recommended by several participants). The discussion also included the need to differentiate the use of WMA for environmental (low temperature) benefits and the use of the technologies as compaction aids.

Summary of Breakout Session 2: Barriers to and Disincentives Limiting the Use of WMA

Introduction

Two panel sessions were used to seed discussion on the barriers to and disincentives that limit the use of WMA. The first panel presented the industry perspective through discussion by asphalt contractors. The second panel included the local agency perspective by a discussion with city and county engineers.

The survey results which cited the reasons for the lack of, or decline, in WMA usage were also presented.

Outcomes

The breakout groups were tasked with creating a list of the barriers and/or disincentives that are limiting the widespread use of WMA. Participants were asked to focus on the barriers (Cooperative Actions were addressed in Breakout Session 3) and to organize their discussion around the following general categories:

- Agency specifications/support;
- Bidding environment/economics;
- Education/knowledge/understanding gaps;
- Production/construction questions/difficulties; and,
- Questions on performance.

Summary

At the end of the breakout sessions, the groups reconvened and identified barriers and disincentives under each category. The outcomes from all of the group discussions are presented in the subsections below.

<u>Agency specifications/support</u>

- Broad definition of WMA;
- Method specifications with restrictive mandates can expose agencies to claims;
- Lack of performance specifications that are permissive of WMA;
- Restrictive or conflicting specifications;
- Restrictive or unclear certification process;
- Limitations or additional procedures required when using WMA (certifications or inspections, WMA technical representative needs to attend preconstruction meeting, etc.) require more time and effort;
- Suppliers cannot get the mix approved unless they have a job (i.e., local agency wants warm mix additive, but contractor cannot get a design approved) to use it on;

- Keeping up with changes in WMA technologies or processes, and continually updating the state DOT approved product lists (APL) or qualified product lists (QPL) as a result, is a time-consuming activity for agencies;
- Who is certifier for the WMA additive? It depends whether certification happens at plant or terminal;
- No champion in a position (at the agency or at the plant) that is empowered to make decisions;
- Upper management concerns about new products and risk; and,
- Lack of agency staff or experience, high turnover puts more pressure on contractors.

Bidding environment/economics

- No incentives for using WMA in some cases and if there is an incentive, how do you verify use of WMA?;
- Lack of a WMA-specific bid or line item;
- Challenges with realizing full savings attributable to WMA when operating in a low-bid environment;
- Cost of additives, costs attributed to production changes;
- No clear quantification of economic savings;
- WMA implementation driven by economics and contractors are not as motivated as in case of reclaimed asphalt pavement (RAP) or recycled asphalt shingles (RAS), particularly because a temperature reduction does not always translate into savings;
- Economic advantages may be understated if full production, placement, and performance are not considered (longer haul, dropping roller, better density, etc.); and,
- WMA needs to perform better than HMA for it to be specified.

Education/knowledge/understanding gaps

- Lack of technology transfer of lots of good research, especially to some end users (local agencies, other DOTs, DOT districts, etc.);
- Myths about WMA and the notion that research conducted in other places may not be applicable to all locations;
- More research exists for some technologies (additives) than for others (foamers);
- Specimen conditioning for testing: what is the appropriate temp for performance testing?;
- The need to manage the perception of risk;
- Communication gap between design and materials engineers at DOT and between state and local agencies;
- Training needs to be brief and to the point;
- Lack of education on proper dosage rates, especially with new products; and,
- WMA is not a magic tool and still needs the employment of sound production and paving practices.

Production/construction questions/difficulties

- Fear of the unknown or change related to existing techniques, along with a lack of experience with WMA materials;
- Aggregate moisture concerns;
- Condensation in silos/baghouses;

- Switching between HMA and WMA; and,
- Contractors are not comfortable reducing temperatures.

Questions on performance

- Long term performance research needs wider dissemination;
- Better documentation and dissemination of the results of early trial WMA sections that have a longer performance history;
- Long-term performance and track record is not available;
- Updates on technologies that failed in the past but may have been adjusted and used more successfully in recent years;
- Performance history does not exist for newer technologies, so agencies are reluctant to use them;
- Who is responsible for tracking (doing and paying for effort)?; and,
- Contractors do not want to be held liable if there are issues with WMA.

Other

- Indifference;
- Geographic constraints (where you have big variance in climate/elevation within state);
- Management of risk;
- Trust between agency and industry to implement change; and,
- Fear of changing techniques from both agencies and contractors.

Summary of Breakout Session 3: Cooperative Actions by Agency and Industry

Introduction

The research program at the US Army Corps of Engineers (USACE) that evaluated the suitability of using WMA technologies for airfield pavements was presented in the next plenary session. The presentation focused on USACE's efforts to proactively investigate WMA performance for airfield pavements and to develop a specification for use of WMA. The research was conducted in three phases: laboratory evaluation, full-scale accelerated pavement testing, and friction testing and emissions monitoring on field projects. The Unified Facilities Guide Specification (UFGS) *32 12 15.16: Warm Mix Asphalt Airfield Paving* is available, but it is likely that it will be condensed to make WMA an option (as part of the HMA specification) instead of a stand-alone specification.

The participants were also shown the summary of the survey results related to the use of and/or challenges with specifications related to WMA.

Outcomes

The breakout groups were tasked with creating ideas on how agencies, industry, and academia can work together to effectively address the list of barriers compiled during Breakout Session 2. These ideas are detailed in Tables D2 through D6. Participants were asked to consider the following items during their discussions:

- Specifications that proactively encourage the use of warm mix technologies? Incentivize the contract by including some LEED-type credits?;
- How the state DOT APL facilitates the use of new warm mix technologies by contractors? Is the state DOT's APL clearly written for local agencies to access? How do local agencies procure asphalt mix?;
- How can WMA be implemented consistently in existing low-bid environment? What contract types are available for local agencies to use WMA?;
- What should the performance criteria be for other specification types?; and,
- Other ways that Agencies and Industry can cooperate to implement the use of WMA.

The discussion focused on actions that could be taken, as opposed to barriers or limitations, to implement WMA.

Summary

The ideas stemming from the breakout sessions generally fell into the following categories:

- More effective training documents for targeted audiences (e.g., one-page fact sheets for key research reports which include the hyperlinks to the full report);
- Short videos (potentially modeled on the FHWA Federal-aid Essential video format that connect to local agencies through the state DOT Local Programs office) and one-page briefs that can be shared with agency upper management);
- Change from method/permissive specifications to end-result or performance-based specifications;
- Incentivize the use of warm mix technologies (e.g., demonstrated improved mat and longitudinal joint densities);
- Ties to asset management;
- Case study sharing and a mechanism for agencies to learn from each other (e.g., create an online accessible repository for APLs); and,
- Clear communication of benefits for agencies and contractors.

TABLE D2

Group A Discussion on Cooperative Actions by Agencies and Industry

Elements	Ideas for Cooperative Actions by Industry and Agencies
Proactive Specifications for WMA	• Incentives for achieving performance
Approved Product List	• Not discussed
Low-Bid Environment	• Educate local agencies – LTAP/APA best practices instead of DOT mandates • Include incentives in the contracts, contractors will bid WMA
Other Ideas for Cooperation	• Need performance tests • The benefits of using warm mix technologies need to be clear for contractors and agencies – outreach and education is needed

TABLE D3

Group B Discussion on Cooperative Actions by Agencies and Industry

Elements	Ideas for Cooperative Actions by Industry and Agencies
Proactive Specifications for WMA	• Write specifications to achieve a desirable outcome • Do not write specifications for outliers, more general is better • Help to write and review local agency specifications • Not necessary to place test sections when other projects in a similar climate have shown successful performance with the technology
Approved Product List	• AASHTO National Transportation Product Evaluation Program (NTPEP) for WMA is currently underutilized by agencies
Low-Bid Environment	• Include incentives in the contracts, contractors will bid WMA
Other Ideas for Cooperation	• Webinar training – shorter and more accessible • Efforts that support dissemination of WMA info to the stakeholders who need it, especially through peer-to-peer contact

TABLE D4

Group C Discussion on Cooperative Actions by Agencies and Industry

Elements	Ideas for Cooperative Actions by Industry and Agencies
Proactive Specifications for WMA	• Use of performance-based specifications • Increase the range of the disincentive/incentive based on density • Call it WMA and pay for it, even if it costs more
Approved Product List	• Process to approve takes too long, necessary to streamline it
Low-Bid Environment	• Mandate a warm mix specification - and pay accordingly
Other Ideas for Cooperation	• Pilot projects build confidence, do not penalize early projects • AASHTO standard practice for WMA design should be established

TABLE D5

Group D Discussion on Cooperative Actions by Agencies and Industry

Elements	Ideas for Cooperative Actions by Industry and Agencies
Proactive Specifications for WMA	• Write specification based on how WMA will be used • Performance specifications that emphasize density (and provide incentive) • Mandate the use of WMA in some cases (e.g., night paving) • Consistent use of warm mix technologies throughout state
Approved Product List	• Use to "reduce risk of unknown" for upper management support – emphasizes that what was used has already been evaluated
Low-Bid Environment	• Require warm mix technologies on every project
Other Ideas for Cooperation	• Easy-to-read one-page Fact Sheet on WMA benefits and provides hyperlink to key reports on warm mix performance and use • DOT/APA/NAPA/AI/academia responsible for moving forward with outreach • Update warmmixasphalt.org website • DOTs understand why they use WMA, white paper from DOT supporting usage • More evidence and clarification on the environmental aspects

TABLE D6
Group E Discussion on Cooperative Actions by Agencies and Industry

Elements	Ideas for Cooperative Actions by Industry and Agencies
Proactive Specifications for WMA	• Either performance specification or method specification; cannot be both • Range of temperatures based on PG binder grade • Incentive specification is key but need buy-in from DOT management
Approved Product List	• Make these less restrictive • Make process faster
Low-Bid Environment	• Eliminate temperature range and institute performance tests • Need training and outreach to build confidence between states and contractors
Other Ideas for Cooperation	• Establish an accessible repository of information related to WMA for agencies to use to learn from each other • Use the AASHTO Product Evaluation List (APEL) which is a resource that is currently underused by agencies

Summary of Breakout Session 4: Quantifying the Impacts of WMA over the Long Term

Introduction

Two presentations were delivered which helped to focus participants on the idea of quantifying the impacts of warm mix technologies over the long term.

The presentation on the FHWA's Long Term Pavement Performance (LTPP) WMA field experiments showed how the research program will establish a framework for evaluating long term performance of WMA relative to HMA. The program is also collecting field data on the use of WMA with RAP. The FHWA LTPP will collect a total of 10 years of data (some sections dating from 2014).

The second presentation discussed the Washington DOT's (WSDOT) use of Pavement Management System (PMS) data in performance evaluations. For example, WSDOT uses data to estimate the timing to next pavement rehabilitation needed and to ascertain the performance measure of cost effectiveness (which ties together cost and pavement life). WSDOT's PMS is an example of how data can be used to drive decisions and to relate changes in pavement structure (e.g. WMA) to pavement performance.

The survey results related to agency activities for tracking WMA usage or performance (through the use of a PMS, construction database, or other tools) were also presented. Although approximately a dozen agencies reported that they have made progress with WMA through tracking and performance monitoring, the survey results indicated a lack of data needed for quantifying the life cycle costs and the long-term impacts of using warm mix technologies

Outcomes

Each breakout group was tasked with creating ideas of how to gather, maintain, and apply information on the usage and service lives of WMA. Participants were asked to consider the following topics in their discussions:

- Details on tracking WMA usage: Who should do it? When should it be done? Why is it important? How will it be done? What will the information be used for?;

- How to measure and assess the short-term impacts of WMA? Are there any ties between use of WMA and impacts on safety and operations?;
- How to measure and assess the long-term impacts of WMA, such as long-term performance of WMA and calculating life cycle costs?; and,
- Other ideas to quantify the impacts of WMA? Beyond tonnage…which metrics should be used to track the benefits of WMA? Ways to use this information once it is collected?

Summary

The ideas stemming from the breakout sessions are captured in Tables D7 through D11 and generally fall into the following categories:

- Cooperative efforts at the regional level to track impact and establish a standard of practice for when tracking no longer needs to be done (e.g., states like VA, TX, and KS that use significant amounts of WMA and do not proactively track its use any longer);
- Long-term impacts of WMA pavements should be disseminated on fact sheets through the Local Technical Assistance Program (LTAP) and the state Asphalt Pavement Association (APA);
- Communication between departments within an agency (e.g., Capital Projects department should be aligned and communication with the Operations unit that does maintenance);
- Environmental benefits/impacts (i.e., all environmental benefits predicated on mix design lives being equal) should be a joint effort between agencies, contractors, and academia. Also, local agencies can use the information to estimate the carbon footprint (which some are required to report to local politicians);
- Database platform and integration for effective monitoring;
- Performance metrics: penalties/incentives paid, density, smoothness, public complaints; and,
- Cost savings: reduced equipment needed, work zone duration, emissions reduction, and energy savings.

TABLE D7

Group A Discussion on Quantifying Efforts for Tracking WMA

Elements	Quantifying Efforts for Tracking WMA Usage and Performance
Details for Tracking WMA Usage	• Track WMA tonnage, type and dosage of additive, and actual temperatures • Material suppliers could be required to do the tracking reports • Track which additive and process was used through regionalized project lists and have site visits to projects within a day's drive
Short-Term Impacts of WMA	• Construction time and calculations for estimates on each project (to understand the short term environmental benefits, difficult to get field data and should use calculated estimates) • Define short term for pavement life (3, 5, or 10 years?)
Long-Term Impacts of WMA	• Common PMS database for all agencies in the state (assistance from state APA in populating the database) • Advertise long term impacts on fact sheets, engage LTAP more on tracking after educating them on warm mix
Other Ideas for Quantifying Impacts of WMA	• Track the reason for the use of a warm mix technology on a job (i.e., production temperature, haul length, cool weather paving, compaction aid, environmental constraints, etc.) • Private sector understands where the market is headed, so assist agencies in tracking this

TABLE D8

Group B Discussion on Quantifying Efforts for Tracking WMA

Elements	Quantifying Efforts for Tracking WMA Usage and Performance
Details for Tracking WMA Usage	• Local agencies track through bid information • State DOT mix design tracking • Track both warm mix as compaction aid and for reduced emissions
Short-Term Impacts of WMA	• Pay factor (bonus, disincentive) and cost savings • Construction savings (larger energy savings, equipment lasts) • Density, smoothness, optimal mix designs
Long-Term Impacts of WMA	• Collect cracking, rutting, and ride performance to calculate life cycle cost
Other Ideas for Quantifying Impacts of WMA	• Public complaints (smell, emissions, etc.) • Equipment (reduced rollers, emissions, etc.) • Large state DOTs could track impacts and smaller DOTs or LPAs with similar conditions could benefit from the larger agency efforts

TABLE D9

Group C Discussion on Quantifying Efforts for Tracking WMA

Elements	Quantifying Efforts for Tracking WMA Usage and Performance
Details for Tracking WMA Usage	• Goals of tracking: quantify benefits of warm mix technologies, use of "green technologies", and forensic tool if jobs go well or go wrong • Tracking only state DOT jobs because LPA records often missing although they sometimes have better records • NAPA annual assessment should be revised (e.g., does not capture all producers, adjustments made to account for missing data, use a standard definition for WMA)
Short-Term Impacts of WMA	• Same as HMA: volumetrics, density, smoothness, binder content • Quantify the benefit the state is getting due to the addition of a warm mix technology
Long-Term Impacts of WMA	• Track faulty products to remove from materials APL (e.g., pavements which were constructed in the past with REOBs)
Other Ideas for Quantifying Impacts of WMA	• Value engineering brings savings and can help in answering the question of whether the warm mix technology is worth the additional cost • Data collection and retention must be done in electronic format (such as through part of an agency's Independent Assurance program) such as "Document Express", "Survey123", geospace location and ID attached to each sample collected from the field, save mix designs - - and link ECMS (electronic construction data collected) to databases using tools such as hand-held devices (like the hand-held thermal gun)

TABLE D10

Group D Discussion on Quantifying Efforts for Tracking WMA

Elements	Quantifying Efforts for Tracking WMA Usage and Performance
Details for Tracking WMA Usage	• LTAP could track WMA usage but not all states have active LTAP • State DOTs can track but need the database built & maintained • Suppliers and paving associations should track usage and share with agencies
Short-Term Impacts of WMA	• Capture during construction including mat temperature behind the paver
Long-Term Impacts of WMA	• Encourage all agencies to develop and use a PMS first
Other Ideas for Quantifying Impacts of WMA	• Produce white papers that specify where WMA is built, when it was built, and which WM technology was used • Keep track of the specific purpose for each warm mix technology (and why it is used)

TABLE D11
Group E Discussion on Quantifying Efforts for Tracking WMA

Elements	Quantifying Efforts for Tracking WMA Usage and Performance
Details for Tracking WMA Usage	• Specific item identifier for new warm mix technologies and through the PMS (e.g., in StreetSaver or annual updates) • Agency collects 'before and after' rutting, cracking, and texture at the network level • Contractor collects average production temperatures (monthly, annually, etc., over a period of time) and cost per energy used at the plant
Short-Term Impacts of WMA	• Monitor density, rutting, and moisture damage • Track MOT duration (could collect it through intelligent compaction)
Long-Term Impacts of WMA	• Monitor cracking • Compile the long-term tracking information so that it's accessible to all agencies
Other Ideas for Quantifying Impacts of WMA	• Keep track internally at DOT (districts and central office) • Monitor energy usage for production and placement of asphalt pavements

Summary of Closing Session: Implementation Plan and Research Needs

Introduction

The closing session was a plenary discussion intended to achieve closer to consensus on a definition for warm mix technologies and on identifying key aspects of future implementation and research efforts.

Many participants provided feedback as part of the joint discussion; however, other participants shared their thoughts after the conclusion of the workshop via email or via the post-workshop survey.

Outcomes

Participants were invited to provide final thoughts on the following key points:

- Definition of WMA for the future;
- Future implementation efforts related to WMA;
- Research needs; and,
- Outreach ideas.

Summary on the Definitions of WMA

The ideas stemming from the joint session and subsequent information shared via email defined warm mix technologies. The following quotes were recorded from participants, relating their thoughts on the definition of warm mix asphalt:

- *"Warm mix should be defined as a technology or tool rather than a mixture type, and must emphasize the benefit of production/construction in a more energy-efficient manner."*
- *"An asphalt mixture that uses a technology that allows for a reduction in production and placement temperatures and may enhance workability and improve compaction."*
- *"Future definition of warm mix technologies should emphasize the following attributes: allows for cool weather paving; extends the paving season; may improve constructed*

pavement by achieving more consistent densities; benefits worker health and safety; provides environmental benefits."

- *"Remove reference to warm or hot: just refer to it as asphalt."*
- *"Define a significant emission reduction to be 25 to 50% less than emissions produced at $\geq 300\,^0$F. That way, any warm mix products and/or processes that do not achieve the stated reduction in temperature to reduce emissions would be defined as compaction aids."*
- *"Assess whether a temperature range or maximum temperature would be desirable in the definition of warm mix."*
- *"WMA is an asphalt mix made by a foaming process or with an additive used for the purpose of:*
    - *Reducing production, plant, or placement temperatures of less than 300 ^{0}F for a given asphalt mix;*
    - *Application;*
    - *Improving workability and compaction of the asphalt;*
    - *Providing potential reduction of plant and site emissions;*
    - *Providing possible cost savings for the Contractor and/or Owner; and*
    - *Providing a longer pavement life cycle when constructed properly."*
- *"Warm Mix Asphalt: Modified asphalt mixes produced with various technologies—including water foaming, chemical additives, and organic waxes—to achieve improved compatibility, in-place density, and sustainability over an expanded range of working temperatures and haul distance and without a diminution of short- and long-term performance."*

Future Implementation Efforts

The ideas stemming from the closing session related to future WMA implementation efforts can be summarized as follows:

- Establish a grant program (federal or state level) that encourages the use of warm mix technologies (similar to what was done with other technologies, such as rumble strips, that FHWA supported with initiatives). This will make it possible for both large and small agencies to incentivize the use of warm mix technologies for contractors.
- Develop a uniform way to track the use of warm mix technologies such that all agencies and/or contractors can access and update data in an easy and efficient manner. This is another way to estimate market conditions and/or direction of warm mix technology advancements.
- Compile a "Lessons Learned" for warm mix technologies (perhaps through a NCHRP 20-07 task-based project or a NCHRP Synthesis project), which can address aspects of risk assessment.
- Industry can track overall WMA production under the current definition (until modified) and agencies (DOTs, counties, local agencies) should track as best they can and the state DOT should report out to the industry. The data can be used to track the WMA market and the State DOTs may need to help with alerting local agencies to installations whose performance should be monitored over time.

Research Needs

The ideas stemming from the closing session related to research needs for WMA implementation can be summarized as follows:

- Develop template specifications for designing asphalt mixtures with warm mix technologies.
- Develop a recommended practice to update or accompany the current AASHTO Standard for WMA. As part of the recommended practice, summarize what information exists such that agencies can pick and choose pieces that make sense for their specific situation.
- Explore the field performance of various types of WMA technologies with RAP, RAS, and rubber.
- Document the trends in pavement performance over time of additive technologies and foaming technologies.
- Assess the impacts of inclement or hazard weather conditions on pavements constructed with warm mix technologies.
- Establish methods for database integration (construction, materials, pavement management system) and maintenance.
- Facilitate the use of performance specifications and warm mix environmental product declarations (EPDs).
- Generate pavement life cycle assessments that include WMA.
- Determine the highest asphalt mix production temperature at which asphalt mixes can be produced without a significant increase in emissions. This research would seek to identify the critical temperature to produce most asphalt mixes without significant emissions.
- Revisit existing TRB research needs statements related to pavement management systems (AFD10 committee) to include the outcomes of the NCHRP 20-44(01) project, specifically:
    - "Use of Pavement Management Information for National Reporting" https://rns.trb.org/dproject.asp?n=39477
    - "Integrating Environmental and Social Performance into Asset Management Practices within Pavement Management Systems" https://rns.trb.org/dproject.asp?n=40605
    - "Methods to Promote Pavement Management as a Management Tool" https://rns.trb.org/dproject.asp?n=39475
    - "Integration of Pavement Management Systems into the Overall DOT Asset Management Systems" https://rns.trb.org/dproject.asp?n=13525
- Air quality and resource usage are paramount for environmental improvements monitoring. Perhaps academia can develop a formula-based approach to monitor environmental benefits by equating to WMA tonnage (based on reporting by industry or agencies), which considers both EPDs and carbon footprint determination.

Outreach Ideas

The outreach ideas for WMA implementation stemming from the closing session can be summarized as follows:

- Provide basic training materials to LTAP centers in all 50 states.
- Provide training on warm mix technologies and tracking performance through the AASHTO Transportation Curriculum Coordination Council (TC3) or Asphalt Institute.
- Develop presentations and one-pagers that can be presented to AASHTO chief engineers, APWA, and other target audiences (ex. pavement preservation & asphalt user/producer groups).
- Contractors should be engaged to provide outreach and/or education to customers. Support this through the NAPA, the Asphalt Institute, and state APA executives. Form a *Community of Practice* that includes DOT central office, DOT district engineers, and local agencies/tribal nations/federal agencies. This endeavor should also include the Local (Agency) Program Coordinators in the DOTs.

Overview of Implementation Plan Ideas

Based on the literature review, survey results, and the workshop feedback, the following ideas are recommended for future implementation of warm mix technologies:

- Review existing TRB committee research needs statements and recommend revisions to capture aspects related to asphalt mixtures using warm mix technologies.
- Recommend revisions to the NAPA survey as related to the redefinition of warm mix.
- Form a FHWA and/or AASHTO Lead States group to participate in and guide outreach activities and form the Community of Practice membership to serve in Peer State Assistance.
- Develop a template of key information for agencies or members of the asphalt industry to use for collecting data on tracking the usage of warm mix technologies.
- Develop on-demand internet informational videos related to warm mix technologies.
- Recommend ideas for the redesign and relaunch of the warmmixasphalt.org website.
- Develop informational briefs for transportation agency managers and industry executives on various topics related to WMA.
- Recommend AASHTO to fund a project (through NCHRP 20-07 series) to write a Recommended Practice for using warm mix technologies.

Workshop Proceedings: Rhode Island

Summary of Workshop

A half-day workshop Overview of NCHRP Project 20-44(01) national two-day workshop was created by the research team and held in Providence, Rhode Island, at the RIDOT headquarters on September 17, 2017. It was open to all paving contractors and state DOTs in the northeastern states and its occurrence was advertised through emails and through the Northeast Asphalt User Producer Group (NEAUPG) list-serve, particularly because only half of the northeastern states were in attendance at the May 2017 NCHRP 20-44(01) two-day workshop in California.

A synopsis of the discussion and feedback from the half-day workshop is as follows:

- There is confusion about what exactly constitutes warm mix asphalt. Additionally, concerns were expressed about moisture susceptibility that creates a hesitancy to allow WMA with the various additives.
- A need exists to create a WMA specification in AASHTO format.
- There are concerns about keeping the term "warm." Using "warm" helps to differentiate the material, while using the term "workable" might imply that any other mix design is not "workable." Some participants suggested renaming it "Warm Mix Additive" or "Asphalt Mixtures Additive" (AMA) instead of Warm Mix Asphalt.
- The Asphalt Institute (AI) could be used as a resource to have more of a role in spreading the word about WMA, such as they did in the 1980s, because of the paving industry's familiarity with AI.
    - If NAPA were to team with AI, could FHWA and AASHTO try to get some of the tracking information?
    - Could NAPA develop a tool for contractors (that shows the savings and profit for WMA use) and then give this information to Industry members?
- There is a question of whether agencies want to quantify savings. It is difficult for DOTs to obtain this information from the bidding process, so the Industry needs a tool that includes a life cycle cost analysis (LCCA) that could be easily used when putting bid estimates together. This tool would also quantify savings to the agency over the long-term.
- WMA needs to be identified in the contract information.
- There is no economic incentive to use WMA, as there is no mandate from the State and contractors will not use it if there is only a remote possibility of saving money. The participants expressed a concern that there is no conclusive data that shows the savings to agencies and contractors or what the impacts are in terms of profit for Contractors.
    - Some specific comments included:
        - We have optimized our operations, so how do we handle a change?
        - We do not have issues now, so why bother?
        - Unless there's a big push to kick us in a different direction, we will not do it.
- There is a need for a written standard or a recommended practice.
- "Contract Document" templates are needed for WMA because there are still a number of contractors and agencies that do not have experience with WMA. The project developer needs a specification for the contract document. A best practices document is needed. This should include a materials specification, design practice, construction guide specification, and quality control. Once these are in place, then education can be targeted. Projects and experience using WMA also need to be available for review. The more projects there are available, the more other agencies and contractors will be willing to work with WMA.

- Research needs include revisiting sections of WMA that have been in the field for a while and focus the investigation on the performance (i.e., additional laboratory research is not likely needed at this point in time).

Feedback from TRB Straight-to-Recording Webinar: Dialogue on Implementation of WMA: Present and Future and Other Outreach Activities

In late 2017 and early 2018, the research team conducted a few more opportunities for the asphalt community to be exposed to the goals and outcomes to-date of the NCHRP 20-44(01) project, and for the broader-reaching collection of feedback to occur. The idea was to provide a way for those not able to travel to the two-day workshop to still learn about the highlights of the meeting and provide feedback. As a result, the research team worked with the TRB staff to create a 90-minute TRB Straight-to-Recording (STR) video series entitled "TRB Straight to Recording for All: Increasing Warm Mix Asphalt (WMA) Implementation". This was recorded and made available online by TRB on November 28, 2017. It was announced in the TRB Weekly Newsletter and by other media blasts the first week of December 2017. More than 400 participants viewed the webinar recording series and there were a small number of those viewers who completed the online survey.

In addition, two other outreach activities were conducted in which participant feedback was gathered through a brief questionnaire. Interactive presentations were delivered at the Pennsylvania Asphalt Pavement Association annual conference in Hershey, Pennsylvania, on January 30, 2018, and at the MidAtlantic Quality Assurance Workshop in Dover, Delaware, on February 14, 2018.

Overall, responses were collected from 65 participants which included members of academia, industry, and agencies.

Redefining Warm Mix Asphalt

When asked whether the term "warm" should continue to be included in the definition of WMA, the majority of 65 of the participants replied "yes." In terms of the most useful definition of WMA moving forward into the future (shown in Table D12), the majority of participants indicated the third definition shown in the table that emphasizes the various aspects and benefits of WMA, while limiting it to a maximum temperature of 300 degrees Fahrenheit.

TABLE D12

WMA Redefinition Suggested by TRB STR Webinar and Other Outreach Activity Participants

Options for Redefinition for Warm Mix Asphalt	Percent	Count
1. Continue using NAPA's WMA definition: Warm-mix asphalt is the generic term for a variety of technologies that allow the producers of asphalt pavement material to lower the temperatures at which the material is mixed and placed on the road by 10 to 100 degrees F.	20%	13
2. WMA (warm mix asphalt) = Modified asphalt mixes produced with various technologies—including water foaming, chemical additives, and organic waxes—to achieve improved compactability, in-place density, and sustainability over an expanded range of working temperatures and haul distances, and without a diminution of short- and long-term performance.	20%	13

Options for Redefinition for Warm Mix Asphalt	Percent	Count
3. WMA (warm mix asphalt) = Modified asphalt mixes produced with various technologies—including water foaming, chemical additives, and organic waxes— that have the capacity to be used with lower production temperatures (at a maximum of 300 deg F), but can also be used at normal production temperatures to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance.	28%	18
4. WMA (warm mix asphalt) = Modified asphalt mixes utilizing various technologies—including water foaming, chemical additives, and organic waxes— produced and placed at a maximum temperature of 300 deg Fahrenheit, to achieve improved sustainability, improved compactability and in-place density, and increased haul distances or durations.	8%	5
5. WMA (workable mix asphalt) = Modified asphalt mixes utilizing various technologies —including water foaming, chemical additives, and organic waxes— to achieve improved compactability and in-place density.	12%	8
If you would like to adjust one of the definitions above, or think it's best to have a combination of some of the definitions above, please write the Option number(s) and indicate your proposed revisions (or combination):	8%	5
If you have a completely different idea for a WMA definition, please write it here:	5%	3

Based on the feedback majority, it appears that the definition to be considered in moving forward could be suggested as:

"*Modified asphalt mixes produced with various technologies – including water foaming, chemical additives, and organic waxes – that have the capacity to be used with lower production temperatures (at a maximum of 300 degrees F), but can also be used at normal production temperatures to achieve improved compactability, in-place density, and sustainability and without a diminution of short- and long-term performance.*"

This finding is consistent with the feedback from the other workshops.

Implementation Actions

The results regarding implementation actions indicated that many participants planned to review the WMA definition with their state/jurisdiction/agency partners, to review the details of current asphalt specifications, and to create an outreach plan for local agencies/DOT/contractors.

Some participants planned other actions such as continuing to develop their agency's or company's current policy related to WMA and getting state DOTs to specify various WMA additives that allows contractors to try using new additives. The full results to this question are shown in Figure D1.

FIGURE D1 WMA Implementation Actions Planned by Participants in TRB STR Webinar and Other Outreach Activities

Additional Feedback

There were 15 participants who provided additional feedback on the implementation of WMA. Many of these included any initiatives that encourage DOTs to take the lead in educating about and promoting WMA technologies, as well as compilation of quantitative information about the benefits of producing asphalt mixtures at lower temperatures. In terms of quantifying the impacts of WMA, 60% of the participants concluded that establishing, collecting, and maintaining performances metrics would be the most effective way to measure these impacts, while 50% of the participants also would support actions that would quantify the cost savings (to the agency and to the industry) of using WMA.

APPENDICES

APPENDIX 1: AGENCY, INDUSTRY, AND OTHER ORGANIZATIONS

- The representatives from the 45 agency offices and 70 other organizations shown in Tables D1-1, D1-2, and D1-3 were interviewed in person, over the phone, or by survey to gather their input on issues and practices in their state or organization related to addressing the impacts of implementing WMA and contributed to the information captured in the Workshop Proceedings.

TABLE D1-1
Agencies that contributed feedback on WMA implementation

Agency	Location	Agency	Location
Alaska Dept of Trans	Juneau, AK	Maryland DOT	Baltimore, MD
Arizona DOT	Phoenix, AZ	Maryland DOT - District 6	Hagerstown, MD
British Columbia (BC) MoTI	Victoria, BC (Canada)	Maryland DOT - Office of Materials Technology	Hanover, MD
California DOT	Sacramento, CA	Massachusetts DOT	Lowell, MA
California DOT - District 7	Los Angeles, CA	New Hampshire DOT	Concord, NH
California DOT - District 7	West Covina, CA	New Jersey DOT	Trenton, NJ
City of Bellingham Public Works	Bellingham, WA	New Mexico DOT	Santa Fe, NM
City of Los Angeles Public Works Street Services	Los Angeles, CA	New York State DOT	Albany, NY
City of Santa Rosa Transportation & Public Works	Santa Rosa, CA	Oklahoma DOT	Oklahoma City, OK
Colorado DOT	Denver, CO	Ontario MTO	Toronto, ON (Canada)
Connecticut DOT	Rocky Hill, CT	Pennsylvania DOT	Harrisburg, PA
County of Orange	Santa Ana, CA	Pennsylvania DOT - District 1	Oil City, PA
Delaware DOT	Dover, DE	Pennsylvania DOT - District 11	Bridgeville, PA
Delaware DOT - District	Georgetown, DE	Pennsylvania DOT - District 2	Clearfield, PA
Dickinson County Road Commission	Kingsford, MI	Pennsylvania DOT - District 8	Harrisburg, PA
Florida DOT	Gainesville, FL	Pennsylvania Turnpike Commission	Harrisburg, PA
Georgia DOT	Atlanta, GA	Rhode Island DOT	Providence, RI
Idaho DOT	Boise, ID	South Dakota DOT	Pierre, SD
Iowa DOT	Ames, IA	Tennessee DOT	La Vergne, TN
Kansas DOT	Topeka, KS	Vermont AOT	Berlin, VT
Kentucky Transportation Cabinet	Frankfort, KY	Virginia DOT	Richmond, VA
Louisiana DOTD	Baton Rouge, LA	Washington DOT	Olympia, WA
Marion County Public Works	Salem, OR		

TABLE D1-2
Industry representatives who contributed feedback on WMA implementation

Industry Member	Location	Industry Member	Location
Alabama Asphalt Pavement Assoc.	Montgomery, AL	HRI, Inc.	Williamsport, PA
Allan Myers	Devault, PA	Ingevity	Charleston, SC
ASMG	Monroe, CT	Jas. W. Glover, Ltd.	Honolulu, HI
Basic Resources Inc. (George Reed Inc.)	Modesto, CA	Lehigh Hanson	Allentown, PA
Bishop Bros	Towanda, PA	Lindy Paving	New Galilee, PA
Blakeslee Asphalt	Blakeslee, PA	Lindy Paving	Zelienople, PA
Blythe Construction	Charlotte, NC	Mathy Construction	Onalaska, WI
California Asphalt Pavement Association	West Sacramento, CA	Narragansett Improvement Co.	Providence, RI
Cardi Construction	Warwick, RI	New Enterprise Stone & Lime Co., Inc.	New Enterprise, PA
Cargill	Plymouth, MN	New Enterprise Stone & Lime Co., Inc.	Winfield, PA
Colorado Asphalt Pavement Association	Denver, CO	Oldcastle Materials	Grand Junction, CO
Coopersburg Materials	Coopersburg, PA	Oldcastle Materials	Gainesville, FL
Duffield Associates, Inc	Wilmington, DE	Pennsy Supply (Oldcastle Materials)	State College, PA
Glenn O. Hawbaker	Grove City, PA	Pennsy Supply, Inc.	Annville, PA
Glenn O. Hawbaker, Inc.	State College, PA	Pennsy Supply, Inc.	Pittston, PA
Glenn O. Hawbaker, Inc.	Montoursville, PA	Pennsylvania Asphalt Pavement Assoc.	Harrisburg, PA
GOH	State College, PA	Pennys Supply, Inc.	Harrisburg, PA
Granite Construction	Sacramento, CA	Rieth-Riley Construction	Goshen, IN
H & K River Asphalt	Dogsboro, DE	River Asphalt	Delmar, DE
H&K Group	Skippack, PA	TDPS Materials	Philadelphia, PA
H&K Group	Skippack, PA	Virginia Asphalt Pavement Association	Richmond, VA
Heritage Research Group	Indianapolis, IN	Vulcan Materials Company	Chino Hills, CA
Highway Materials, Inc.	Flourtown, PA	Walter R. Earle	Jackson, NJ
Highway Materials, Inc.	Malvern, PA	York Materials Group	Hanover, PA
Highway Materials, Inc.	Plymouth Meeting, PA	York Materials Group	York, PA
HRI, Inc.	State College, PA		

TABLE D1-3
Other organizations that contributed feedback on WMA implementation

Other Organization	Location
Advanced Material Services, LLC	Auburn, AL
Federal Highway Administration	Washington, DC
Federal Highway Administration	McLean, VA
Federal Highway Administration	Harrisburg, PA
Federal Highway Administration	Dover, DE
Frank Fee, LLC	Media, PA
Louisiana State University	Baton Rouge, LA
National Asphalt Pavement Association	Kensington, MD
National Center for Asphalt Technology	Auburn, AL
North Carolina State University	Durham, NC
Pennsylvania State University	University Park, PA
Polytechnic University of Bari	Bari, Italy
Texas A&M Transportation Institute (TTI)	College Station, TX
U.S. Army Corps of Engineers	Vicksburg, MS
Univ. of California-Davis	Sacramento, CA
University of Arkansas	Fayetteville, AR
University of Science and Technology-Beijing	Beijing, China
University of South Alabama	Mobile, AL

APPENDIX 2: 2-DAY WORKSHOP (MAY 2017) PARTICIPANTS ROSTER

TABLE D2-1
Participants in the 2-day national workshop on WMA implementation

Count	First	Last	Affiliation	Email
1	Chandra	Akisetty	Maryland DOT	cakisetty@sha.state.md.us
2	Freeman	Anthony	City of Bellingham, WA	fanthony@cob.org
3	Parveez	Anwar	New Mexico DOT	Parveez.Anwar@state.nm.us
4	Edith	Arambula	Texas A&M University	e-arambula@tti.tamu.edu
5	Tim	Aschenbrenner	FHWA – HQ Pavt	timothy.aschenbrener@dot.gov
6	Dave	Aver	City of Santa Rosa, CA	daver@srcity.org
7	Anthony	Avery	NCHRP	aavery@nas.edu
8	Denis	Boisvert	New Hampshire DOT	Denis.Boisvert@dot.nh.gov
9	Gregory	Brouse	Pennsy Supply/Oldcastle Materials (PA)	gbrouse@oldcastlematerials.com
10	Mark	Brum	Massachusetts DOT	Mark.Brum@dot.state.ma.us
11	Cassie	Castorena	North Carolina State University	cahintz@ncsu.edu
12	Tom	Clayton	Colorado Asphalt Pavement Assoc.	tomclayton@co-asphalt.com
13	Samuel	Cooper	Louisiana DOTD	samuel.cooperiii@la.gov
14	Audrey	Copeland	NAPA	acopeland@asphaltpavement.org
15	Matthew	Corrigan	FHWA – HQ Pavt	Matthew.corrigan@dot.gov
16	Jim	Costello	South Dakota DOT	Jim.costello@state.sd.us
17	Jo	Daniel	University of New Hampshire	jo.daniel@unh.edu
18	Jeff	de Vries	Iowa DOT	Jeff.devries@iowadot.us
19	Stacey	Diefenderfer	Virginia DOT	stacey.diefenderfer@vdot.virginia.gov
20	Jesse	Doyle	US Army Corps of Engineers	jesse.d.doyle@usace.army.mil
21	Ervin	Dukatz	Mathy Construction (WI)	ervin.dukatz@mathy.com
22	Neal	Fannin	Pennsylvania DOT	nfannin@pa.gov
23	Frank	Farshidi	City of San Jose, CA	frank.farshidi@sanjoseca.gov
24	Frank	Fee	Consultant	frank.fee@verizon.net
25	Daryl	Finlayson	British Columbia MOT	daryl.finlayson@gov.bc.ca
26	Kee	Foo	California DOT	kee.foo@dot.ca.gov
27	Stevenson	Ganthier	New Jersey DOT	Stevenson.Ganthier@dot.nj.gov
28	Nelson	Gibson	TRB	ngibson@nas.edu
29	Richard	Gribbin	Jas. W. Glover, Ltd. (HI)	richg@gloverltd.com
30	Edward	Harrigan	NCHRP	eharriga@nas.edu
31	Sheila	Hines	Georgia DOT	shines@dot.ga.gov
32	Gerry	Huber	Heritage Research Group (IN)	gerald.huber@hrglab.com
33	David	Jones	University of California Pavement Research Center	djjones@ucdavis.edu
34	Chris	Kubasek	County of Orange, CA	Chris.Kubasek@ocpw.ocgov.com
35	Hugh	Lee	City of Los Angeles, CA	hugh.lee@lacity.org
36	Christopher	Leibrock	Kansas DOT	Christopher.Leibrock@ks.gov
37	Tony	Limas	Granite Construction, Inc. (CA)	tony.limas@gcinc.com

38	David	Luhr	Washington DOT	LuhrD@wsdot.wa.gov
39	Lance	Malburg	Dickinson County Road Commission, MI	lance@dickinsoncrc.com
40	Pascal	Mascarenhas	Vulcan Materials (CA)	mascarenhasp@vmcmail.com
41	Leslie	McCarthy	Villanova University	leslie@myersmccarthy.com
42	Rebecca	McDaniel	Purdue University	rsmcdani@purdue.edu
43	Brandon	Milar	California Asphalt Pavement Assoc.	BMilar@calapa.net
44	Louay	Mohammad	Louisiana State University	Louaym@Lsu.edu
45	Howard	Moseley	Florida DOT	Howard.Moseley@dot.state.fl.us
46	Jim	Musselman	Oldcastle Materials (FL)	Jim.Musselman@oldcastlematerials.com
47	David	Newcomb	Texas Transportation Institute	d-newcomb@tti.tamu.edu
48	Alfonso	Ochoa	Caltrans District 11 Materials	al.ochoa@dot.ca.gov
49	Hong	Park	Tennessee DOT	Hong.park@tn.gov
50	H. Skip	Paul	Consultant and TRB AFK-10 Chair	captskippaul@gmail.com
51	Justin	Price	Idaho DOT	Justin.Price@itd.idaho.gov
52	Randy	Reichert	Caltrans D12	randy.reichert@dot.ca.gov
53	Octavio	Rivas	County of Orange, CA	Octavio.Rivas@ocpw.ocgov.com
54	Carolina	Rodezno	NCAT	mcr0010@auburn.edu
55	Tate	Sallee	Kentucky Transportation Cabinet	Tate.sallee@ky.gov
56	Jesus	Sandoval-Gil	Arizona DOT	JSandoval-Gil@azdot.gov
57	Jack	Springer	FHWA TFHRC - LTPP	jack.springer@dot.gov
58	Michael	Stanford	Colorado DOT	michael.stanford@state.co.us
59	Blaine	Thomann	County of Orange, CA	Blaine.Thomann@ocpw.ocgov.com
60	Bob	Trousil	Alaska DOT	Robert.trousil@alaska.gov
61	Jack	Van Kirk	George Reed, Inc. (CA)	jack.vankirk@reed.net
62	Bobby	Williams	Oklahoma DOT	BWilliams@odot.org
63	Richard	Yahn	City of Santa Rosa, CA	ryahn@srcity.org
64	Zoeb	Zavery	New York State DOT	zoeb.zavery@dot.ny.gov

APPENDIX 3: 2-DAY WORKSHOP AGENDA (MAY 2017)

The National Academies of
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TRB
TRANSPORTATION RESEARCH BOARD

NCHRP 20-44(01) WMA Implementation
May 8th and 9th
Irvine, California

Introduction

8:00 - 8:30 Opening remarks *Leslie McCarthy, Jo Daniel*
- **Introduction of participants**
- **Scope, purpose, and expectations of workshop**
- **Logistics of meals, breakout groups, etc.**

8:30 - 9:15 National Perspective: ***State of Knowledge and Barriers & Gaps***
- **Impetus and Outcomes for NCHRP project 20-44(01)** *H. Skip Paul*
- **Topical Bibliography** *Jo Daniel*
- **Agency and Industry Survey Results** *Leslie McCarthy*

Part I
Defining Warm Mix Asphalt: Past and Future - Green Technology or Compaction Aid? Energy Savings or Engineering Tool?

9:00 - 9:15 Redefining WMA *Leslie McCarthy, Jo Daniel*

9:30 - 10:30 Breakout Session #1 *Redefining WMA*
- **Introduction** *Jo Daniel*
- Facilitated small group discussions

10:30 - 10:45 Break and Refreshments

10:45 - 11:30 Plenary #1 *Jo Daniel, moderator*
- Reports from each of the breakout groups
- Discussion of results

Part II
Barriers and Disincentives Limiting WMA

11:30 - 12:00 The Real Economics of WMA: ***Industry Panel of Asphalt Producers and Contractors***
- ***Jack Van Kirk,*** *George Reed, Inc. - CA*
- ***Cindy LaFleur****, Tilcon NY - NY*
- ***Greg Brouse,*** *Old Castle Materials -PA*
- ***Tony Limas,*** *Granite-CA*

500 Fifth Street, NW, Washington, DC 20001
Phone 202.334.3224 Fax 202.334.2006 www.TRB.org

NCHRP 20-44(01) WMA Implementation
May 8th and 9th
Irvine, California

12:00 - 1:00 Lunch

1:00 - 1:30 WMA and the Other Customers: ***Local Agency Perspective***
- ***Freeman Anthony*** *(City of Bellingham, WA), APWA Transportation Committee*
- ***Lance Malburg*** *(Dickinson County Road Commission, MI), NACE Pavement Preservation*

1:30 - 2:30 Breakout Session #2 *Barriers to expanding WMA*
- **Introduction** *Leslie McCarthy*
- Facilitated small group discussions

2:30 - 2:45 Break and Refreshments

2:45 - 3:45 Plenary #2 *Jo Daniel, moderator*
- Reports from each of the breakout groups
- Discussion of results

Part III
Cooperative Actions

3:45 - 4:15 USACE Efforts with WMA for Airfields *Leslie McCarthy, Moderator*
- ***Jesse Doyle,*** *US Army Corps of Engineers*

4:15 - 5:15 Breakout Session #3: *Cooperative Actions*
- **Introduction** *Leslie McCarthy*
- Facilitated small group discussions

5:15 - 5:30 Summary

5:30 – 6:00 Reception (Beckman Center)

6:00 Dinner

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NCHRP 20-44(01) WMA Implementation
May 8th and 9th
Irvine, California

Day Two (8:00 – 2:30)

8:00 - 9:00 Plenary #3 *Jo Daniel, moderator*

- Verbal reports from each of the discussion groups
- Discussion of results

Part IV
Quantifying the Impacts of WMA over the Long Term

9:00 - 9:30 FHWA LTPP SPS-10 WMA Experiments

- ***Jack Springer,*** *FHWA Turner-Fairbank Highway Research Program, LTPP*

9:30 - 10:00 Pavement Performance Management Systems: Adapting for Better Evaluating WMA Over Time

- ***David Luhr,*** *Washington Department of Transportation*

10:00 - 10:15 Break with Refreshments

10:00 - 11:15 Breakout Session #4 *Quantifying WMA Impacts*

- **Introduction** *Leslie McCarthy*
- Facilitated small group discussions

11:15 - 12:15 Plenary #4 *Jo Daniel, moderator*

- Verbal reports from each of the discussion groups
- Discussion of results

12:15 - 1:00 Lunch

Conclusions

1:00 - 2:30 Summary and Next Steps *Leslie McCarthy, Jo Daniel*

2:30 Adjourn

APPENDIX 4: 2-DAY WORKSHOP SPEAKERS (MAY 2017)

The National Academies of
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TRB
TRANSPORTATION RESEARCH BOARD

Warm Mix Asphalt Workshop Speakers

Day One

8:30 AM National Perspective*: State of the Knowledge, and Barriers and Gaps in Knowledge*

- **Harold "Skip" Paul** worked for the Louisiana Department of Transportation and Development for 39 years in both the research section and the Louisiana Transportation Research Center. He conducted asphalt and materials research for the first 18 years of his career, and was involved in research program administration for 21 years. He has over 50 publications at the Transportation Research Board, Association of Asphalt Paving Technologists and other technical publications. Mr. Paul is a graduate of Lehigh University holding two degrees, a B.S. n Mechanical Engineering (1976) and a B.A. in English (1976).

- **Leslie Myers McCarthy** has spent her career in a mix of academia, consulting, and public sector. She worked at the Federal Highway Administration's (FHWA) Office of Pavement Technology as a Pavement Design engineer and managed the Mobile Asphalt Testing Laboratory program. In 2009, she joined the Civil Engineering faculty of Villanova University. She is a graduate of Penn State University (B.S. 1996) and University of Florida (M.S. 1997, Ph.D. 2000).

- **Jo Sias Daniel** is a professor in the Department of Civil and Environmental Engineering at the University of New Hampshire. Her research work focuses on characterization of asphalt materials and mixtures and pavement evaluation and analysis. She is also the director of the UNH Center for Infrastructure Resilience to Climate. Dr. Daniel is a graduate of UNH (B.S. 1994) and North Carolina State University (M.S. 1996, Ph.D. 2001).

11:30 AM The Real Economics of WMA ***Industry Panel of Asphalt Producers and Contractors***

- **Jack Van Kirk** is currently the Director for Asphalt Technology for Basic Resources Inc. He provides internal consulting, regarding materials engineering and pavement preservation for the Reed Group of Companies, which includes George Reed Inc. Jack is a registered Civil Engineer in the State of California. Prior to joining Basic Resources, Jack worked for CalTrans for almost 20 years. He was the departmental expert in the area of flexible pavement.

- **Cindy LaFleur** is currently the Director of Quality Control for Tilcon NY, Inc., an Oldcastle company. Tilcon NY is the leading supplier of construction materials in the Metropolitan NY market. Cindy has worked for Oldcastle companies for 28 years, with a brief hiatus with MeadWestvaco as Technical Marketing Manager for the Evotherm business.

- **Greg Brouse** is a Quality Assurance Director for Pennsy Supply/Oldcastle. His forte is quality and process innovation in HMA, WMA, and CRM asphalt. Afforded by progressive administrations and DOT support, his teams have developed many successful contributions for the benefit of our industry and its customers.

- **Tony Limas** began his career building dams with the Corps of Engineers in 1975. In 1980 he left the Corps to work for a joint venture contractor building airbases oversees. In 1983 Tony returned to work for the Corps of Engineers before joining Granite Construction in 1990. Tony is currently a member of Granites Quality Management team serving as a Public/Private Liaison and providing technical support for Granite's California materials and construction operations.

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1:30 AM Contractors, WMA, and Other Customers

- **Freeman "Fritz" Anthony** is a registered Professional Engineer in Utah and Washington States with 18 years of experience as a both a private consultant and public sector project engineer. He has worked in New Zealand, Indonesia, and the United States. He currently works for the City of Bellingham managing design/delivery of water/wastewater facilities and multi-modal transportation corridors projects including sustainable design concepts such as porous concrete, rain-gardens, and recycled aggregates. He serves on the APWA National Transportation Committee and Board of Directors for the Greenroads Foundation.

- **Lance Malburg** is a Michigan Tech graduate. He has been an engineer for the Dickinson County Road Commission since 2011. Previously he was the Oceana County Road Commission Engineer, later promoted to their Engineer-Manager. Prior work experiences include Project Manager for Abonmarche Consultants, Inc., dealing with municipal design & construction projects; Village Engineer for Glendale Heights, IL; Civil Engineer for West Chicago, IL, and the Illinois Department of Transportation. Honors received include the Michigan Transportation Asset management Council Individual Award, County Road Association of Michigan Merit Award, and ARRA's Award for Excellence.

3:45 PM USACE Efforts with WMA for Airfields

- **Jesse Doyle, Ph.D.,** is a research civil engineer at the U.S. Army Engineer Research and Development Center located in Vicksburg, MS. He has provided technical expertise at Department of Defense installations all over the world for forensic investigations of pavement failures and for quality assurance of pavement construction projects. He was part of the research team that developed a Department of Defense guide specification for the use of warm mix asphalt for airfield paving.

Day Two

9:00 AM HWA LTPP SPS-10 WMA Experiments

- **Jack H. Springer** has over 35 years of experience in pavement management, design, research and construction. He is a member of the Long Term Pavement Performance Team at Turner-Fairbank Highway Research Center where he oversees field operations and materials for LTPP. He is a graduate of NC State University and a registered engineer in South Carolina.

9:30 AM Pavement Performance Management Systems – *Adapting for Better Evaluating WMA Over Time*

- **David Luhr**, PE, is the Pavement Management Engineer for Washington State DOT. He has a Bachelors Degree in Civil Engineering from the University of Illinois, Urbana, and a Masters and Ph.D. from the University of Texas, Austin. David joined WSDOT in 2007. He has a wide background with 40 years of experience (20 years in private sector and 20 years in public sector) related to pavement engineering and asset management.

APPENDIX 5: RHODE ISLAND MINI-WORKSHOP (SEPTEMBER 2017) PARTICIPANTS

TABLE D5-1
Participants in the 1-day regional workshop on WMA implementation

Count	First	Last	Affiliation	Email
1	Dave	Howley	Connecticut DOT	David.howley@ct.gov
2	Chris	Toegemann	Narragansett Improvement Co.	Ctoegemann@nicori.com
3	Nic	Giardion	Cardi	nick@cardi.com
4	Kate	Wilson	Rhode Island DOT	Kate.wilson@dot.ri.gov
5	Colin	Franco	Rhode Island DOT	Colin.franco@dot.ri.gov
6	Mike	Byrne	Rhode Island DOT	Michael.byne@dot.ri.gov
7	Elizabeth	Cornell	Rhode Island DOT	Elizabeth.cornell@dot.ri.gov

APPENDIX 6: RHODE ISLAND MINI-WORKSHOP AGENDA (SEPTEMBER 2017)

Overview of NCHRP Project 20-44(01) National Workshop [*held May 8-9, 2017*]
Increasing WMA Implementation by Leveraging the State-Of-The-Knowledge

September 20, 2017
9 am – 12 pm

Rhode Island Department of Transportation
Room 140 (TMC Conference Room)
Two Capitol Hill
Providence, RI 02903

AGENDA

9:00	Introduction of Speakers, NCHRP 20-44(01) Background and Goals
9:10	Overview of National State-of-the-Knowledge on WMA
9:30	Overview of Redefining WMA: Workshop Suggestions
9:35	Feedback # 1 – discussion of your thoughts on the definition of WMA
10:00	Overview of Industry and Local Agency perspectives on WMA (Session 2)
10:05	Feedback # 2 – discussion of your thoughts on Barriers/Disincentives of using WMA
10:30	BREAK
10:45	Overview of Addressing Challenges to WMA (Session 3)
10:50	Feedback # 3 – discussion of your thoughts on Cooperative Actions by Agency and Industry
11:15	Summary and Discussion of Workshop Outcomes and formulation of next steps: future research needs, peer state assistance, brief post-workshop survey
11:50	Questions and Answers from workshop participants
12:00	Adjourn

APPENDIX 7: TRB STRAIGHT-TO-RECORDING VIDEO VIEWERS (NOVEMBER 2017)

TABLE D7-1
Participants in the TRB Straight-to-Recording Webinar on WMA implementation who provided feedback

Count	First	Last	Affiliation	City, State
1	Mel	Monk	Alabama Asphalt Pavement Association	Montgomery, AL
2	Blair	Heptig	Kansas DOT	Topeka, KS
3	Hassan	Tabatabaee	Cargill	Plymouth, MN
4	Shenghua	Wu	University of South Alabama	Mobile, AL
5	Seyed	Tabib	Ontario Ministry of Transportation	Toronto, ON (Canada)
6	David	Fife	Oldcastle Materials	Grand Junction, CO
7	Vittorio	Ranieri	Polytechnic University of Bari	Bari, Italy
9	David	Howley	Connecticut DOT	Rocky Hill, CT
10	Aaron	Schwartz	Vermont Agency of Transportation	Berlin, VT
11	Ryan	Crowther	Marion County Public Works	Salem, OR
12	Peter	Capon	Rieth-Riley Construction	Goshen, IN
13	Terry	Dreher	Pennsylvania Turnpike Authority	Harrisburg, PA
14	Meng	Guo	University of Science and Technology Beijing	Beijing, China
13	Mel	Monk	Alabama Asphalt Pavement Association	Montgomery, AL

APPENDIX 8: TRB STRAIGHT-TO-RECORDING VIDEOS ON WMA IMPLEMENTATION (NOVEMBER 2017)

Overview of NCHRP Project 20-44(01) National Workshop [*held May 8-9, 2017*]
Increasing WMA Implementation by Leveraging the State-Of-The-Knowledge
November 28, 2017
Transportation Research Board
Straight-to-Recording Video Series
TRB Straight to Recording for All: Increasing Warm Mix Asphalt (WMA) Implementation
View the videos at the following link: http://www.trb.org/ElectronicSessions/Blurbs/176886.aspx

AGENDA

Video #	Presenter	Title of Video
1	Skip Paul	*Background on Implementation of WMA: Present and Future*
2	Leslie McCarthy	*Opening Remarks: NCHRP Project 20-44(01)*
3	Jo Daniel	*State-of-the-Knowledge for WMA*
4	Jo Daniel	*Redefining Warm Mix Asphalt*
5	Jo Daniel	*Barriers and Disincentives that Limit the Use of WMA*
6	Leslie McCarthy	*Cooperative Actions by Agency and Industry*
7	Leslie McCarthy	*Closing Remarks: Future Steps for WMA Implementation*

Survey* **Online** **Available at the following site:**
http://www.surveygizmo.com/s3/3912542/Straight-to-Recording-NCHRP20-44-Dialogue-on-WMA
*Please respond to the survey by December 30, 2017

The status of this ongoing research can be found in NCHRP Project 20-44(01) Increasing WMA Implementation by Leveraging the State-Of-The-Knowledge.

APPENDIX E

PROJECT SUMMARY BRIEF FOR EXECUTIVES

Increasing WMA Implementation

Topic and issues

Warm mix asphalt (WMA) technologies were first introduced in the U.S. in the early 2000s and rapidly gained popularity. Industry and agencies recognized the potential benefits including cost savings from lower production temperatures; environmental benefits from reduced emissions; and construction benefits from more consistent and higher in-place density and/or extended paving seasons or haul times. Despite the significant resources dedicated to advancing the use of WMA through national level research and the Federal Highway Administration (FHWA) Every Day Counts program, use of WMA has leveled off or declined in recent years. In response, the National Cooperative Highway Research Program (NCHRP) initiated research project NCHRP 20-44(01) to identify barriers to implementation; identify where and why tonnage has leveled off; and establish and update performance indicators for WMA implementation.

A national level workshop involving industry, academics, and local, state, and federal agencies was developed and run by consultants to address these issues. Surveys, additional local/regional workshops, and webinars were also conducted to gather information and feedback. A new consensus definition for WMA was developed and cooperative actions between agencies and industry to continue to move WMA implementation forward were suggested.

WMA = Modified asphalt mixes produced with various technologies – including water foaming, chemical additives, and organic waxes – that have the capacity to be used in lower production temperature (below 300° F), but can be used at normal production temperatures, to achieve improved compatibility, in-place density, and sustainability and without a diminution of short- and long- term performance.

What are the benefits for my organization?

The use of WMA provides benefits. Reduced emissions are good for the environment and good for those working directly with WMA. Cost savings can benefit both the agency and the contractor. The ability to achieve higher in-place density for a variety of materials under a range of conditions is another benefit.

What should my organization do?

Engage your organization and those you work with on current policies and views on WMA. A discussion on the revised definition of WMA is a good place to start, while the items under "What should be done" can move the discussion forward.

What should be done?

- Move towards the use of end-result or performance-based specifications in order to allow for more flexibility and innovation by paving contractors;
- Incentivize the use of WMA through innovative project award techniques or funding;
- Develop a database platform that supports the WMA community, perhaps coordinated with the annual NAPA-FHWA survey, which includes a template for tracking key data related to WMA;
- Develop and maintain web-based training resources including informational brief documents and recorded webinars; and,

Support the development of a community of practice that allows for agencies and contractors to benefit from the experience of other practitioners, to problem solve, and to confidently move forward with the more routine use of WMA.

APPENDIX F

DRAFT SCOPES OF WORK AND SUBMITTED TRB SYNTHESIS SUGGESTION

DRAFT SCOPE OF WORK
NCHRP Project 20-07/Task XXX
Development of a Warm Mix Asphalt Standard Practice to Accompany AASHTO M320 and a Recommended Practice for using WMA Technologies

BACKGROUND

The use of warm mix asphalt (WMA) technologies including specialty chemicals, waxes, and foaming provide potential benefits that include cost savings from lower production temperatures, environmental benefits with reduced emissions, and construction benefits with the ability to extend paving windows and achieve more consistent and higher in-place density. State agencies were encouraged to allow WMA, develop WMA specifications, and track usage through the FHWA Every Day Counts (EDC) initiative. Many states have developed standard specifications for WMA, however, there are also many states that have not implemented widespread use of WMA and still have WMA in specifications only as special provisions. There is also anecdotal evidence that the use of WMA is declining

The NCHRP 20-44(1) project "Increasing WMA Implementation by Leveraging the State-of-the-Knowledge" identified that the lack of standard or recommended practices for WMA technologies are a barrier to increased usage of WMA.

OBJECTIVE

The objectives of this research are to:

- Develop a standard practice for WMA to accompany AASHTO M320
- Develop a recommended practice for using WMA technologies

TASKS

Task 1. Review current practices by the states and industry for WMA technologies. The review shall include (1) relevant results from NCHRP Projects 9-43, 9-47A, 9-49, 9-49A, 9-52, and 9-55, (2) the guidelines available from the WMA Technical Working Group at http://www.warmmixasphalt.com/Default.aspx, (3) NAPA Publication QIP-125, "Warm-Mix Asphalt: Best Practices," and (4) comparable AASHTO practices

Task 2. Develop a standard practice to accompany AASHTO M320 and a recommended practice for using WMA technologies in standard AASHTO format.

Task 3. Submit a project final report summarizing the findings from Task 1 and the draft AASHTO documents.

NCHRP Project 20-05

Synthesis Topic 50-##

Warm Mix Asphalt Usage and Implementation

Draft Scope

WMA technology and deployment were largely driven by the asphalt industry. Research was performed at both the state and national levels as well as by private industry. A number of WMA technologies were developed and marketed during the mid to late 2000s. These technologies included the use of foam (water), waxes, and other specialty chemicals. A large number of demonstration sections were placed in the late 2000s by multiple states and contractor groups and performed favorably. This resulted in the continued and more rapid acceptance of WMA as the benefits were recognized. These benefits included lower production temperatures, reduced emissions and energy consumption, extended construction day and season, and additional opportunities for more uniform and higher density construction. The National Asphalt Pavement Association (NAPA) reported that in 2015, WMA was estimated to comprise 30% of the total estimated asphalt mixture market. The survey reported that plant foaming was the most commonly-used warm mix technology (72% of the market) and chemical additive technologies represented approximately 25% of the market.

This project will synthesize the state-of-the-practice in the use of warm mix asphalt (WMA) and seeks to address information on long term monitoring of WMA field sections, use and criteria of standard or supplemental specifications, and the establishment of appropriate curing times and temperatures during the mix design process. WMA mixtures include both hot mix asphalt enhanced with additives or foaming technologies or those in which the hot mix asphalt is produced at lower temperatures.

Much of the research conducted to date has indicated that immediately after construction, WMA pavements have lower stiffness and are more susceptible to rutting than HMA. However, their properties evolve over time (due to aging in the field) and the expected rutting performance becomes more similar, or equal, to HMA. Field densities have generally been observed to be similar for HMA and WMA pavements, with slightly better compactability observed with the WMA materials. In some cases, WMA pavements were observed to have lower asphalt absorption levels during production, but the volumetric properties of WMA and HMA are similar if a low absorption aggregate is used. The use of recycled materials generally increases the stiffness WMA pavements, but this effect depends on the combination of the specific material type and WMA technology used. Additional research indicated that the properties of foamed asphalts were found to be different when evaluated in the laboratory versus at the point of production at the plant. Several studies pointed out the unknown interactions between WMA and higher percentages of various types of recycled materials.

The scope of this synthesis study will focus on asphalt mixtures produced with the goal of allowing for cool weather paving; extending the paving season; improving constructed pavement by achieving more consistent densities; benefitting worker health and safety; and/or providing environmental benefits. For this project, WMA is defined as an asphalt mixture that uses a technology that allows for a reduction in production and placement temperatures and may enhance workability and improve compaction. Results will benefit government agencies, researchers, and the road-building industry by providing information that can assist in decisionmaking for making better use of WMA by tracking its use and performance to capture the benefits related to sustainability.

This synthesis will include a literature review and a survey of state and local departments of transportation (DOTs), Canadian ministries of transportation and support organizations (specifically Local Technical Assistance Program and Tribal Technical Assistance Program coordinators). International agencies' experience will be reviewed as available. From the results of the survey, at least 5 agencies are to be selected and case examples of their practices will be developed. Lessons learned, gaps in information, and barriers to implementation will also be covered.

Information gathered on specifications will include, but not be limited to the following:

- Agency mix design or construction specifications for WMA
    - Specifications that proactively encourage the use of warm mix technologies
    - DOT Approved Product List (APL) facilitate the use of new warm mix technologies by contractors
- Agency use of WMA
    - How use is being tracked (tonnage, project construction information, pavement management database, etc.)
    - Project selection criteria for when WMA is specifically requested or bid
    - Use of contract provisions (incentives or inclusion of sustainable rating tool certification credits)
    - Use of sustainability rating tools or credits
- Performance tracking of pavements built with WMA
    - Performance criteria, data collection and maintenance, life cycle assessment
- Were the benefits worth the investment in terms of cost, time, or equipment

- Supporting information (e.g., life cycle cost analysis, other metrics tracking the benefits of WMA)
- Ways that Agencies and Industry cooperate to document the benefits of using WMA

- On-going research and needs
    - Appropriate performance tests

TRB Synthesis Proposal
Template for Standing Committees

*Required fields**

Submitted By* *Only one name per submission. Please use the "Notes" section below, to credit co-submitters.	Dr. Jo Sias Daniel University of New Hampshire
Program*	__X_ NCHRP (Highways) ___ TCRP (Transit) ___ ACRP (Airports)
Title* (500 character limit) Briefly and immediately convey what the synthesis study is about	Warm Mix Asphalt Usage and Implementation
Scope* (7500 character limit) This is an opportunity to convince the reviewer that the information to be gathered addresses a serious issue and merits funding. It should set the context and relate the particular issue to larger national or regional goals and objectives	WMA technology and deployment were largely driven by the asphalt industry and encouraged through the FHWA Every Day Counts Program. Research was performed at both the state and national levels as well as by private industry. A number of WMA technologies were developed and marketed during the mid to late 2000s. These technologies included the use of foam (water), waxes, and other specialty chemicals. A large number of demonstration sections were placed in the late 2000s by multiple states and contractor groups and performed favorably. This resulted in the continued and more rapid acceptance of WMA as the benefits were recognized. These benefits included lower production temperatures, reduced emissions and energy consumption, extended construction day and season, and additional opportunities for more uniform and higher density construction. The National Asphalt Pavement Association (NAPA) reported that in 2015, WMA was estimated to comprise 30% of the total estimated asphalt mixture market. The survey reported that plant foaming was the most commonly-used warm mix technology (72% of the market) and chemical additive technologies represented approximately 25% of the market. This project will synthesize the state-of-the-practice in the use of warm mix asphalt (WMA) and seeks to address information on long term monitoring of WMA field sections, use and criteria of standard or supplemental specifications, and the establishment of appropriate curing times and temperatures during the mix design process. WMA mixtures include both hot mix asphalt enhanced with additives or foaming technologies or those in which the hot mix asphalt is produced at lower temperatures. Much of the research conducted to date has indicated that immediately after construction, WMA pavements have lower stiffness and are potentially more susceptible to rutting than HMA. However, their properties evolve over time (due to aging in the field) and the expected rutting performance becomes more similar, or

	equal, to HMA. Field densities and rut depths have generally been observed to be similar for HMA and WMA pavements placed on the same project, with slightly better compactability observed with the WMA materials. In some cases, WMA pavements were observed to have lower asphalt absorption levels during production, but the volumetric properties of WMA and HMA are similar if a low absorption aggregate is used. The use of recycled materials generally increases the stiffness WMA pavements, but this effect depends on the combination of the specific material type and WMA technology used. Additional research indicated that the properties of foamed asphalts were found to be different when evaluated in the laboratory versus at the point of production at the plant. Several studies pointed out the unknown interactions between WMA and higher percentages of various types of recycled materials.
	The scope of this synthesis study will focus on asphalt mixtures produced with the goal of allowing for cool weather paving; extending the paving season; improving constructed pavement by achieving more consistent densities; benefitting worker health and safety; and/or providing environmental benefits. For this project, WMA is defined as an asphalt mixture that uses a technology that allows for a reduction in production and placement temperatures and may enhance workability and improve compaction. Results will benefit government agencies, researchers, and the road-building industry by providing information that can assist in decision making for making better use of WMA by tracking its use and performance to capture the benefits related to sustainability.
	This synthesis will include a literature review and a survey of state and local departments of transportation (DOTs), Canadian ministries of transportation and support organizations (specifically Local Technical Assistance Program and Tribal Technical Assistance Program coordinators). International agencies' experience will be reviewed as available. From the results of the survey, at least 5 agencies are to be selected and case examples of their practices will be developed. Lessons learned, gaps in information, and barriers to implementation will also be covered.
	Information gathered on specifications will include, but not be limited to the following:
	• Agency mix design, construction or performance specifications for WMA
	    • Specifications that proactively encourage the use of warm mix technologies
	    • DOT Approved Product List (APL) facilitate the use of new warm mix technologies by contractors
	• Agency use of WMA
	    • How use is being tracked (tonnage, project construction information, pavement management database, etc.)
	    • Project selection criteria for when WMA is specifically requested or bid
	    • Use of contract provisions (incentives or inclusion of sustainable rating tool certification credits)
	    • Use of sustainability rating tools or credits
	• Performance tracking of pavements built with WMA
	    • Performance criteria, data collection and maintenance, life cycle assessment
	• Were the benefits worth the investment in terms of cost, time, or equipment
	    • Supporting information (e.g., life cycle cost analysis, other metrics tracking the benefits of WMA)
	    • Ways that Agencies and Industry cooperate to document the benefits of using WMA
	• On-going research and needs
	    • Appropriate performance tests

Information Sources (1500 character limit)	NCHRP Project 20-44(01) final report and topical bibliography; NCHRP Report 691; NCHRP RRD 374; NAPA http://www.asphaltpavement.org/; National Center for

Short	Asphalt Technology http://www.ncat.us/ ; FHWA https://www.fhwa.dot.gov/pavement/asphalt/wma.cfm; NAPA-FHWA Information Series 138 Recycled Materials and Warm-Mix Asphalt Usage; NCHRP Synthesis Report 492; NCHRP Projects 9-47, 9-47A, 9-49, 9-49A, 9-52, 9-53, 9-54, 9-55; FHWA LTPP SPS-10 experiments; US Army Engineer R&D Center: Warm-Mix Asphalt for Airfield Pavements; AASHTO NTPEP WMA-15 Evaluation of Warm Mix Asphalt Technologies
Notes (1500 character limit)	This synthesis idea was developed by Dr. Leslie McCarthy and Dr. Jo Sias Daniel as part of the NCHRP 20-44(1) project and is supported by TRB AFK30 standing committee.