WARM MIX ASPHALT PROCESSES APPLICABLE TO NORTH DAKOTA

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MASTER OF SCIENCE

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ABSTRACT

Warm mix asphalt (WMA) represents a group of technologies that allows production of asphalt mixtures at lower temperatures compared to traditional hot mix asphalt (HMA). This results in less fuel consumption and reduction in CO_2 and fumes emission.

This research was conducted in order to provide North Dakota department of transportation (NDDOT) with a thorough study on state of the practice of WMA in USA and compare WMA performance with HMA. Extensive literature study was conducted, collecting reports and field experiment data from DOTs of states with climate similar to ND. Viewpoints of experts in the field were collected and analyzed using a comprehensive survey. These were added to analysis of collected data on WMA performance. The research results suggest using foaming processes (Double Barrel Green in particular) and chemical additives (Evotherm in particular) at this early stage with guidelines for modifications in WMA specification and testing compared to HMA.

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DEDICATION

To my wife, Aida

for her continuous support and love and the joy she has brought to my life

PREFACE

This research was funded by North Dakota Department of Transportation (NDDOT) as NDDOT Project Number: NDSU 11-01 - SPR-R033 (003). Arash Saboori was the lead graduate student assigned and was responsible to provide deliverables of each stage of the research from beginning to the end under supervision of Professor Magdy Abdelrahman. Mr. Mohy Eldin Ragab contributed to the research project and was assigned research tasks by Professor Abdelrahman. Mr. Ragab's work is acknowledged in footnote of respective chapters where his collaboration is used.

The raw data for chapter 4 and 5 of the thesis was taken from experiments conducted by a number of state DOTs. Their work is cited within the text and is available in the reference section of the thesis. Only raw data were taken from their studies and graphs and analysis were conducted by Arash Saboori.

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CHAPTER 1. INTRODUCTION

1.1. History of Warm Mix Asphalt (WMA)

Warm mix asphalt (WMA) represents a group of technologies that allow production and placement of asphalt mixes at lower temperatures compared to hot mix asphalt (HMA). This is achieved through reducing the viscosity of asphalt and complete coating of aggregate at lower temperature (D'Angelo, 2008). The first WMA pavements were constructed in Europe in 1995 by experimenting with Aspha-min zeolite. Shell Bitumen began experimenting with WAM (Warm Asphalt Mix) in Norway in 1996, which has now developed into WAM Foam. The first pavements with Sasobit were constructed in 1997 in Hamburg, Germany. In 2002, a National Asphalt Pavement Association (NAPA) study tour introduced WMA technology to the U.S. Later on in 2005, NAPA and Federal Highway Administration (FHWA) formed WMA Technical Working Group (WMA TWG).The primary goal of WMA TWG was to develop a data collection framework for WMA trials that agencies would use for their own evaluations on WMA technologies (Prowell, 2011). In 2008, the WMA TWG published a WMA Guide Specification for Highway Construction in AASHTO format.

1.2. Advantages of WMA Compared to Hot Mix Asphalt (HMA)

WMA is typically produced at temperatures 35 to 100°F lower than HMA. The characteristic of WMA, that has higher workability at lower temperature, also results in better compaction in the field. This results in less permeability and lower aging of the binder. The fact that WMA is softer than HMA is also an advantage in areas with low temperatures because the risk of thermal cracking is lower. Lower mixing and compaction temperatures also result in less fuel consumption and reduction in CO_2 and fumes emission, which imposes less health risk on workers and shows better stewardship towards the environment. Considering paving benefits, there are several advantages to using WMA. The ability to pave in cooler temperatures, haul longer distances, compact mix with less effort, incorporate higher percentage of RAP, place thick lifts, and open roads to traffic in a shorter period of time are some of the benefits of using WMA (Prowell, 2011).

1.3. Problem Statement

Introduction of WMA to the pavement industry has offered a lot of advantages compared to HMA but at the same time have put so many unanswered questions forward. There are so many products available for use and the performance and suitability of each are not totally known. Due to the limited experience of pavement agencies limited data is available and lack of reliable design and implementation guides adds more to the complexity. At the same time, advantages offered by WMA use cannot be neglected specially reduction on fuel consumption and its less environmental impact. North Dakota Department of Transportation has started few limited pilot studies, but their approach toward WMA needs to be based on a structured research on current technologies available in the market and their suitability for use in North Dakota. To determine the suitability of different technologies, it is rational to collect viewpoints of the experts and evaluate field performance of technologies based on previous studies.

1.4. Objectives

The main objectives of this research were:

a. Evaluate current WMA processes and additives and their applicability, as used in target states, to North Dakota projects.

b. Recommend techniques, equipment, and additives that are most suitable for the use of WMA in North Dakota.

c. Recommend specification changes to account for differences in production and/or placement of WMA, as compared to HMA.

1.5. Approach

For the literature review task, literature on the use of WMA technologies in the US and in other states/countries was collected. This task also included a collection of published data and information on the processes, the specifications, and the materials as used in the construction of WMA in the northern and central tier states. To collect literature multiple data bases were investigated consisting of DOT's websites and publications, Transport Research International Documentation (TRID) of Transportation Research Board (TRB), scholarly papers from Science Direct and Web of Science, and WMA manufactures' websites.

The second task was to collect specific data on the design, performance, and constructability of WMA applications in neighboring states. A questionnaire was prepared and sent to target states, followed by phone interviews to collect additional data/information on using

WMA from local authorities and state agencies (DOTs) of other states. The objective of this section was to:

1. Identify the WMA additives and processes currently used in the following northern and central tier states and provinces: Montana, South Dakota, Minnesota, Iowa, Wisconsin, Michigan, Nebraska, Kansas, Missouri, Illinois, Indiana, Ohio, New York, Pennsylvania, Vermont, New Hampshire, Maine, Colorado, Utah, Nevada, Wyoming, Idaho, Oregon, Washington, Manitoba, Saskatchewan, and Alberta.

2. Identify the selection method used by states/provinces to approve a particular WMA process (approved products list, field experimentation, experience of others, etc.), and how they developed that selection process.

3. Collect individual state/province WMA specifications.

Data collected through questionnaire was analyzed and summarized to understand current state of practice and understanding of WMA at state DOTs' level.

To have a perspective on WMA performance compared to HMA, performance test data from projects were collected and analyzed. Two main issues identified from literature study and questionnaire, were rutting and moisture susceptibility. Therefore, the focus was put on these two issues. Statistical analysis and graph produced from collected data were used in comparing WMA performance with that of HMA.

1.6. Thesis Organization

Chapter 2 summarizes the information collected in the literature study. The chapter begins with a comprehensive section on current available technologies in United States categorizing them in three main sections: Foaming, Chemical, and Organic. More than 20 technologies are discussed with contact details of the manufacturers and modifications required to the production plant. The chapter continues with current suggestions about WMA mix design and presents a study conducted previously at NDSU regarding the use of WMA in ND through a questionnaire sent to WMA contractors within the state. The chapter concludes with a summary of publications and specifications by states of interest (with similar climate to ND). Collected documents of 20 states are presented with details regarding the changes they have had compared to HMA with references to the complete document at NDSU WMA Report (Saboori, 2012).

Chapter 3 presents data analysis of the survey results which was designed and sent to 26 states of north tier of USA and Canada that has similar climate to ND. 24 questions in different areas (performance, cost, specifications, quality control & assurance…) were sent and the collected responses are analyzed and presented in graphs and tables and conclusions are made based on them. The survey is available in Appendix A. Full responses to the survey and the comments of the participants are tabulated and accompanied with all the graphs in Appendix B.

Chapter 4 discusses the experimental design of the experiments used for collecting data in order to evaluate performance of WMA. Two main issues of concern in WMA are rutting and moisture susceptibility and focus of the data collection were on them.

In Chapter 5 collected data of chapter 4 were tabulated and graphs were built for better interpretation. Statistical analysis was conducted on the collected data and conclusions were made based on observations.

Chapter 6 summarizes the findings of the research and offer conclusions and presents recommendations and guidelines for NDDOT for implementation of WMA in their future projects.

CHAPTER 2. LITERATURE STUDY

2.1. Introduction

WMA technologies could be categorized in to three main types: chemical additives, foaming processes, and organic additives. This chapter summarizes the information about WMA technologies available in the market for each of the three categories mentioned. For each WMA process the followings are presented: dosage, reduced temperature compared to HMA, manufacturer, and modifications required for mix design or needed for mix plant.

NCHRP Report 619: "Mix Design Practices for Warm Mix Asphalt" was published in 2011 that provided an appendix to AASHTO R35(Standard Practice for Superpave Volumetric Design for Hot-Mix Asphalt (HMA)), even though WMA is currently produced mostly based on manufacturer's advice. A review of the NCHRP research is presented in this chapter.

Of the many reports and papers available in WMA, a survey from North Dakota contractors is of special interest, as it reflects the viewpoint of the parties other than NDDOT involved in development of WMA in pavement projects in ND. A summary of this study is also presented in this chapter.

As one of the major goals of this study was to collect information regarding specifications, standards, and publications of other states agencies in WMA, the chapter is concluded with a section summarizing other states status in this regard with references to a collection of all their standards and publications in the warm mix asphalt report prepared by NDSU (Saboori, 2012)

2.2. WMA Technologies

WMA technologies could be categorized based on the temperature reduction that can be achieved by using them, but it is more common to classify them based on the method of production where WMA technologies are generally of three types: chemical additives, foaming processes, and organic additives.

Chemical additives causes mechanism that help asphalt binder to have lower viscosity at lower temperature and therefore improve coat aggregate and also improve compaction of WMA mixture. Chemical additives normally do not require much modification to the production line

Foaming processes are based on the fact that water when changed into steam at atmospheric pressure will expand by a factor of approximately 1700 (Cengel, 2006) therefore by adding small amount of water either through a foaming nozzle or using damp aggregate water steam is produced which causes asphalt binder to go through the same expansion in volume and therefore increase coating and also decrease the temperature for achieving such a level of coating.

Organic additives or waxes mechanism for lowering the binder viscosity is that they melt and cause binder to be more flowable and flexible at lower temperature compared to HMA. A point to remember is that melting point of the wax should be higher than the pavement service temperature otherwise permanent deformation would occur (Prowell, 2011)

Table 2.1. Chemical additives for WMA currently available (Prowell, 2011)

Brand	Dosage (by weight of binder)	Reduction in Temperature	Manufacturer	Modification to Mix Design/Plant	Comments
CECABASE® RT	0.3 to 0.5 percent	70°F (40°C)	Arkema Group	Should be pre-blended with the binder before mixing	1) Reduces the surface tension at the aggregate interface resulting in better coating at lower temperatures 2) it acts as a lubricant at temperatures higher than 190°F (90°C), thus improving lay down and compaction.
Evotherm ™	0.25 to 0.75 percent	100°F (55°C)	MeadWestvaco Asphalt Innovations	Mix modifications depend on the type of Evotherm used. For the plant changes, in terminally blended Evotherm 3G, no modifications are required. For Evotherm DAT, an injection point is needed. For Evotherm ET, the plant setting should be adjusted to account for 30 percent water in emulsion.	Has three types: ET (Emulsion Technology), DAT (Dispersed Asphalt Technology) and 3G (Third Generation).
HyperTherm™/QualiTherm	0.2 to 0.3 percent	Mixing as low as 248°F (120°C) and compaction as low as 194°F (90°C)	Coco Asphalt Engineering	Can be added to the liquid asphalt at binder terminal or in-line injected at the asphalt plant.	
Rediset™WMX	1.5 to 2.5 percent	Up to 60°F (33°C) reduction in coating and compaction temperatures	Akzo Nobel Surfactants	No Change to Mix Design procedure except for the temperatures. No anti-stripping agent is needed. Either pre-blended with the binder or added to the mixture after adding the binder.	

Table 2.2. Foaming technologies for WMA (Prowell, 2011)

Brand	Dosage	Reduction in Temperature	Manufacturer	Modification to Mix Design/Plant	Comments
Accu-Shear™	Dependent on the additive/manufacturer.	50-70˚F (122-158°C)	Stansteel® Asphalt Plant Products	Changes to mix design are dependent on the type of liquid that is being added to the binder.	Allows a combination of liquids (water and/or additives) to be injected simultaneously into the asphalt line.
Advera® WMA	0.25 (0.15 to 0.3) percent by total weight of mix.	50°F (28°C)	PQ Corporation	Should be thoroughly blended with the binder prior to mixing In the plant, Advera is added using a designed feeder. For a drum plant, the material could be added close to the point where the binder is added. For batch plants, the pipe is installed as close as possible to the center of the pug mill	A synthetic zeolite composed of alumninosilicates and alkali metals.
AQUABlack™ WMA System	NA	Lowers fuel consumption as much as 15 percent.	Maxam Equipment, Inc.	Must be added to the binder line just before entering the drying drum	Uses a stainless steel foaming gun in conjunction with a center convergence nozzle to produce foaming.
AquaFoam	1.5 percent by total mix weight.	NA	AquaFoam, LLC	The system is mounted in the asphalt line just before it enters the drum	Two nozzles at 180 degrees to one another and perpendicular to the asphalt stream.
Aspha-Min®	0.3 percent by total weight of mixture	54°F (30°C)	Aspha-min GmbH	Usually added to the mixture at the same time as liquid asphalt binder.	Coarser than Advera®.
Double Barrel® Green	1 lb of water per ton of mix.	Production temp.: 250-275°F (121-135° C) compaction temp.:as low as 220°F (104°C)	Astec Industries, Inc.	No changes to mix design. For the plant it is needed to install the foaming manifold and corresponding feeder lines	Uses a multi nozzle foaming device.
Eco-Foam II	1 to 2 percent of the liquid asphalt flow rate.	50-60°F (28-33°C)	AESCO/MADSEN	. In the plant, the system is installed outside the dryer drum	Uses the principle of shear zone turbulence to enhance mixing/foaming process.

Table 2.2. Foaming technologies for WMA (Prowell, 2011) - continued

Brand	Dosage	Reduction in Temperature	Manufacturer	Modification to Mix Design/Plant	Comments
LEA (Low Emission Asphalt)	0.4 percent by weight of binder	Final mix temperature is less than 212°F (100° C)	McConnaughay Technologies	For the plant, a volumetric pump is needed to add cohesive additives to the binder. An injection port must be added to asphalt line or pug mill.	
Meeker Warm Mix	NA	NA	Meeker Equipment	Could be added to both batch plant and mixer. Meeker'sfoamer is added to the binder piping, and for drum plant it is installed just before entering the mixer mixing chamber	
Terex® WMA System	NA	90°F (32.2°C) / 10-20% in fuel.	Terex Roadbuilding	Simply installed onto an existing drum	Uses a single expansion chamber that produces foams just outside the drying drum, then immediately injects the foamed asphalt into the mixing drum to coat the aggregate.
Tri-Mix Warm Mix Injection System	Water up to 4 percent by total weight of binder	70-100°F (39-56°C) when using Evotherm.	Tarmac International, Inc.	Installed in the asphalt line	Uses two opposed high pressure injection nozzles followed by a downstream static mixer to foam the binder or adds a water-based chemical additive such as Evotherm DAT
Ultrafoam GX2™ System	1.5 to 2 percent water by weight of total asphalt binder.	NA	Gencor Industries	The only changes to plant are to install the foaming system	
WAM Foam	2 to 5 percent by mass of the hard asphalt fraction	Up to 35% in energy consumption.	Shell Bitumen	For plant, the original asphalt line is used for soft asphalt and second line is needed for hard binder. Also a foaming nozzle and expansion chamber is needed above the pugmill.	Uses two stages of adding binder, one nominally soft (20 to 30 percent of the total binder content) and the other nominally hard.

Table 2.3. Organic additives for WMA (Prowell, 2011)

Brand	Dosage	Reduction in Temperature	Manufacturer	Modification to Mix Design/Plant	Comments
AstechPER®	0.5 to 0.75 percent by the total weight of RAP plus RAS in the mix	NA	Engineered Additives, LLC.	Can be pre-blended in to the binder at the terminal or injected into the binder before binder enters the plant.	Liquid at ambient temperature. Formulated for high-RAP or reclaimed asphalt shingles (RAS) mixes.
Sasobit®	1.5 (0.8 to 4) percent by weight of the total (including RAP and RAS) binder	50°F (28°C) / Up to 19% in fuel cost	Sasol Wax North America Corporation	Pre-blended with the binder, mix design proceeds with no change. For drum plants, can be blown into the drum through a feeder approximately the same time as asphalt. It can also be added in-line with the binder in a molten state.	A synthetic paraffin wax.
SonneWarmix™	0.5 to 1.5 percent by weight of the total binder	50°F (28°C) reduction in compaction temperature	Sonneborn, Inc.	Added to liquid asphalt at the terminal or refinery, no other modification is required.	A high melt point paraffinic hydro carbon blend.
Thiopave™	Up to 25% (by mass) of the bitumen	36-72°F (20-40°C) reduction in compaction temperature	Shell Silver Solutions	In batch plants, installing a small chute above the pug mill is needed.	
TLA-X™ Warm Mix	NA	60-90°F	Lake Asphalt of Trinidad and Tobago	Can be added directly to the asphalt binder or pneumatically blown into the asphalt mixture at the same time as the liquid asphalt binder.	A natural asphalt emulsion in its crude state, composed of soluble bitumen, mineral matter and minor components, mostly water.

2.3. WMA Mix Design

2.3.1. Introduction

Due to absent of a mix design specification specifically for WMA, National Cooperation of Highway Research Program (NCHRP) conducted a first step-study toward development of a standard for design of WMA mixtures, although some agencies have developed some sort of special provision or amendment to their HMA specs for WMA most agencies are currently using the same specification they use for HMA. Considering the numerous WMA technology available in the market, and also new technologies introduced in the future, the modifications to conventional HMA mix design are not significant and are mostly in forms of suggestions. NCHRP report 619 (Bonaquist, 2011) summarized the finding of NCHRP project 09-43 : “Mix Design Practices for Warm Mix Asphalt” and is briefly discussed in this section to give an idea of main areas of concern in design of WMA and to serve as a guideline for NDDOT in acquiring as specification for their WMA project or use to develop their own. The main product of the NCHRP study was a draft appendix to AASHTO R35 (Standard Practice for Superpave Volumetric Design for Hot-Mix Asphalt (HMA)) which was titled: “Special Mixture Design Considerations and Methods for WMA) and also a draft standard practice titled: “Standard Practice for Measuring Properties of WMA for Performance Analysis Using the Mechanistic Empirical Pavement Design Guide (MEDPG) software”.

2.3.2. Main Areas of Emphasis in Mix Design Process

HMA mixture design could be broke down in five main stages (Bonaquist, 2011):

Materials selection

- Design aggregate structure
- Design binder content selection
- Evaluate moisture sensitivity
- Performance analysis

The appendix to AASHTO R35 which was the main product of the NCHRP report suggests the following suggestion for each category:

2.3.3. WMA Process Selection

NCHRP 691 recommends choosing the process after consultation with the specifying agency and also the WMA technology provider, in doing so factors that could be taken into consideration are: (1) performance data of the WMA technology, (2) added cost of WMA additives/equipment compared to HMA (3) mixing and compaction temperatures (4) production rates compared to HMA (5) required modifications to the plant and lab.

2.3.4. Binder Grade Selection

The report suggest using the same grade of binder that is used for HMA (based on the region) and to make sure the performance grade of the binder is in accordance with section 5 of AASHTO M 323. It is stated that if the WMA technology is to be produced at 100 □ F lower than HMA then it may be needed to increase the high temperature grade of the binder one level. This is to prevent rutting.

2.3.5. Reclaimed Asphalt Pavement (RAP) in WMA

The report suggests selecting RAP according to section 6 of AASHTO M 323 but with attention to the point that the planned field compaction temperature of the WMA shall be higher than the high temperature grade of the RAP binder this is done to make sure that the new binder and recovered binder would mix.

2.3.6. WMA Mixture Evaluation

The appendix recommends evaluating the WMA mixture in four areas: (1) coating, (2) compactability, (3) moisture sensitivity, and (4) rutting resistance.

For coating it is recommended to prepare enough mixture at design binder content and then prepare samples according to the WMA technology method under investigation and test samples according to AASHTO T 195. It is suggested not to short-term condition the mixtures and the recommended coating criterion is that at least 95% of the coarse aggregate particles should be fully coated.

For compactability test, the mixtures prepared according to the WMA technology should be short-term conditioned for 2 hours at the planned compaction temperatures and maximum specific gravity shall be determined according to AASHTO T 209 and AASHTO T 166. The recommended compactability criterion is that the gyration ratio should be less than or equal to 1.25 it should be noted that the criterion limits the temperature sensitivity of WMA to that of a typical HMA mixture, this shall be further investigated.

For moisture sensitivity six gyratory specimens shall be prepared and compacted to 7.0±0.5 percent air voids and tested according to AASHTO T 283. The report suggests a minimum TSR (tensile strength ratio) of 0.8 and there should not be any visual evidence of rutting.

For evaluating rutting in the WMA mixture, the report recommends testing the samples and measuring flow number according to AASHTO TP 79. Based on the traffic level a minimum is set for the measure flow number (3 to 10 million ESALS: 30, 10 to 30 million ESALS: 105, more than 30 million ESALS: 415)

2.4. WMA Study in North Dakota

A study on WMA was conducted in 2011 at North Dakota State University (Gullickson, 2011). The aim of the study was to determine which type of WMA is best suited for use in North Dakota based on previous WMA research, cost, asphalt performance in North Dakota climatic conditions, and a survey of North Dakota contractors' opinions of WMA. After a literature study on research findings related to WMA performance, a survey was prepared and sent to nine contractors in North Dakota, which were identified by looking at bid results from NDDOT paving projects. Six of the contractors responded to the survey on the condition of anonymity. In general, contractors are hesitant to invest in WMA technologies mainly due to lack of any clear directions by NDDOT for the use of WMA in North Dakota.

The survey consisted of seven questions. The first question was, "Which type of Warm Mix Asphalt would your company invest in if future projects required the use of one of the following WMA technologies? What factors drove your choice(s) for the previous question?" They could choose more than one of the listed options. Five out of six respondents chose water-based additives and four out of six selected chemical additives. Three of the contractors stated that they are also open to any technology specified by the owner. Regarding the factors that drove them to this conclusion, three chose technologies that they already have experience with and two chose water-based additives because of cost. The contractors are willing to invest more if NDDOT provides more guidance for what it wants, since their experience with WMA is mostly based from projects in other states.

The second question was, "How many years have you (or your company) worked in the asphalt pavement industry," with the minimum response of 20 years and the largest of 75 years. The aim of this question was to assure the credibility of the responses to the survey.

The third question was, "Have you (or your company) ever worked on a Warm Mix Asphalt project? If so, what was the most common type of additives among the WMA projects that your company completed?" Of the six respondents, four indicated that they have worked on WMA projects in their previous projects. Three of them stated that water-based WMA was the most common type, and the other two stated that chemical additives were also commonly used as water-based technologies. None of the respondents had any experience with organic additives.

The fourth question was, "As a contractor, what are the main issues you would face when beginning to work with Warm Mix Asphalt?" Two of the respondents considered that the additional cost would a main issue of implementing WMA, while two others cited that the owner's fear of unknown performance and the owner wanting extended warranties. Setting up equipment and addition of additives to the mixing process were other issues that were mentioned.

The fifth question was, “What benefits do you think the use of Warm Mix Asphalt would provide to your company?” Five of the contractors chose lower overall cost or at least reduced fuel cost, easier compaction effort, and ability to haul longer distances. Three of the respondents also mentioned reduced emission of fumes, worker safety, and extended paving seasons as the benefits of WMA.

The sixth question was, “What are the drawbacks you see to using WMA?” Five of the six contractors considered extra cost or extra equipment as a downfall, while two of them mentioned moisture damage or stripping.

The seventh and last question was, “Given your knowledge of asphalt performance in North Dakota's weather conditions, do you think any type(s) of Warm Mix Asphalt will perform better in North Dakota versus the other types? Please select which type you think will perform the best and then discuss your selection.” The responses to this question were not uniform. Two of the contractors thought water-based (foaming) would be the best, two were unsure, and the other three chose between organic and chemical additives. The results of this question show that North Dakota contractors are not totally backing a particular type of technology and they are not ready to risk investing in a technology that is not confirmed by NDDOT.

Based on the literature study on the performance of WMA technologies, the results of the survey, and cost issues the research found foaming technologies as most suitable for ND.

2.5. Specifications and Publications

The DOTs are at different stages regarding specifications for WMA. Some have already prepared a separate specification for WMA, some are in the process of making one and others consider HMA specification sufficient for WMA. In this section, a review of available information regarding this matter is provided. Currently, no uniform specification is accepted by all DOTs regarding WMA construction. The Warm Mix Asphalt Technical Working Group (TWG) has prepared a generic specification for use by agencies and it is available through their website http://www.warmmixasphalt.com/. Some agencies have a list of pre-approved processes, these lists are updated periodically. For new technologies or technologies not approved yet, there is an “Approval Process” in some agencies.

In appendices C and D of the report prepared by NDSU for North Dakota DOT: “Warm Mix Asphalt Process Applicable to North Dakota” (Saboori, 2012), specifications, special provisions, list of approved technologies and approval processes for new technologies and other related official documents for WMA are provided. That report is referred to as NDSU WMA Report in here. In this section an overview of the target states of study is provided and references are made to NDSU WMA Report.

2.5.1. Colorado

Colorado has developed a “Standard Practice for Contractor Non-Standard Asphalt Mix Approval” which is available in NDSU WMA Report, Appendix C, page C10, (Saboori, 2012).

Their list of approved processes (as of September 2011) consists of Advera, AQUABlack Solutions, Evotherm, Green Systems, and Ultra Foam GX2.The documents are available in NDSU WMA Report, Appendix C, page C15, (Saboori, 2012).

They have also published the final report of a project sponsored by Colorado DOT and conducted by NCAT titled "Three-Year Evaluation of the Colorado Department of Transportation's Warm-Mix Asphalt Experimental Feature on I-70 in Silverthorne, Colorado" (Aschenbrener, 2011). In this project, three additives (Advera, Sasobit, and Evotherm DAT) were used to build three sections of WMA and compare to HMA control sections. Production, constructability, laboratory performance testing, and field performance were observed. The results of their three-year study showed that field performance of WMA sections were comparable to HMA sections, and despite the harsh weather conditions, they were in excellent condition considering rutting, raveling, and cracking. Production and placement were done with no problem and field compactions were achieved at 30 to 50 ˚F lower than HMA control sections. Lab tests showed that VTM and VMA of WMA mixes were lower than HMA samples by 0.5% to 1%. Regarding moisture sensitivity, WMA had loser TSR values, but still passed the requirements. Dynamic modulus and flow number testing showed that HMA were stiffer than WMA samples, which was expected.

2.5.2. Idaho

For specifications at this time (Sep 2011), Idaho DOT is looking at NCHRP 9-43 and the appendix to R35 and discussing the need to require Commercial Mix labs in Idaho to purchase and use asphalt foaming equipment in the design of foaming WMA. Currently foaming WMA is designed per their Superpave HMA specs. Their WMA Technology Committee has produced a standard Change Order for inclusion in contracts where the contractor has proposed the use of WMA, with some requirements the contractor must meet in order to use WMA technology. This special provision is available in NDSU WMA Report, Appendix C, page C21, (Saboori, 2012).

Idaho DOT is in the process of formulating a formal approval process and has approved the technologies below strictly due to their success in other states. The only WMA process used in Idaho to date (Sep 2011) is Double Barrel Green. Their approved technologies (as of September 2011) are Evotherm by MeadWestvaco (chemical process), Double Barrel® Green by Aztec Industries, and Terex® WMA System by Terex Road building (foaming Processes).They allow no organic additives at this time.

2.5.3. Illinois

Illinois has a draft WMA special provision at this time (Sep 2011) and this draft version is subject to change prior to first use. This special provision, available in NDSU WMA Report, Appendix C, page C26, (Saboori, 2012), revises their standard specifications which can be accessed using this link: http://www.dot.il.gov/desenv/hwyspecs.html (accessed in Sep 2011)

Illinois has a new WMA specification that will be used for the first time on upcoming January Letting. They have done some experimental projects with WMA but they were not let as WMA. They were an equal cost substitution requested by the contractor after the projects were awarded.

2.5.4. Indiana

Indiana DOT has prepared a thorough special provision for WMA, which is available in NDSU WMA Report, Appendix C, page C34, (Saboori, 2012).

2.5.5. Iowa

Iowa DOT has developed a specification for WMA with several revisions. The latest specification is available, with the previous revisions, in NDSU WMA Report, Appendix C, page C60, (Saboori, 2012).

Iowa has investigated WMA performance in field and laboratory-produced mixes. The technologies used in lab were Advera, Sasobit, and Evotherm. In the field study, Evotherm 3G/Revix, Sasobit, and double Barrel Green Foaming technologies were applied. The result of their study was published in 2011 titled "Investigation of Warm Mix Asphalt Using Iowa Aggregates" (Buss et al., 2011). The study showed that mixing and compaction temperature were reduced. Tensile strength ratio (TSR) values of WMA were lower than HMA; especially in the lab were none of the additives performed as well as the HMA. Regarding dynamic module, HMA samples had higher modulus which is expected and WMA samples had reduced flow numbers compared to HMA counterparts.

2.5.6. Kansas

Kansas DOT has developed a seven page special provision to their HMA standard specification, plus a list of approved technologies. Both of these are accessible in NDSU WMA

Report, Appendix C, page C83, (Saboori, 2012). As of September 2011, their approved technologies are AQUAblack Solutions, Double Barrel Green, Terex, and Ultrafoam GX in foaming technologies. For chemical and organic additives, they allow Advera, Aspha-Min, Evotherm, Redi-Set WMX, and Sasobit.

2.5.7. Maine

Their special provision for WMA is attached in NDSU WMA Report, Appendix C, page C93, (Saboori, 2012).

2.5.8. Michigan

Michigan DOT has developed a special provision for WMA that could be accessed in NDSU WMA Report, Appendix C, page C97, (Saboori, 2012).

In a report titled "Michigan Field Trial of Warm Mix Asphalt Technologies" (Hurley et al., 2009), they have published their observations of constructing a test section, M95, in Iron Mountain to evaluate field performance of Sasobit technology. The experimental study showed that placement was successfully done at 50°F lower than HMA control sections. Air voids of WMA samples measured in the lab were statistically different form the control samples. Regarding rutting, lab tests did not show statistical difference between WMA and HMA. In moisture susceptibility, similar performance to control was observed; even tensile strength was higher for Sasobit mixes. Dynamic modulus of Sasobit mixes were statistically the same as control. Finally, it was concluded that using WMA resulted in reduction of emission and fuel consumption.

2.5.9. Minnesota

Minnesota standard specification is permissive, which means they allow WMA on any project unless expressly prohibited. They also allow shingles permissively, and only on a few projects they have not allowed shingles.

Minnesota is most interested in evaluating WMA potential for satisfactory low-temperature cracking performance. To test WMA performance, they have paved six cells with WMA on the MnROAD Mainline, which carries fewer than one million ESALs per year. The mix used is a level 4 Superpave with PG 58-34 binder and 20 percent of RAP. They used Evotherm 3G in all mixes have also made a control section. Production was done at approximately 50°F cooler than HMA production, and the same compaction with HMA was achieved with less effort. The lab tests showed good tensile strength ratios, leading them to the conclusion that WMA is not prone to moisture damage. The DSR testing showed that WMA binders may be more susceptible to short term aging. In stiffness test, both WMA and HMA binders failed at approximately same temperature.

2.5.10. Missouri

Missouri DOT has not developed or adopted any particular warm mix additive/technology list yet. To allow WMA, they have removed and lowered some temperature restrictions in their standard specification. They allow contractors to choose the technology that they are more comfortable with as long as they follow the specifications. Acceptance or rejection of a new technology by the contractors is based on their own investigation and DOT does not mandate anything. Currently, foaming and Evotherm are the predominant technologies in their projects.

2.5.11. Montana

They have published a report in 2009 titled "Synthesis of Warm Mix Asphalt Paving Strategies for Use in Montana Highway Construction" (Perkins, 2009), in which a discussion is presented on available WMA technologies at that time, their advantages, and the required modifications. The report presents a thorough literature study on ongoing research of the time, including NCHRP Project 9-43 (which is completed now, September 2011, and a summary of it is presented in chapter 3 of this report) and some case studies on WMA, like two demonstration projects that were conducted in Yellowstone National Park and studies by NCAT and Montana DOT. The report further studies WMA specifications and special provisions in use by DOTs nationwide, and the report is finalized by proposing a roadmap for future research and implementation at MDT.

2.5.12. Nebraska

Nebraska DOT will be coming out with a permissive specification in January 2012, basically allowing the WMA materials that they have used and allow requests for any other materials, with approval by the Flexible Pavements Engineer. This draft specification is not available for distribution before January 2012.

In a research project to evaluate WMA technologies for use in Nebraska paving projects, three additives (Sasobit, Evotherm, and Advera synthetic zeolite) were used to build trial sections in Antelope County, Nebraska. Lab and field performance of samples of this sections were compared to HMA controls. They observed and compared two-year actual field performance of WMA and HMA sections, plus their long-term performance simulated through MEPDG. The results of their study showed that WMA additives do not significantly affect the viscoelastic stiffness of mixtures. Their WMA mixes generally had better rut resistance, particularly Sasobit. For moisture susceptibility, AASHTO T283 and semi-circular bend fracture tests were used, in which WMA samples showed more susceptibility. Both pavement types performed excellently in the two-year field performance monitoring and simulating. The long-term performance of WMA and HMA sections by MEPDG showed no major difference in performance between the two (Kim et al., 2010).

2.5.13. New Hampshire

They have a list or approved technologies, accessible in NDSU WMA Report, Appendix C, page C99, (Saboori, 2012).As of September 2011, they allow Aqua Foam, Double Barrel Green, Eco-Foam II, Maxam, Terex, and Ultrafoam GX in foaming technologies. Additionally, SONNEWARMix is approved for organic technologies and Evotherm in chemical technologies.

2.5.14. New York

The Specification for the use of WMA can be found in NDSU WMA Report, Appendix C, page C101, (Saboori, 2012), which needs reference to their most current Standard Specifications Sections 401 and 402 (this can be obtained at: https://www.nysdot.gov/main/business-center/engineering/specifications/updated-standard-specifications-us). They also have a WMA Tech Approval Process which is available in NDSU WMA Report, Appendix C, (Saboori, 2012), plus a more in-depth description of the information they use, in the “Production, Testing and Compaction Details” provided by each WMA Technology as part of the Approval process.

NYDOT has an approved list of WMA Technologies which is also provided in NDSU WMA Report, Appendix C, page C116, (Saboori, 2012).

They are expected to write a document after their experimental work plan on WMA has been completed, but that is not expected in a near future.

2.5.15. Ohio

They have two publications on WMA, “Performance Assessment of Warm Mix Asphalt (WMA) Pavements” (Sargand et al., 2009) and “Mechanical Properties of Warm Mix Asphalt Prepared Using Foamed Asphalt Binders” (Abbas et al., 2011). The results of their study show that WMA mixes made by foaming are more workable and easily compacted, although they are produced at lower temperature. Their study showed that WMA mixes are slightly more susceptible to moisture damage, but can satisfy the minimum requirement on TSR. WMA prepared using natural gravel and unmodified binder is more prone to rutting than HMA counterparts. However, using appropriate aggregate and binders can help in overcoming any adverse effects that WMA have on mix performance.

2.5.16. Oregon

Their special provision for WMA and list of approved technologies are available in NDSU WMA Report, Appendix C, page C123, (Saboori, 2012).

2.5.17. South Dakota

SDDOT has a research project currently underway on warm mix asphalt. The status of the research project and the Special Provision used for the warm mix are attached in NDSU WMA Report, Appendix C, page C129, (Saboori, 2012).

As of September 2011, the warm mix additives that they have used are Evotherm and water injection methods at the plant sites. They have plans to use Advera in the future. The mix designs were the standard gyratory designs and the warm mix changes were only to lower the mix delivery temperatures. They have asked for and tried to follow the warm mix additive supplier recommendations for mix design and additional testing. They have also followed the SDDOT Gyratory Special Provision for the testing requirements. The mixes are monitored in the field and samples are obtained for additional testing for the research project.

In their research project, no changes were made to the binder grade for the warm mix sections. The warm mix design and field samples were prepared and tested for moisture sensitivity. All control and warm mix sections had the same binder targets. The research project matrix is to try the warm mix with three aggregate types (limestone, quartzite, and a natural aggregate) and three different warm mix additives (Advera, Evotherm, and plant water injection systems). All the mixes are 12.5 nominal size and use the standard compaction specification.

The mixes are checked using the Asphalt Pavement Analyzer for rut depth of both the control and the warm mix.

2.5.18. Utah

Utah DOT has no WMA specification at this time (September 2011) and they use the same specification they use for HMA, with the only exception that the temperature can be lowered until it is sufficiently workable. Gradation, volumetric parameters, and all other specifications are the same. There is one sentence in their specifications for HMA that says that the contractor may use WMA if they so choose. Utah has seen little difference in how their WMA projects have performed as compared to their WMA projects, so it is typically left to the contractor's discretion.

2.5.19. Washington

They have added a section in their standard specification that discusses WMA (Division 5 (5-04), and they also have a single page of Process Approval that contractors are required to fill out and submit in order to receive approval to produce WMA on any WSDOT project. These documents are available in NDSU WMA Report, Appendix C, page C133, (Saboori, 2012).

Washington DOT has initiated an experimental study to evaluate long and short term performance of WMA produced with Sasobit. For this, they will monitor the section for five years considering friction, rutting and ride measurements, as well as overall pavement condition assessment with special emphasis on cracking and rutting resistance. The project is still ongoing, but an interim report titled “Evaluation of Warm Mix Asphalt” (Russell, 2009) has been published. Based on production and placement of Sasobit, they have concluded that mix design, production, and placement of WMA is the same as HMA. Compaction and placement were possible at the same density of HMA, but lower temperatures were obtained at a reduction of 30-50°F.

2.5.20. Wyoming

WYDOT has little experience with warm mix and has just constructed their first warm mix test section in August 2011, with a plant foaming process. They will most likely construct a test section summer 2012 with several different additives and processes.

CHAPTER 3. SURVEY ANALYSIS[1]

3.1. Introduction

A comprehensive survey was designed to collect information and data from DOTs of target states and communicate with the experts of the field to know their viewpoint about WMA and what should be the approach in implementing WMA in North Dakota's paving projects. In the survey, questions were categorized into 5 sections:

- General observations
- Technologies
- Mix design
- Specification
- Acceptance plan

After initial sessions with North Dakota DOT regarding their concerns and points of interests the first draft of the survey was prepared and was finalized through correspondence with NDDOT personnel. The main objective of this part of the research was to collect as much as information regarding other states experiments with WMA processes, the modifications they have in their specifications on WMA, how they test the performance of WMA and how sample preparation is done. Survey consisted questions about cost issues of WMA compared to HMA, if they have a

[1] The graphs in this chapter are the result of a survey designed and conducted by a research team consisted of Arash Saboori and Mohyeldin Ragab working under supervision of Professor Magdy Abdelrahman. Arash was the lead graduate student in the project responsible for organizing the tasks and distributing assignments required to achieve the deliverables between the team. Mohy was assigned to help in parts of literature study phase, design of survey, collecting data and developing graphs.

separate mix design or if they have modifications in specific parts. The survey is available in appendix A of the thesis.

3.2. General Observations

In this section questions were about general perception of WMA, production tonnage and cost comparison between HMA and WMA, and preference of respondents for a specific WMA process.

As figure 3.1 shows, when asked about comparing WMA to HMA in categories of bidding, contractor's willingness, constructability, performance, maintenance, and cost, most of the respondents considered WMA and HMA more or less the same.

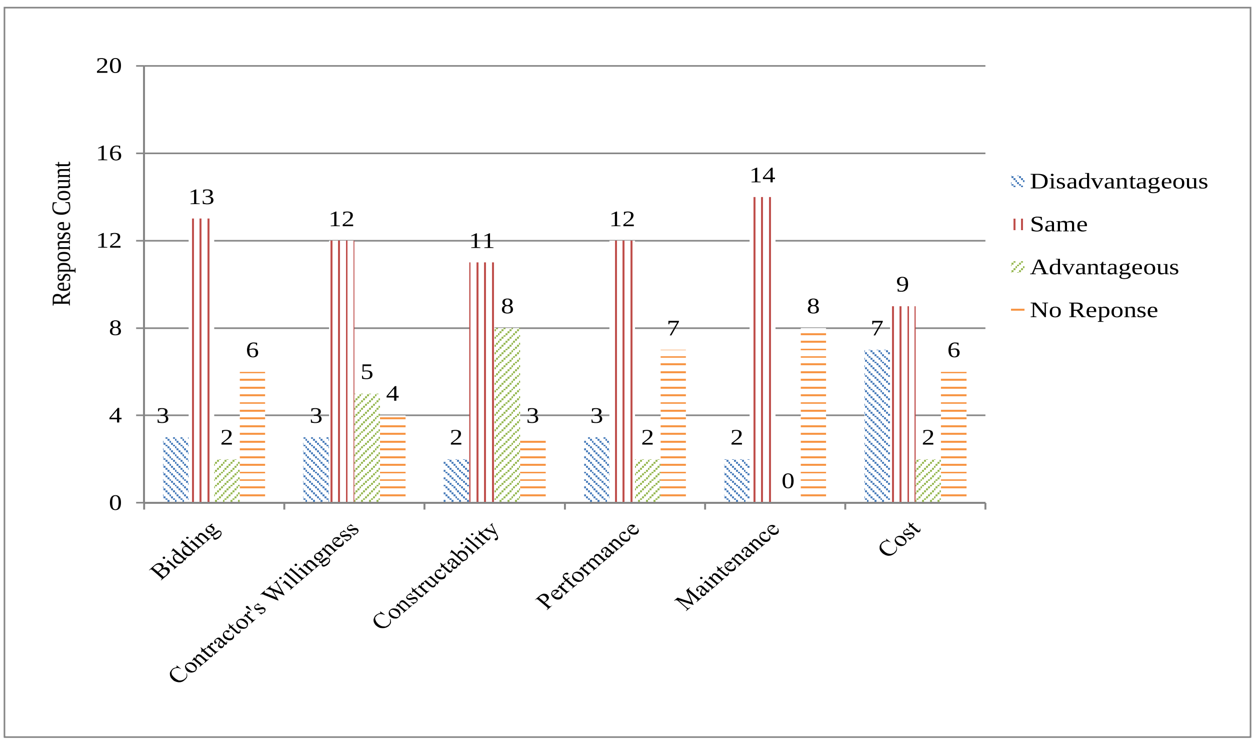

Figure 3.1. Comparison between WMA and HMA based on agencies' experience

WMA was considered more advantageous in constructability and contractors' willingness while cost of WMA was the main concern of the respondents. It should be mentioned that this question was aimed to the general experience of the agency with WMA.

Figures 3.2 and 3.3 show the average yearly production of HMA and WMA in the last five years. In HMA South Dakota has the highest production with 8 million tons per year followed by Ohio and Washington, 6 and 4.8 millions. Where Manitoba (Canada) and Montana has the lowest HMA production with 40.5 and 25.6 thousand tons per year respectively. In WMA, Ohio has the highest amount of production (1900 thousand tons per year) followed by Indiana and New York with 500 and 225 thousand tons per year compared to Utah that produces the minimum (5 thousand tons per year).

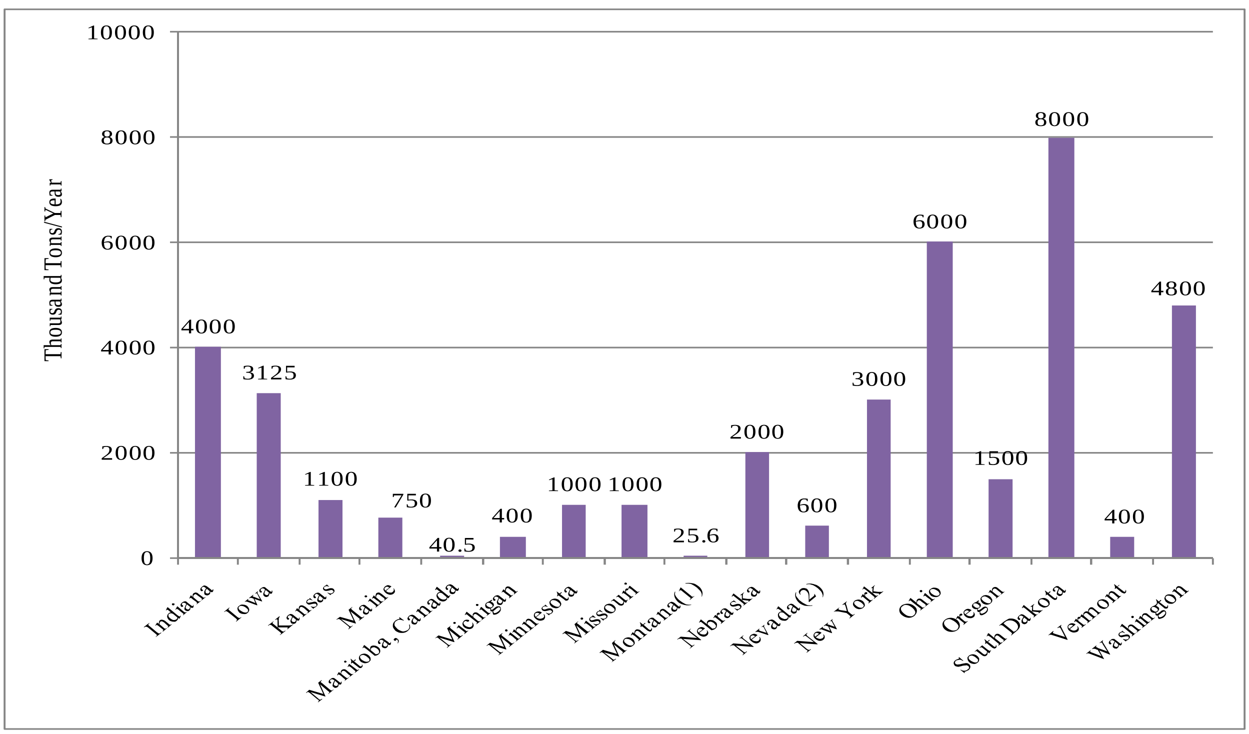

Figure 3.2. Approximate HMA production (average of last five years)

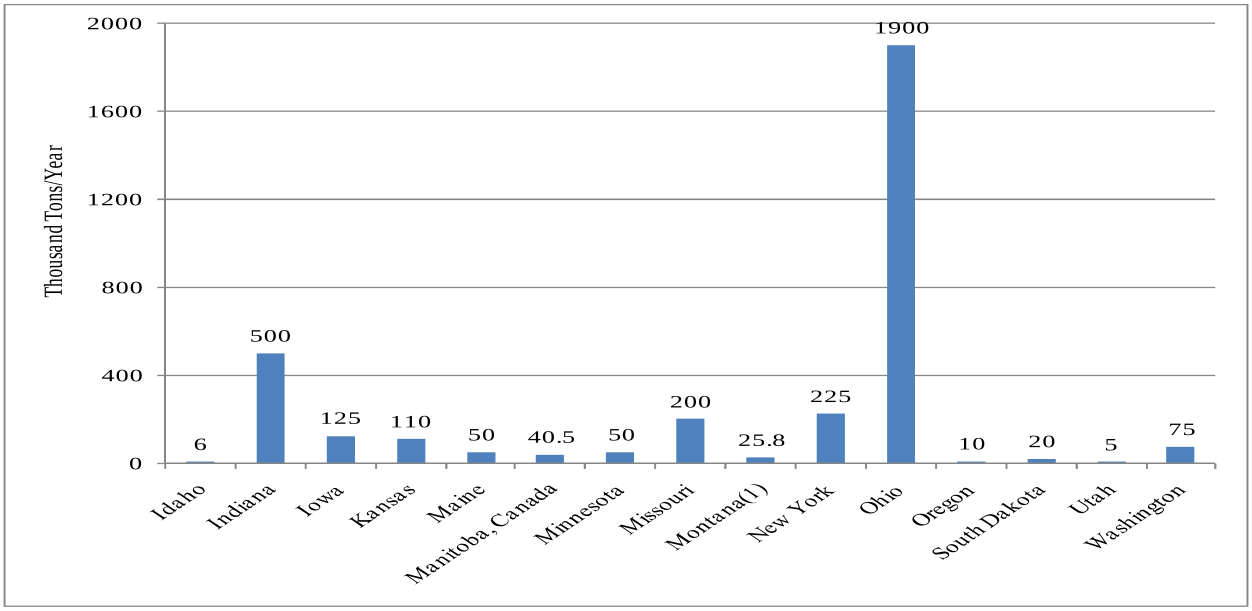

Figure 3.3. Approximate WMA production (average of last five years)

When asked to compare bidding cost of WMA to HMA, seven out of 15 respondents considered WMA bidding cost are more than HMA and eight thought their costs were more or less the same as can be seen from Figure 3.4**.**

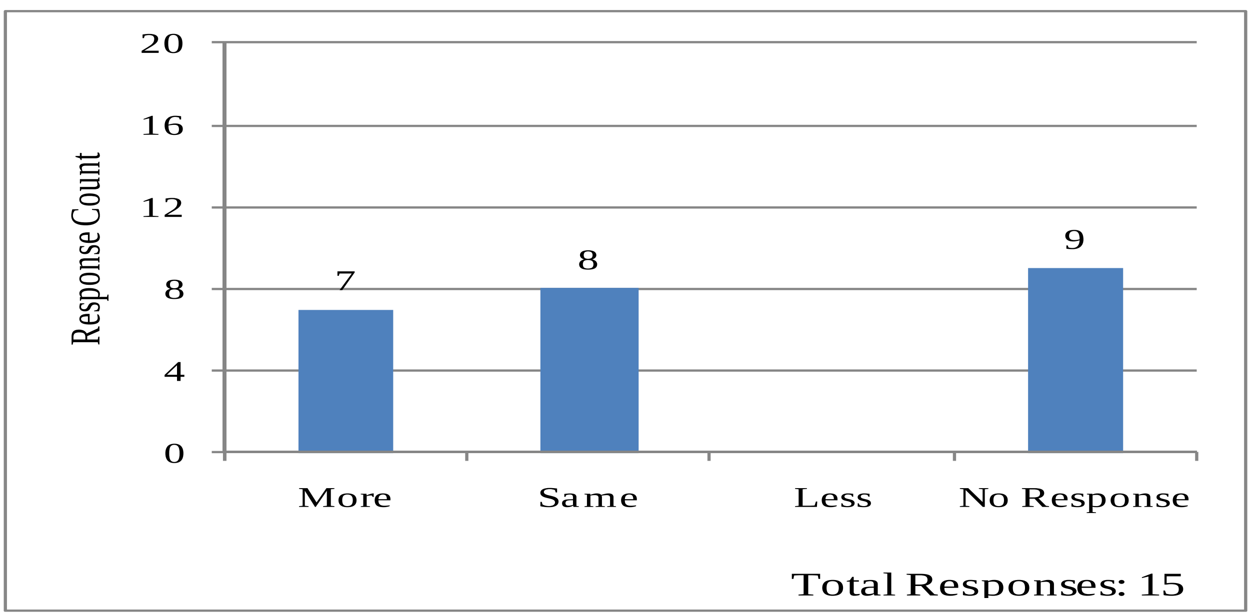

Figure 3.4. WMA bidding cost compared to HMA

Of these respondents, eight people expressed their opinion about the percentage increase/decrease in WMA bidding costs compared to HMA, of which four think that the increase is between 1 to 5% and three chose 6 to 10%, Figure 3.5 shows the results. According to the comments, the increase is dependent on the technology used while some technologies require major modifications to the plant itself which causes higher increase in the bidding price while other technologies use only additives.

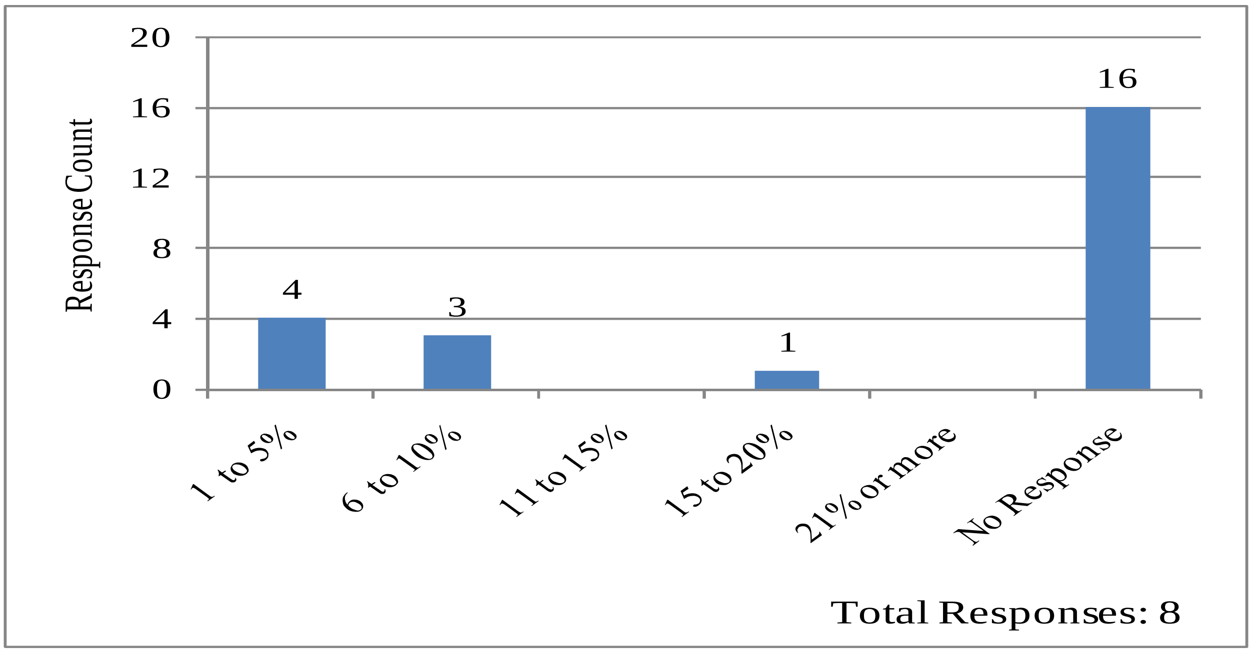

Figure 3.5. Increase of WMA bidding cost compared to HMA

Regarding the approximate range of additional costs ($/ton) for WMA, as long as most agencies have experimented with foaming technologies they are more concerned with the initial additional cost of equipments for the plant (Missouri, Iowa, …) and they see the cost of WMA quite similar to HMA, Figure 3.6. New York reported a $3-6/Liquid Ton increase at the refinery and $8/Liquid Ton increase at the field location for WMA cost of additives compared to HMA.

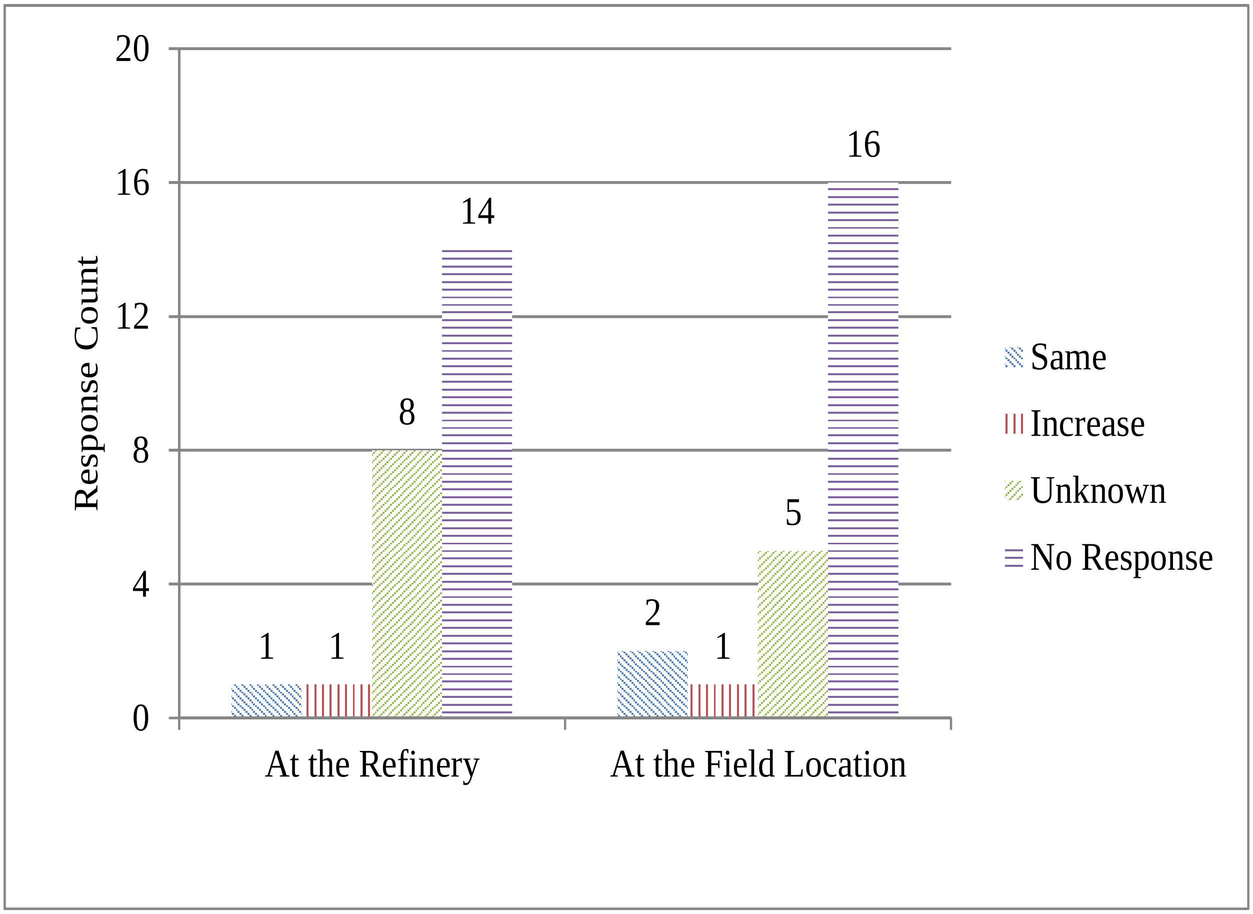

Figure 3.6. Additional costs for WMA production in terms of cost of additives

When asked about the approximate range of additional costs ($/ton) for WMA production in terms of total cost including processing, at both the refinery and field locations, Iowa has an increase of $2 to 4 per ton for WMA production at refinery. Minnesota stated an increase of $2 per ton for the refinery location and $1.75 per ton for field location. Ohio and Michigan both stated that no increase except for cost of initial equipment installation. Vermont had a $1-2 per ton increase for both locations. For Washington $25K to $50K increase at field location was reported. Figure 3.7 shows the number of responses to the question. As can be seen from the figure due to lack of data most respondents provided no answer to this question.

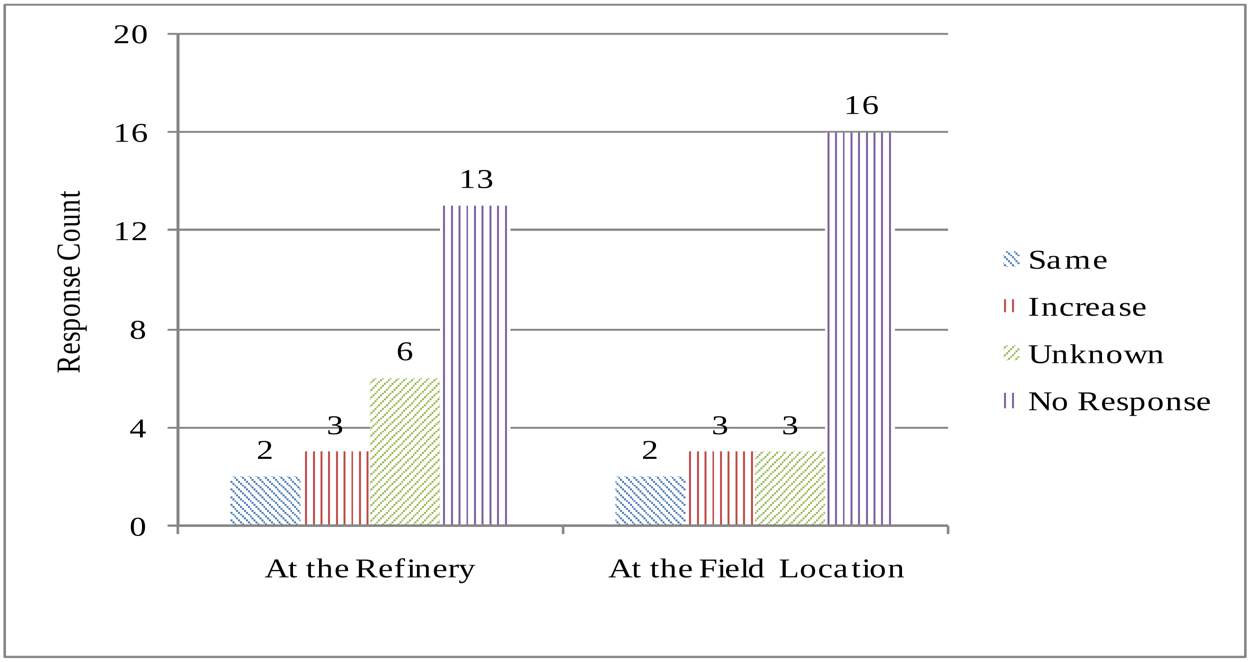

Figure 3.7. Additional costs for WMA production in terms of total cost including processing

Figure 3.8 shows the responses of the participants when asked about possible documentations, information, data sets related to their experiments with WMA.

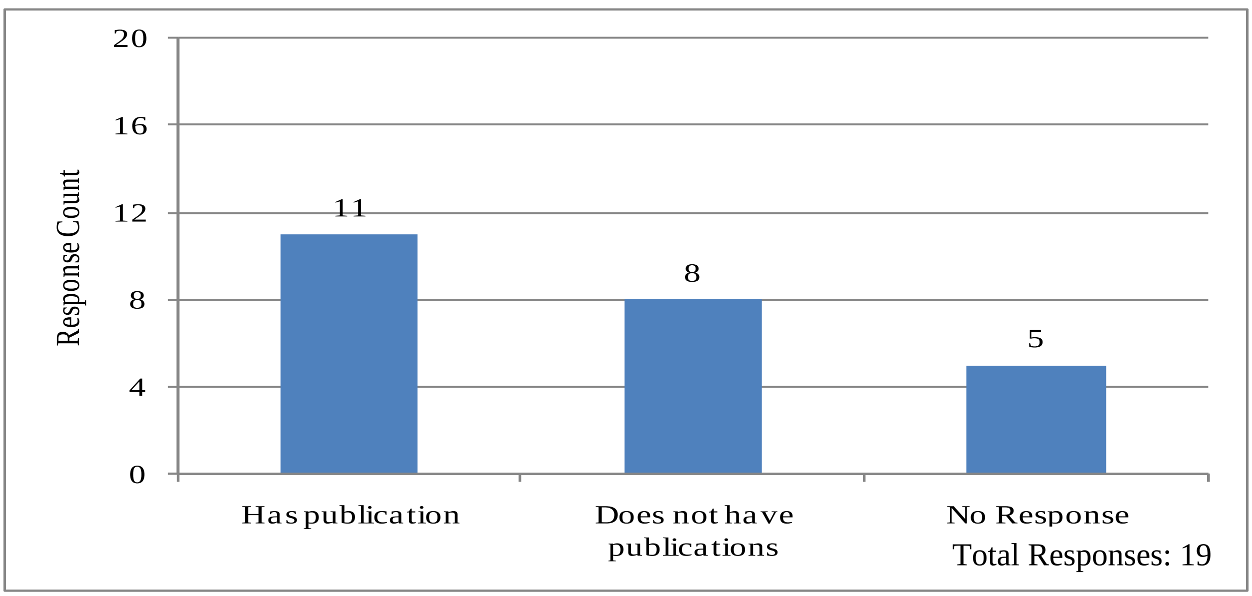

Figure 3.8. Agencies that have WMA publications

The general section of the survey was concluded with the question on what would be the agency choice if they were to select one kind of technology. Figure 3.9 shows the distribution of agencies' preference on using each type of WMA technologies. It seems like foaming processes and chemical additives are the more favorable among practitioners.

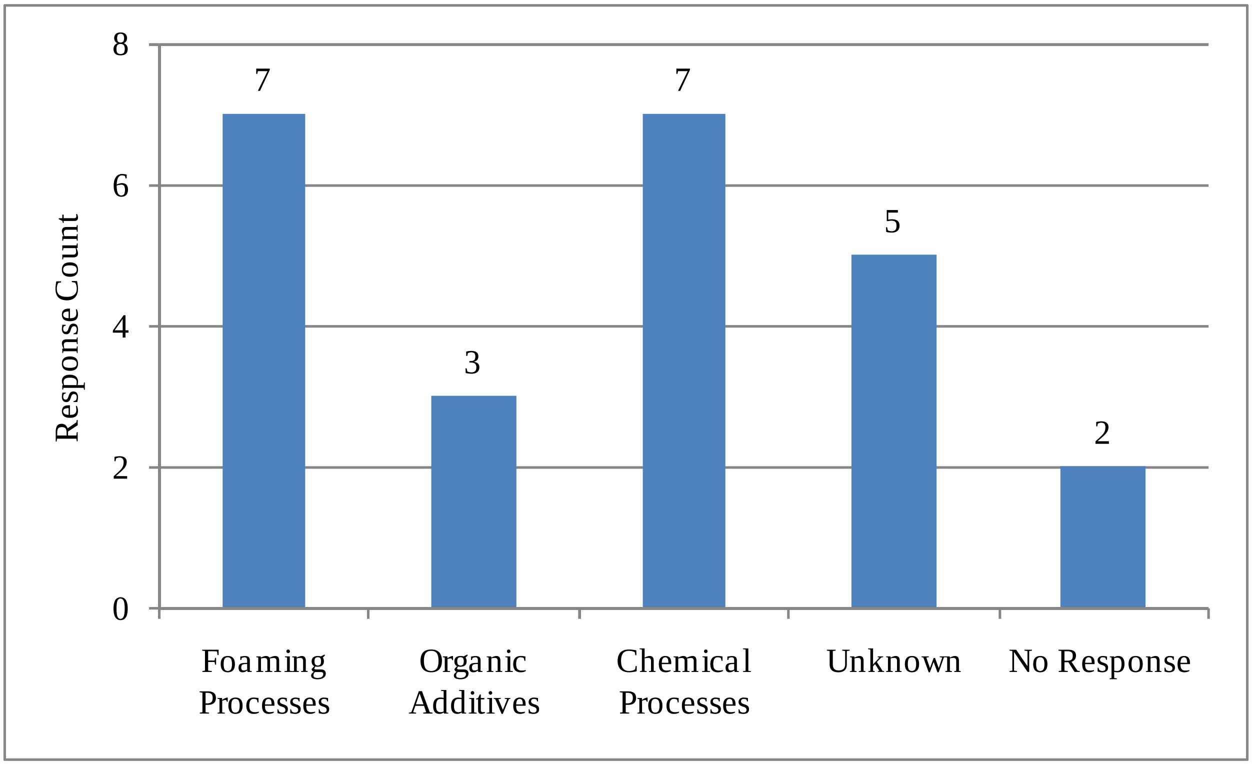

Figure 3.9. Distribution of WMA type preferences

3.3. WMA Technologies

In the technologies section, information about number of project for each type of technology and main distresses that has so far been experienced were questioned.

In chemical processes (additives) as can be seen in Figure 3.10, of the 32 projects conducted by the responding agencies 29 projects were built using Evotherm™ followed by

CECABASE with a significant difference in popularity. When asked about the amount of reduction in mixing temperature that was achieved using these chemical additives compared to mixing temperature of HMA, as illustrated in Figure 3.11 most of the answers were in the region of 40-60 ^{o}F which is promising.. Regarding the number of projects with moisture damage or rutting, as can be seen in Figure 3.12, moisture susceptibility is a frequent distress. Although all the responses were related to Evotherm this is related to the fact that almost all the projects of the respondents were done using Evotherm as additive and there is no evidence that the other three technologies have better performance in moisture resistance.

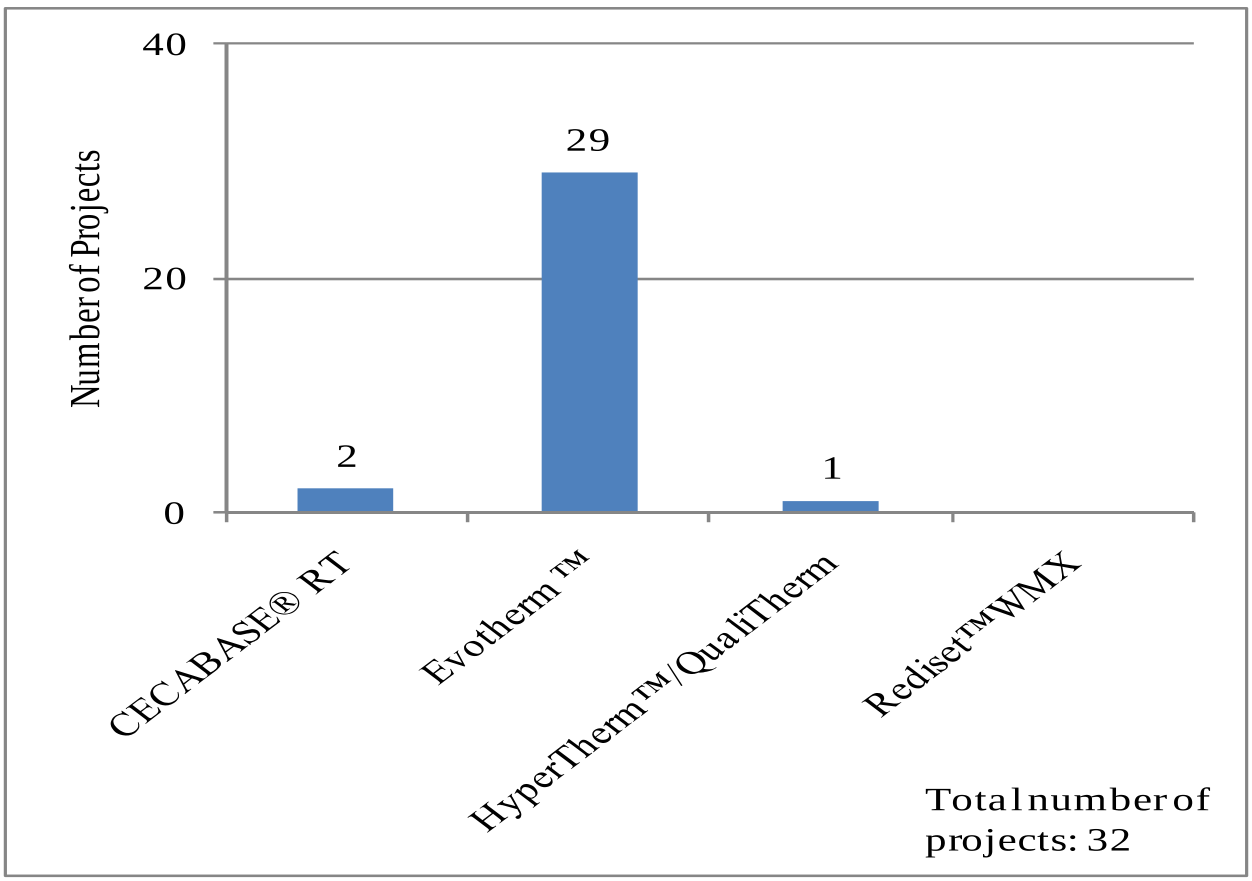

Figure 3.10. Number of constructed projects for each chemical process

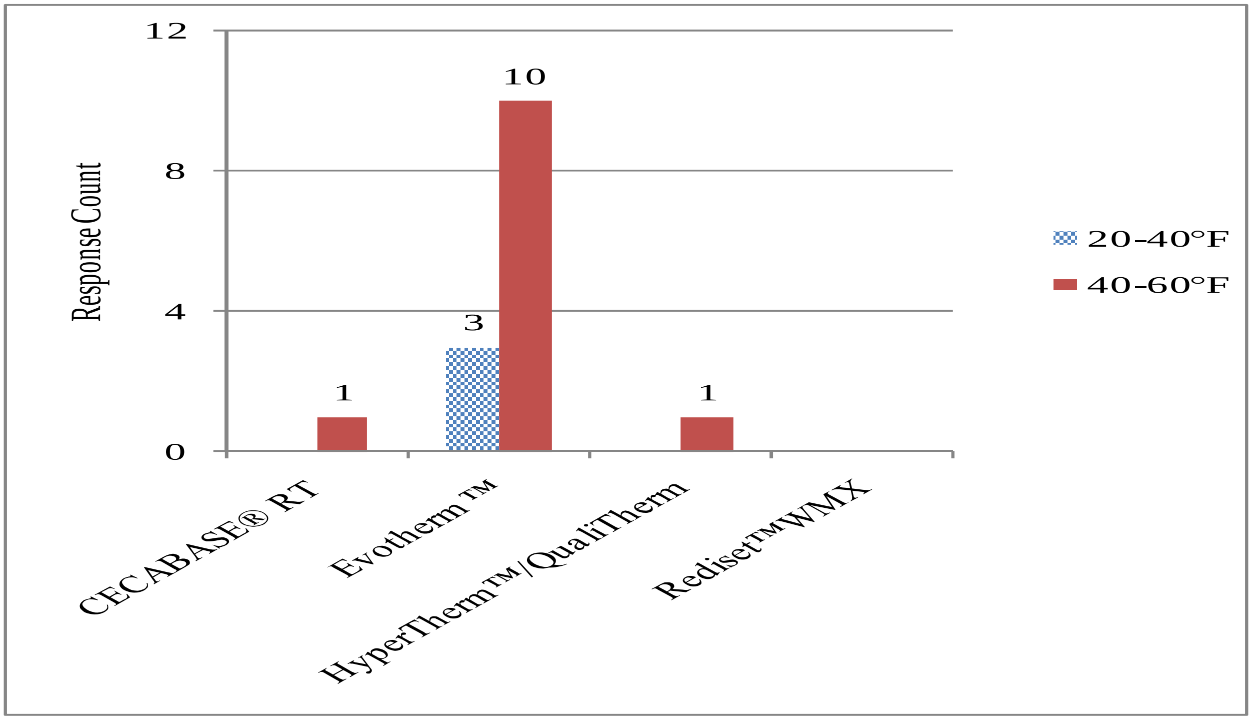

Figure 3.11. Mixing temperature reduction (°F) achieved for each chemical process

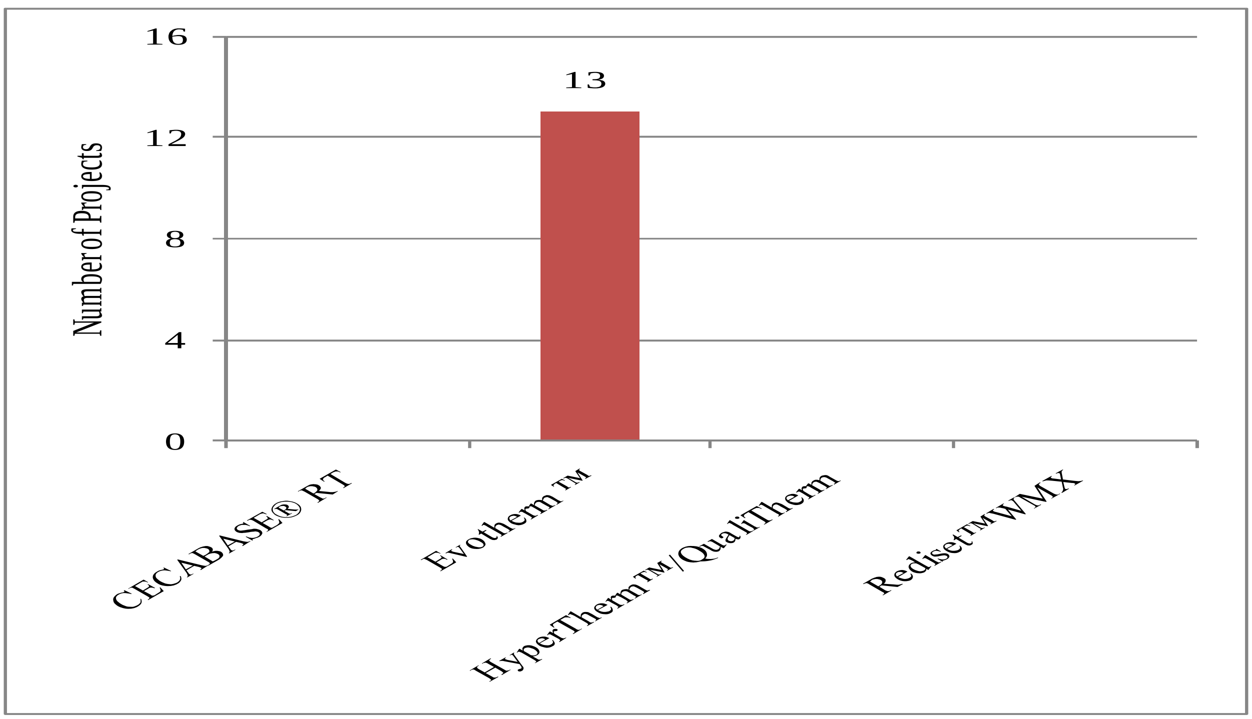

Figure 3.12. Number of projects with moisture damage for each chemical process

The survey continued with questions about Foaming processes and the agencies experience in working with them. As can be seen in Figure 3.13 the number of projects conducted using foaming technologies are far more than the chemical additives (and also organic additives as can be seen in few paragraphs ahead) of the 122 projects done using foaming technologies Double Barrel Green is the most used one (44 projects) followed with AQUA Black WMA System (33 projects) and Terex WMA System (17 projects). Regarding the reduction achieved through using foaming technologies as Figure 3.14 suggests the reduction in temperature were mostly within 20 – 40 ºF which put foaming technologies a step behind chemical additives in this regard, but still as the results of this survey reveals they are more popular. The respondents did not provide useful information regarding type and number of distresses that they have encountered in WMA produced using foaming technologies.

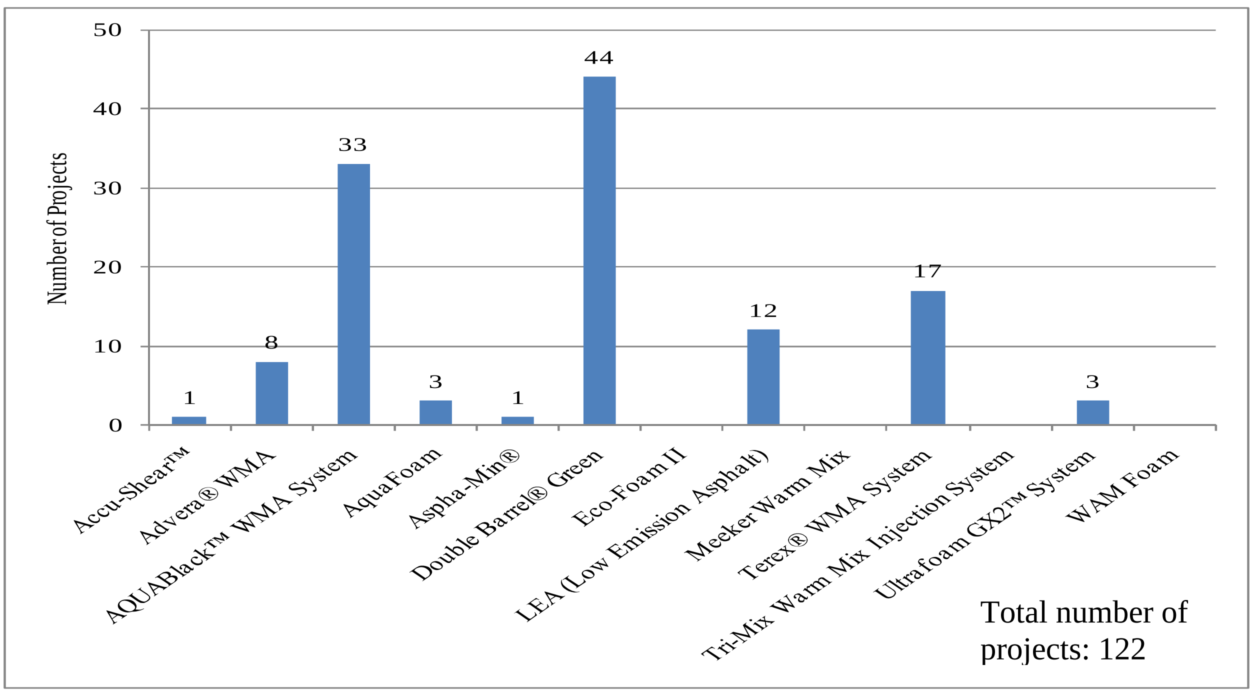

Figure 3.13. Number of constructed projects for each foaming process

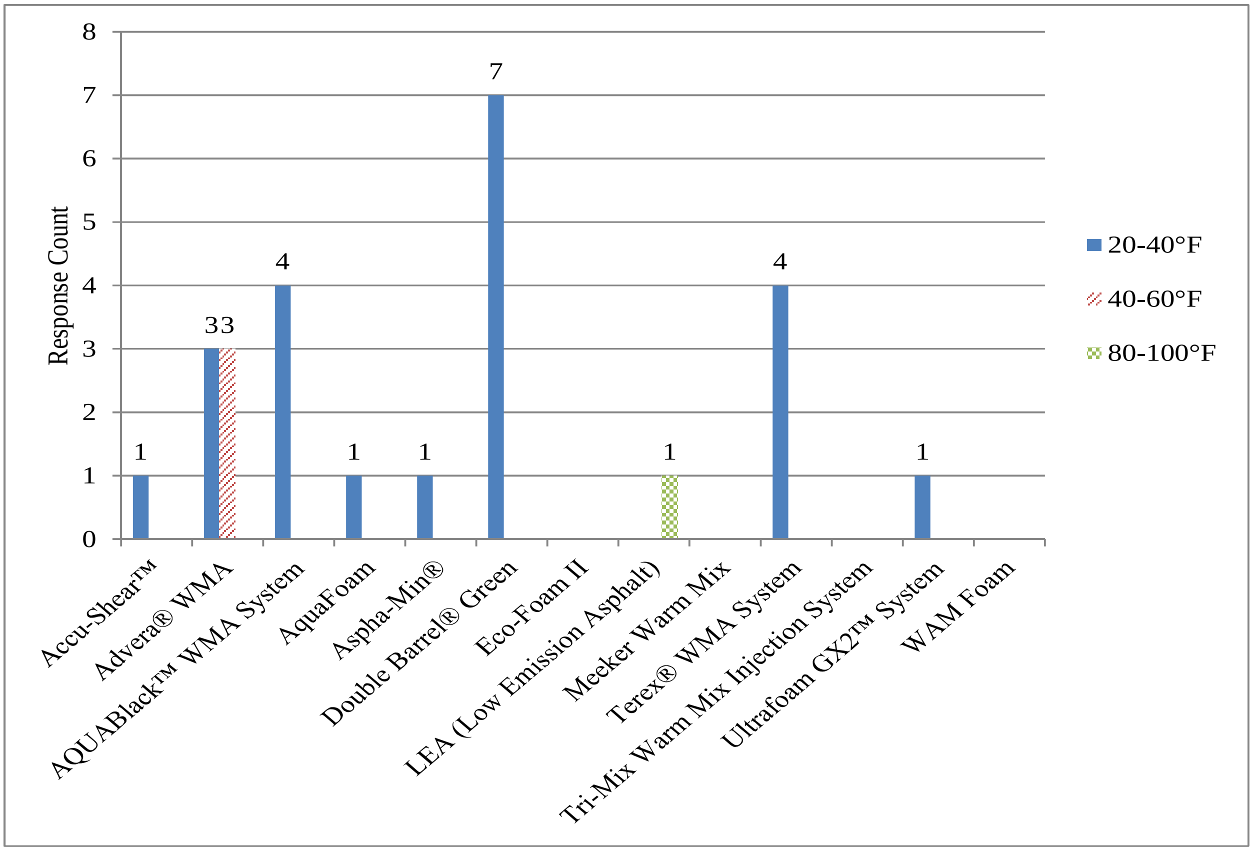

Figure 3.14. Mixing temperature reduction (°F) achieved for each foaming process

Figure 3.15 shows the number of projects constructed using organic additives (waxes). As the figure shows, Sasobit is the most popular choice with 16 projects built with it, this followed by Thiopave with 3 projects. As can be seen from the figure the minimum number of projects are constructed using organic additives, indicating that they are the least favorable among the three types of WMA processes.

When asked about the temperature reduction encountered using organic additives, the responses were not consistent, as shown in Figure 3.16 most of the respondents had a 20-40 ºF reduction in mixing temperature but for Sasobit nearly half of the responses reported 40-60 ºF.

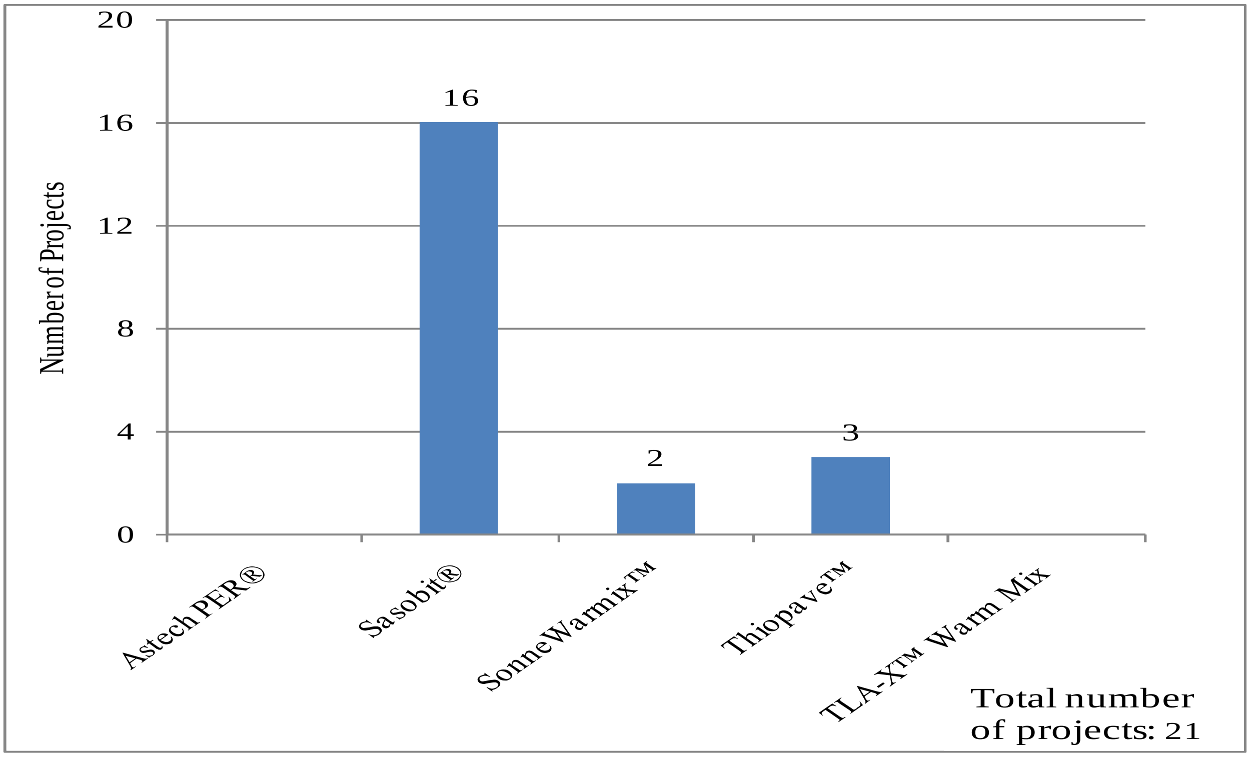

Figure 3.15. Number of constructed projects for each organic additive

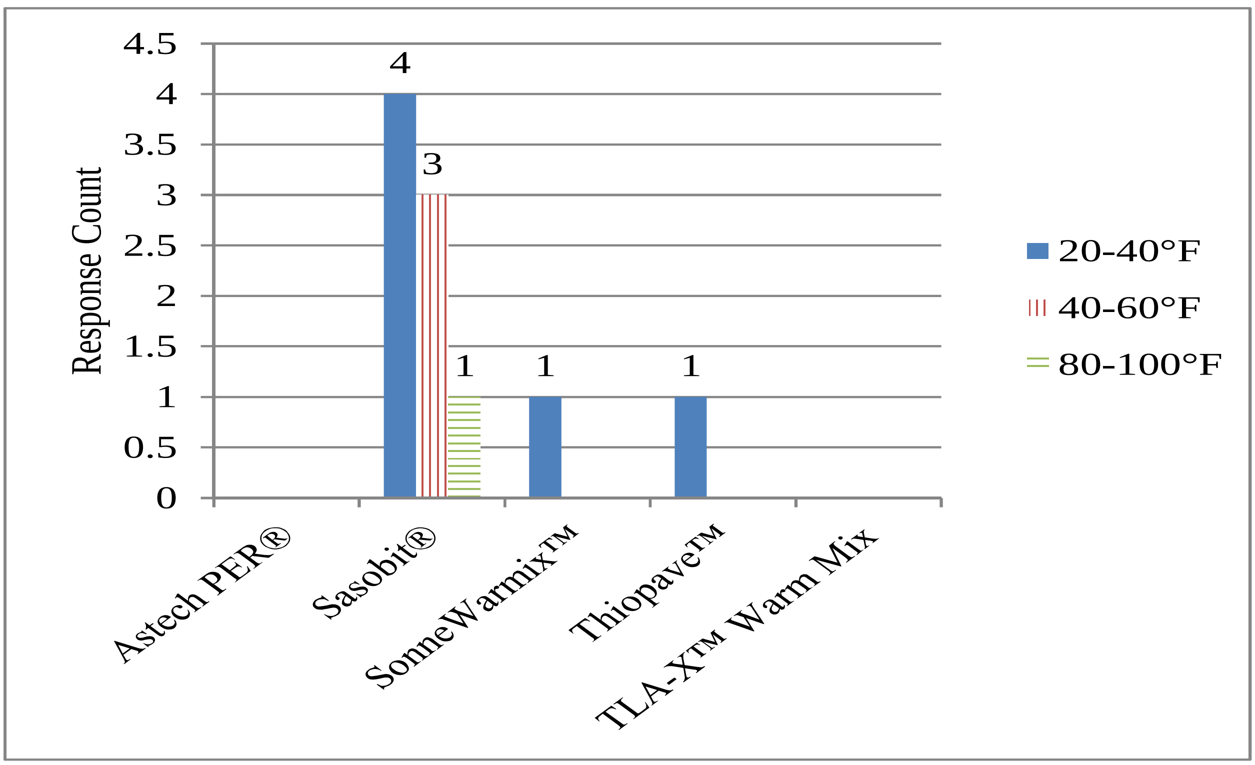

Figure 3.16. Mixing temperature reduction (°F) achieved for each organic additive

3.4. Mix Design

In the third section of the survey modification in mix design process was the topic of questions. Focus was on binder selection, aggregate properties, volumetrics, use of recycled materials (recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS)), and additives. Initially it was investigated if any modification exist in any of the major categories and then the questions were directed toward detailed aspects of each category.

Figure 3.17 shows that currently most of the agencies do not have any modifications in their mix design method compared to HMA. Few answers that show modifications are later investigated in their respective questions that are discussed later on but mostly their replies were of the form that agencies are following manufacturer's recommendations. One of the agencies replied that their current mix design does not allow use of recycled materials due to the early stage of development of the subject.

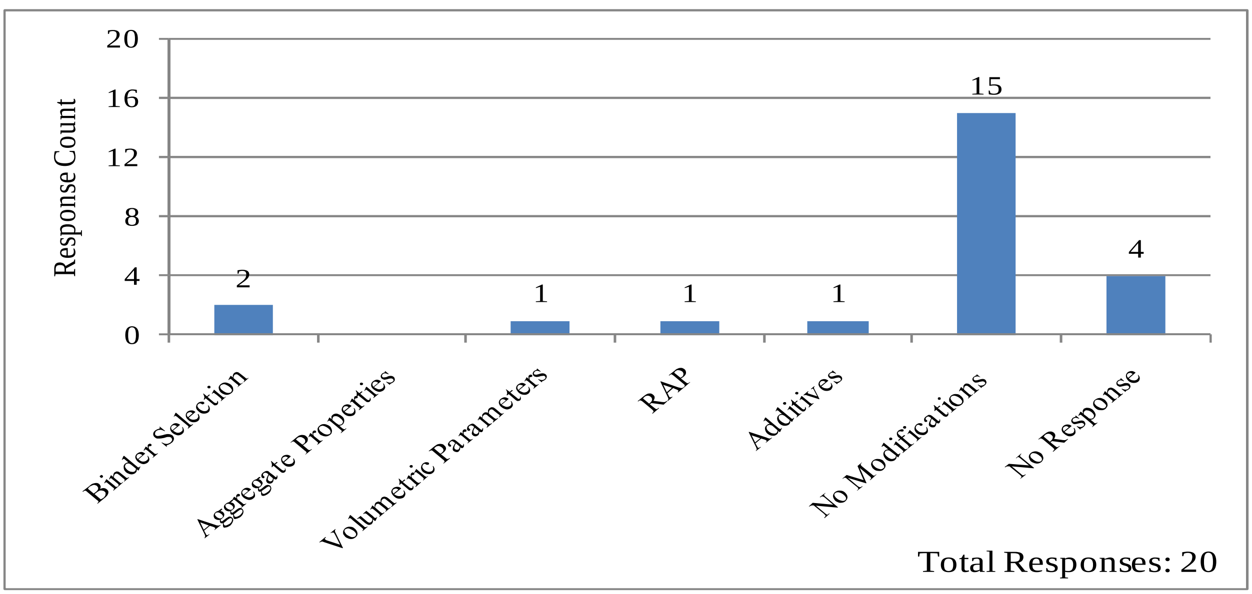

Figure 3.17. Modifications in WMA material selections items compared to HMA

Survey further concentrated on specific changes that agencies have in each of the main categories of the previous question. For modifications in binder selection these issues were investigated compared to HMA: binder content, binder grade, and binder preparation/testing. As Figure 3.18 shows, the majority of agencies do not have any modifications at the time in their binder selection method for WMA mixes. The few that indicated modification were minor corrections, such as for binder content an agency indicated that they adjust for the reduced absorption in WMA mixes, and another agency explained that they "suspect 0.1% to 0.2% in optimum binder content when specimens are fabricated using the WMA technology".

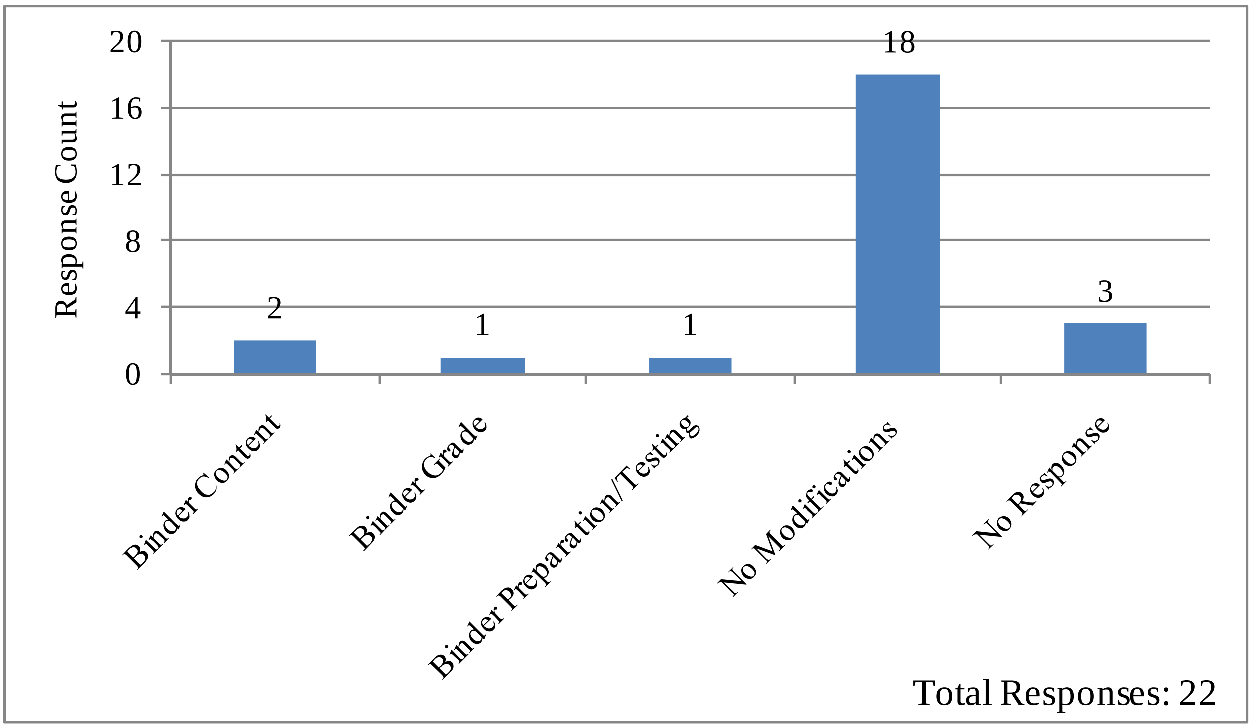

Figure 3.18. Modifications in WMA binder selection items compared to HMA

The second category in mix design was aggregate structure design and modifications were investigated in areas of aggregate sources, nominal maximum aggregate size, trial gradations and aggregate compaction. As figure 3.19 shows, all the agencies responded that they do not any modifications in their aggregate selection/design process and treat WMA the same as HMA in aggregates.

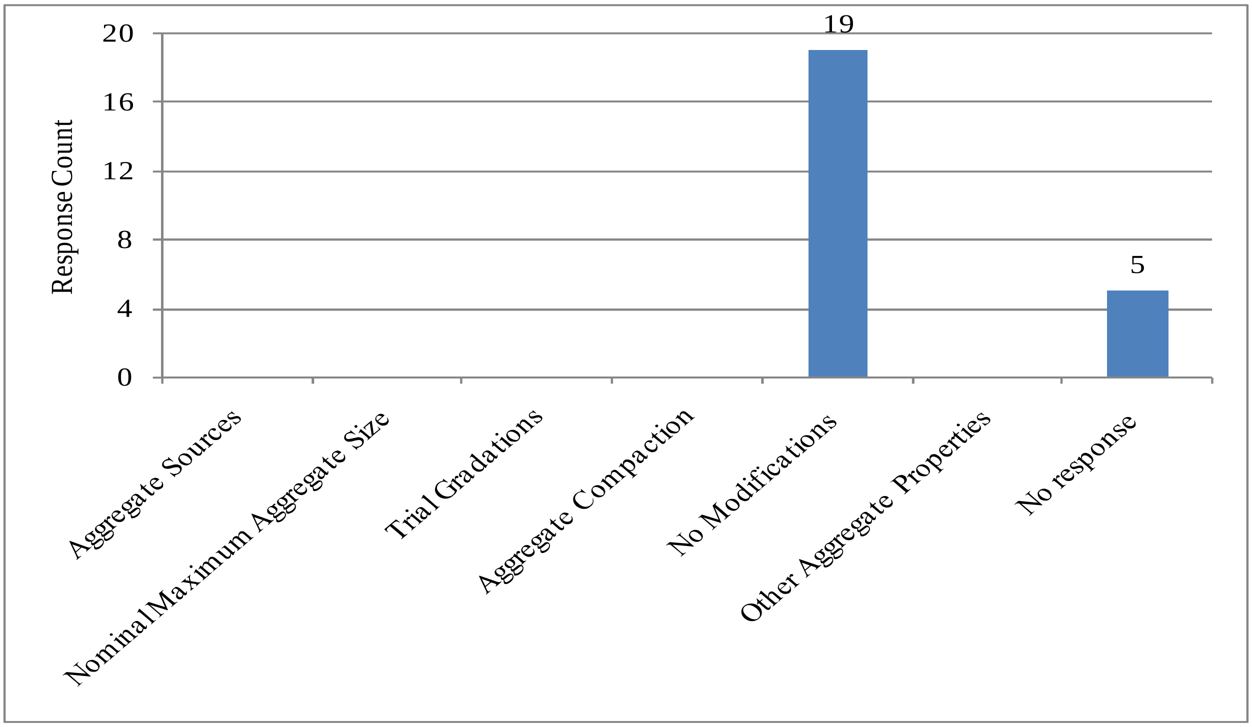

Figure 3.19. Modifications in WMA design aggregate structure compared to HMA

The next issue of interest in the mix design process would be the possible modifications in lab performance tests. Particular experiments of interest were rutting, thermal cracking, fatigue, and moisture sensitivity. Questions were directed toward modifications in sample preparation and testing method. Figure 3.20 shows that agencies are still at preliminary stages and mostly do not have modifications compared to HMA. The few that indicated modifications explained that they require samples to be made with the WMA technology that is to be used on site or that they have modification to match the filed mixing and compaction temperatures which is needless to say.

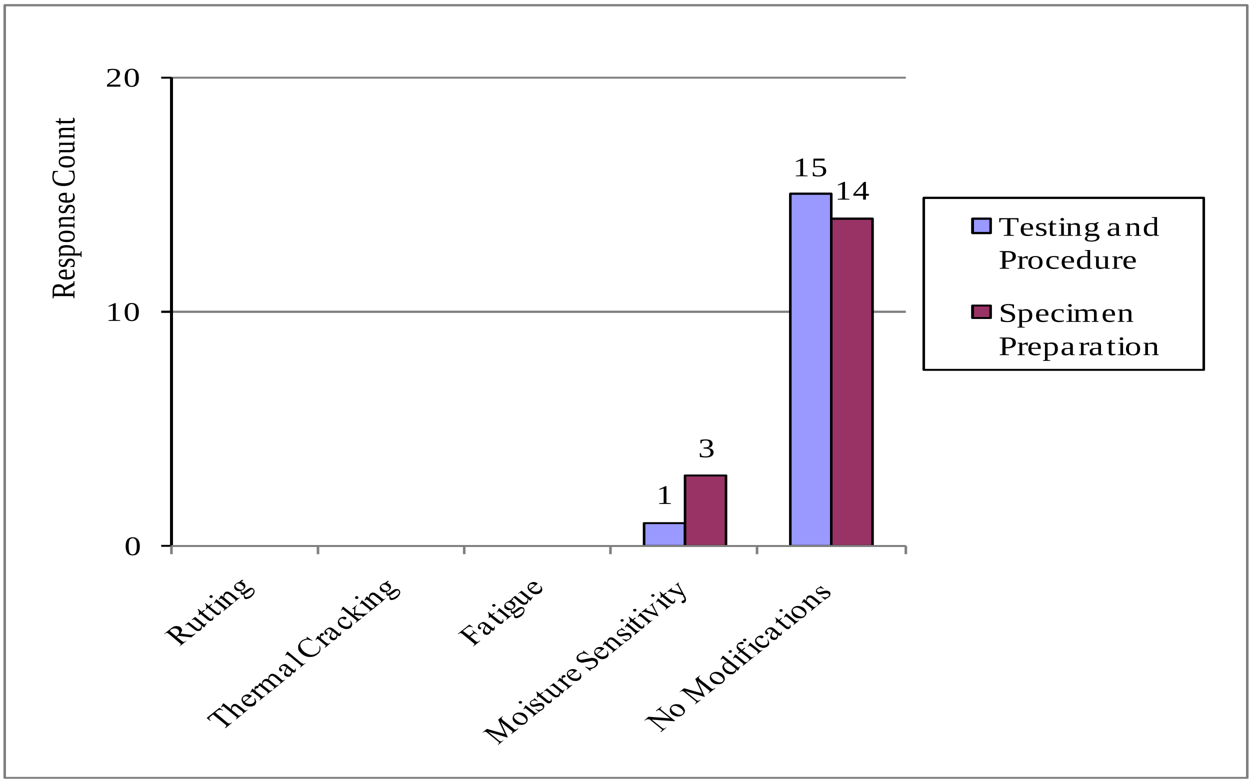

Figure 3.20. WMA lab performance tests modifications compared to HMA

When asked about the modifications they have on the requirements of anti stripping agents for WMA compared to HMA as Figure 3.21 shows most of the agencies has no modification until now although some of the comments were of interest where Maine mentioned that there will be “potential changes in the future” or Indiana stated that due to non-sensitive materials to moisture they see little use of anti stripping materials for all their mixes. Iowa does not have a prescribed dosage, instead dosage is determined after evaluating TSR of 3 different dosages for HMA or WMA. Nebraska stated that: “Yes, currently we require 1.0% lime by weight of virgin aggregate. For Evotherm or any other WMA with amine anti strip material no lime is added, but the contractor must find a way to meet 80% or greater on TSR. Most other additives still require 1.0% lime at this time, but this is still preliminary."

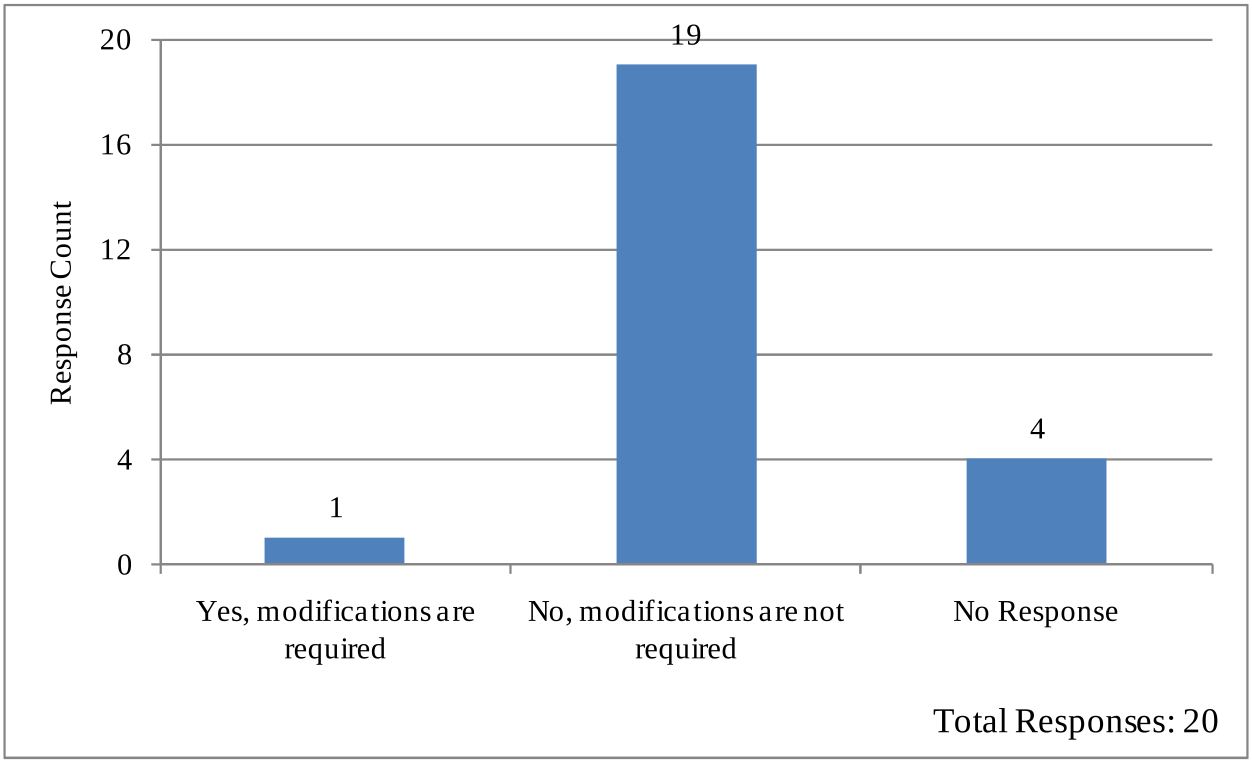

Figure 3.21. WMA requirements on anti-stripping agent compared to HMA

Investigation of the mix design modifications was continued by questioning the agency's requirements on RAP (Reclaimed Asphalt Pavement) and RAS (Reclaimed Asphalt Shingles) and if there is any modifications compared to HMA and as Figure 3.22 indicate agencies are mostly following the same requirements they have for HMA. Manitoba does not allow use of recycled materials for WMA, Montana does not allow RAS for HMA nor WMA and RAP is only allowed in their HMA mixes. Nevada allows 15% of RAP but does not allow RAS. Saskatchewan and Washington also do not allow RAS.

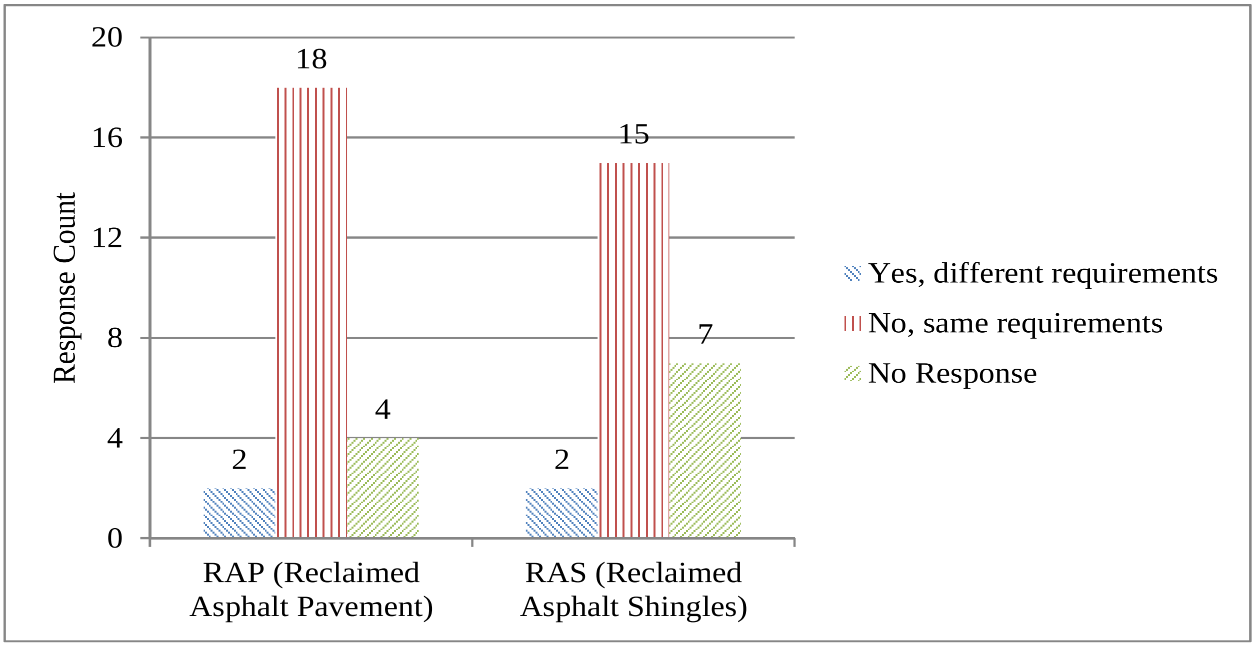

Figure 3.22. WMA requirements on RAP and RAS compared to HMA

The mix design section concluded with inquiry about whether WMA mix design is dependent on the type of technology used.

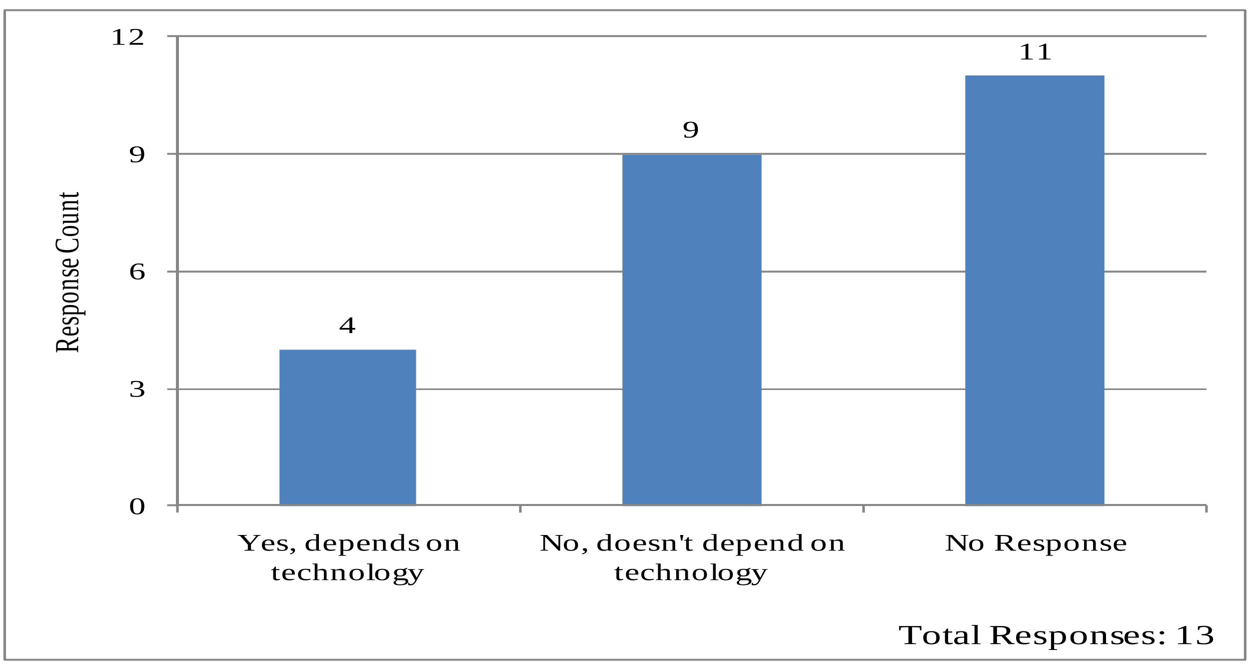

Figure 3.23. WMA design dependence on the technology employed

Figure 3.23 shows the responses to this question. Of the agencies that replied yes to this question Montana stated that they require the mix design is needed to be sent to the agency for verification and approval. Iowa stated that: “For the time being, contractors do not need a foaming table to do a foam design. We will require the raw materials be sent to our lab where we will foam the contractor's design and compare air voids. If we see a significant difference between the foamed and HMA designs we will eventually require contractors to foam their designs.”

3.5. Specifications

The fourth section of the survey aimed the specifications that has been developed for WMA or modifications in HMA specifications to manage WMA projects. Main areas of interest was how they have developed their WMA specification and if the agency has a list of approved processes and finally what is the approach of the agency toward new technology and if they have a process for approving new (unknown to the agency) technologies

In response to these issues, Figure 3.24 illustrates the response of the participants. Of the 21 respondents seven agencies stated that they have a separate specification for WMA projects (namely Iowa, , Maine, Minnesota, Montana, Nebraska, New York, , South Dakota) and six of the 21 respondents have a list of approved process, in fact this list is quite common in states of other regions (not contacted for this survey) and contains WMA technologies that have been approved by the agency either through testing or field-studies and normally these lists are periodically updated. In some states the agency has also developed a guideline for contractors that would like to use new technologies. For this purpose an approval procedure is developed which in most cases consist of preparing trial mixes and submission of tests results of the samples to the agency for approval. Of the 21 respondents six stated that they have such procedure (Figure 3.24).

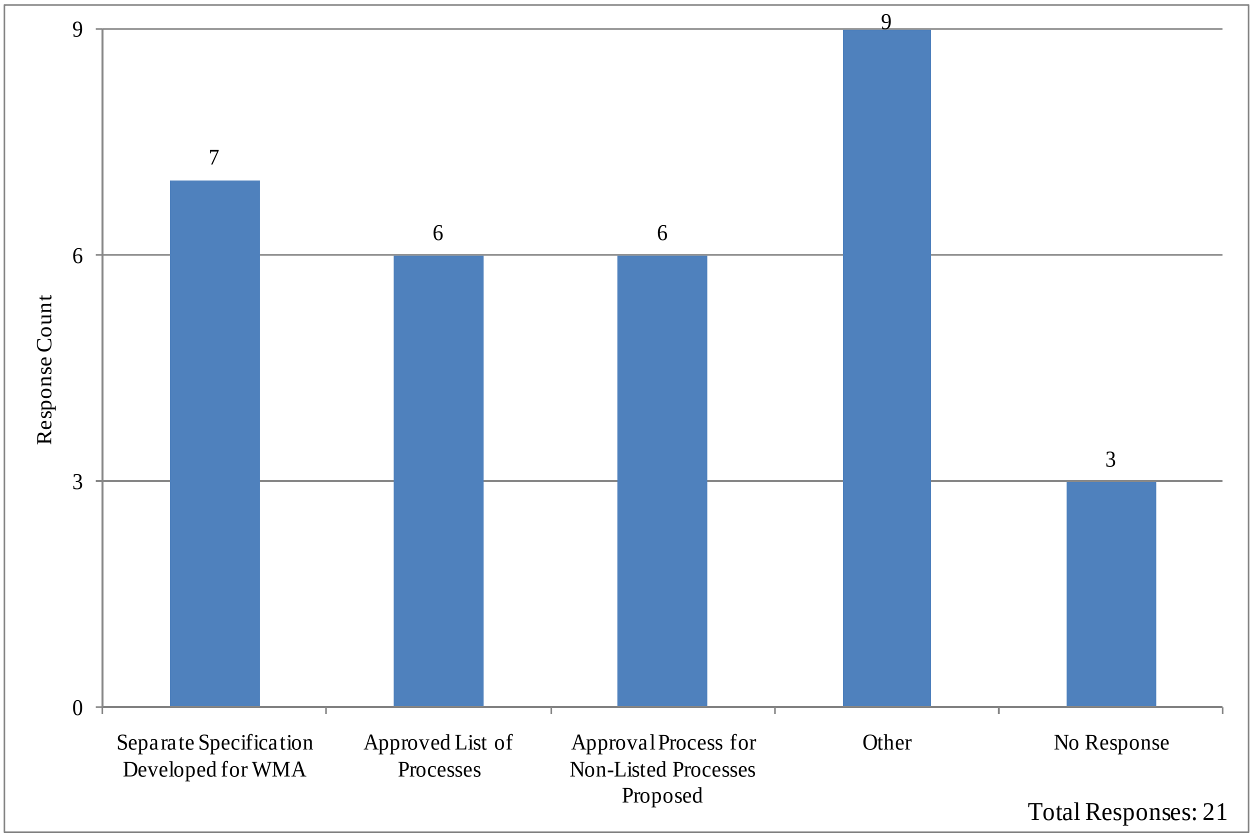

Figure 3.24. Mechanisms for developing warm mix asphalt in agencies

The survey further asked about how the agencies have developed their specification and list of approved processes. Figure 3.25 shows the results and that six agencies have used national studies and guidelines such as NCHRP reports, six agencies have used specifications of other DOTs as guideline and starting point and 16 agencies have developed the specification or list of approved technologies by themselves.

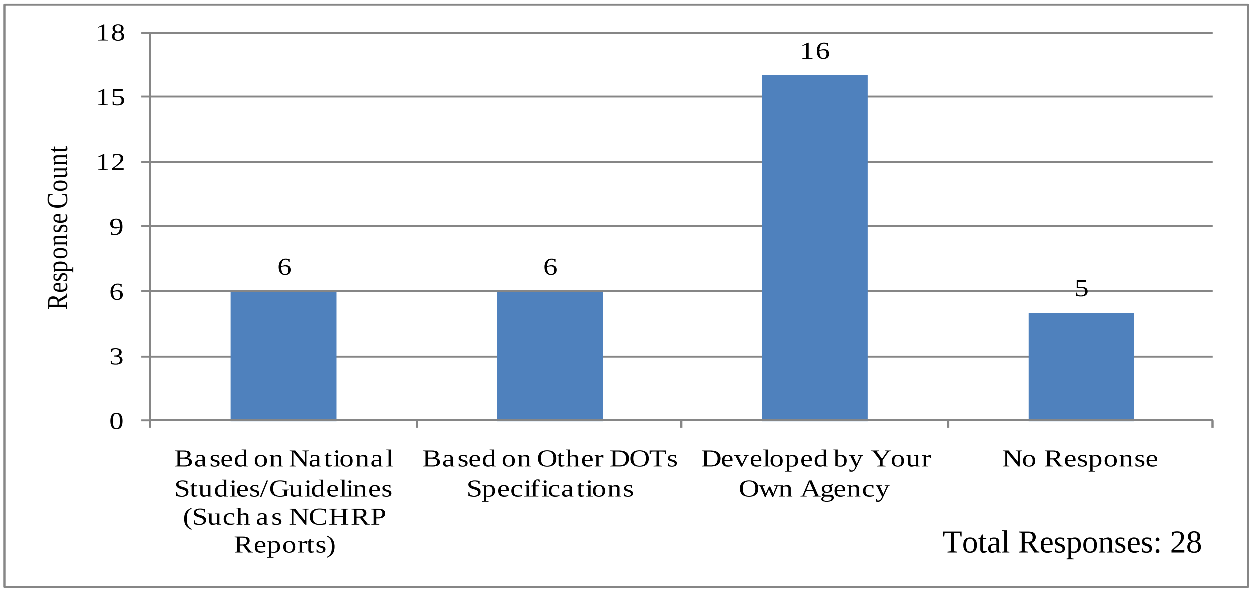

Figure 3.25. Development methods for specification or approval procedure in agencies

The last question of this section was to check whether agencies have a not permitted technology in their specification. This was to gather possible information of records of non-acceptable performance of a certain WMA technology in any of the states and as Figure 3.26 shows none of the agencies have such list in their specifications.

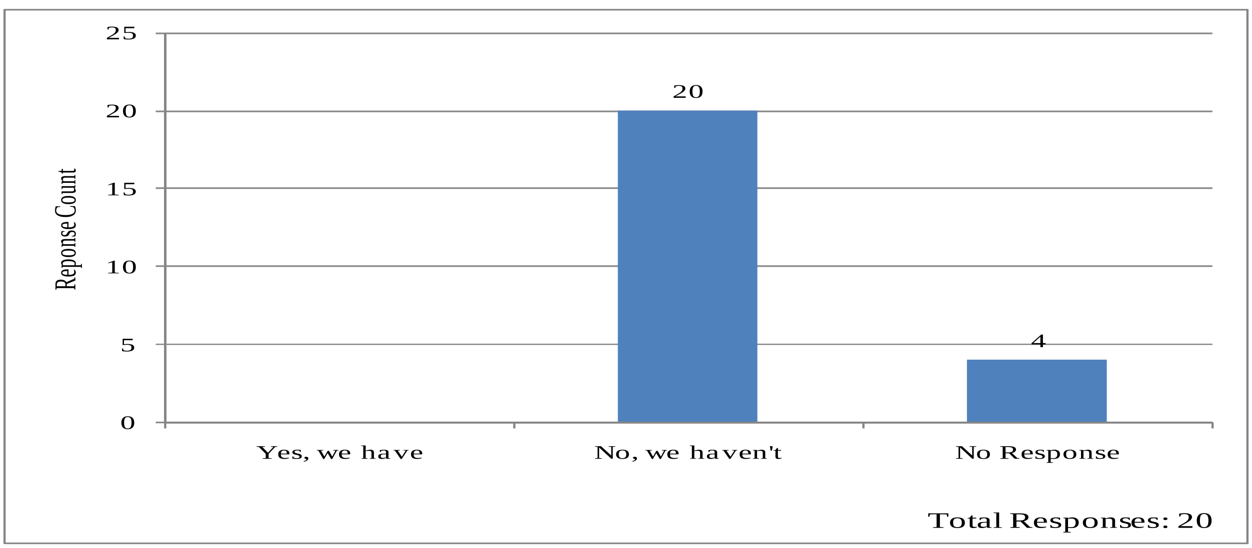

Figure 3.26. Agencies having any NOT-PERMITTED list in their specification

3.6. WMA Acceptance Plan Modifications

The fifth and last section of the survey focused on acceptance plan and possible modification that agencies have compared to HMA. Main areas of interest were sampling plan, quality characteristics, specifications limits, quality level goals, risk, and pay factors. As illustrated in Figure 3.27, almost in all cases there are no modifications in the acceptance plan compared to HMA. Maine stated that: "Modification to specification limits is for mixing and placement temperatures as determined by the manufacturer recommendations" and New York stated that "the plant receives no incentives/disincentives for mixture quality".

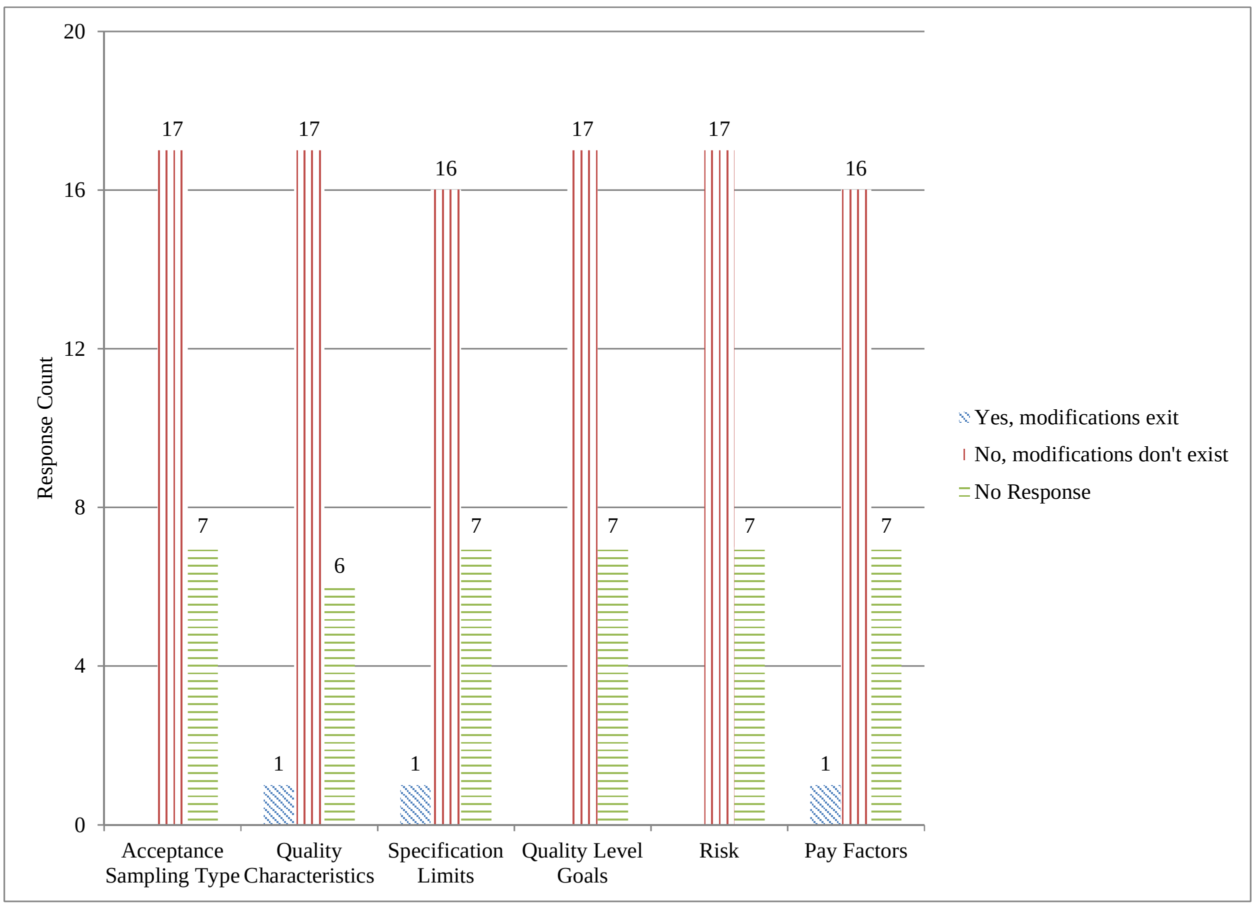

Figure 3.27. Modifications in WMA acceptance plan components compared to HMA

The survey continued with detailed questions about each of the main categories discussed at the beginning of this section. Modifications in temperature monitoring in mixing and compaction were investigated and Figure 3.28 shows the responses. Most agencies (11) has no modification in temperature monitoring for WMA as compared to HMA for both mixing and construction or compaction, this is mostly due to the fact that agencies have to check WMA mixes according to the lower temperatures of WMA and other than that the comments sections did not show significant changes in the method.

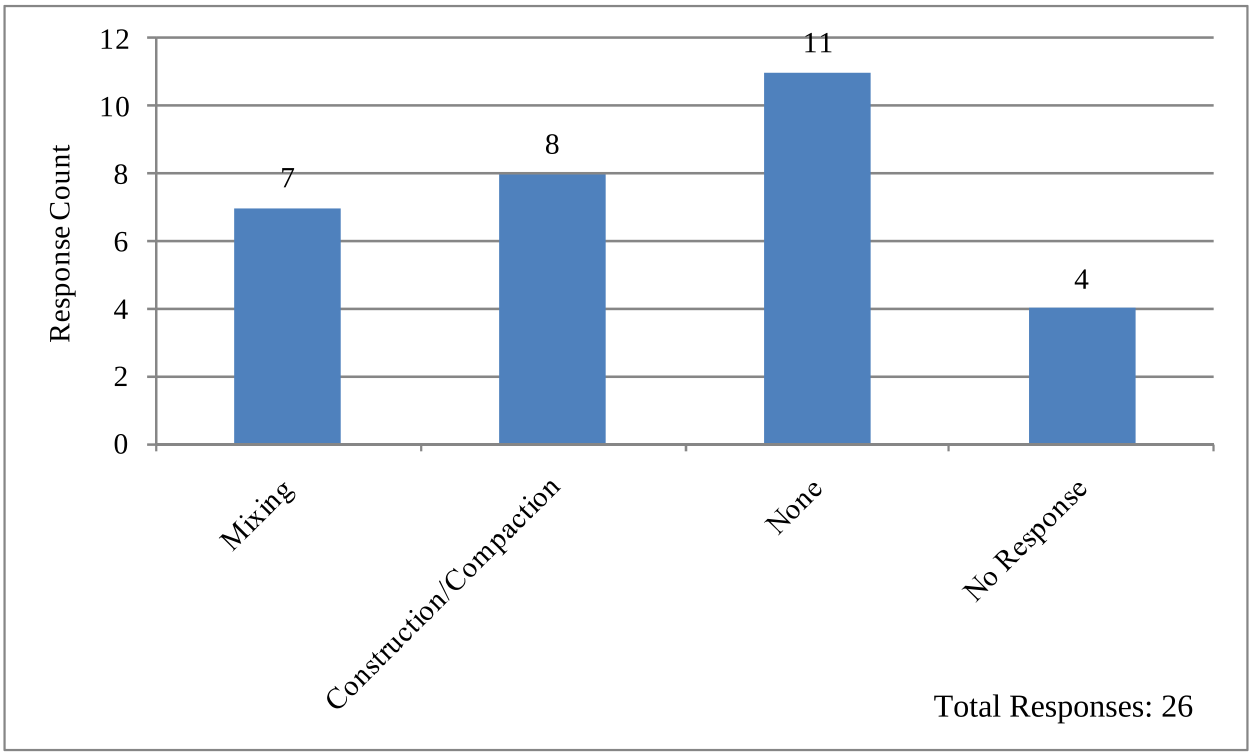

Figure 3.28. Modifications in temperature monitoring for WMA compared to HMA

Next when questioned about the changes in sampling schedule of WMA mixes compared to HMA almost all agencies stated that they have no modifications, as Figure 3.29 shows. Iowa as thy only state that responded yes to this question commented that: “Only in the realm of

AASHTO T283. We normally only sample T283 for HMA on interstates and quartzite mixes; however, we will sample T283 for all WMA mixes above 3M ESALS."

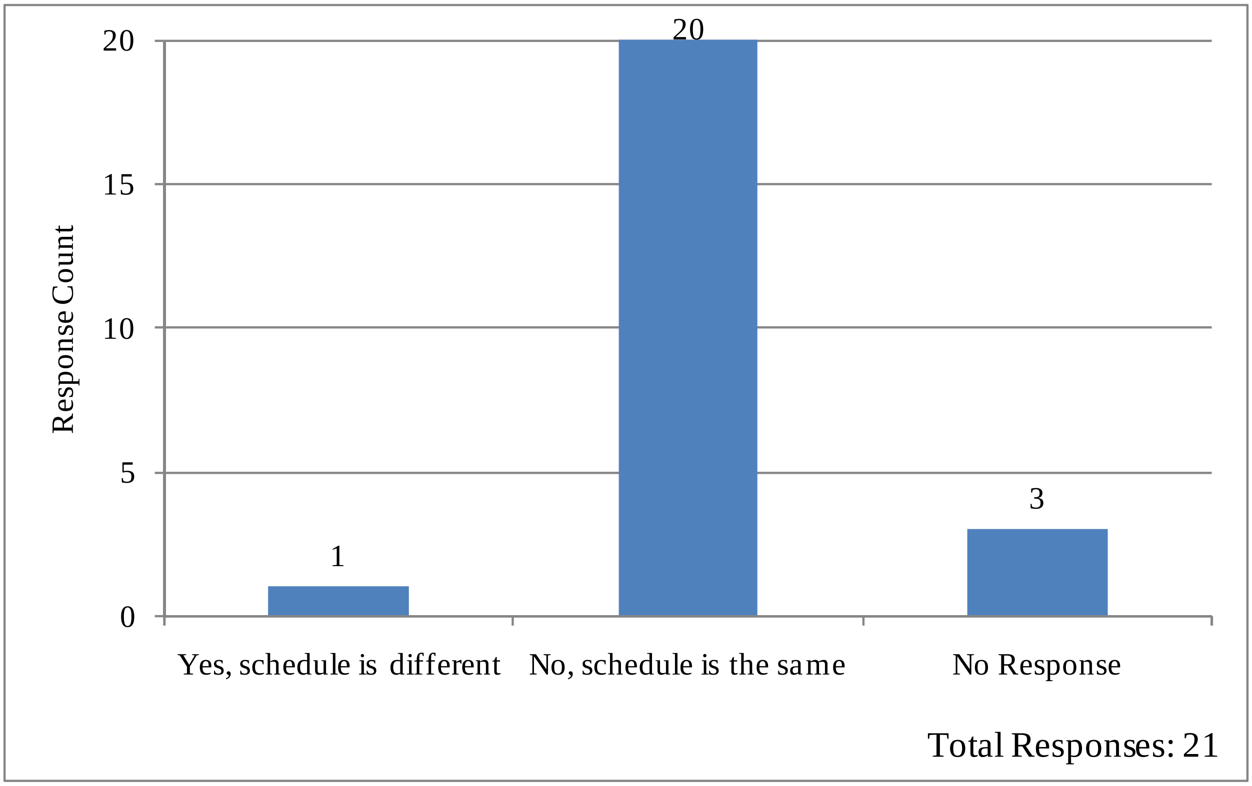

Figure 3.29. Changes in WMA quality assurance sampling schedule compared to HMA

Lab testing was investigated from two perspectives, modifications in sample preparation and testing procedure and as Figure 3.30 shows 13 of the 21 respondents stated that they have no changes for WMA compared to HMA. Those agencies that have modifications are mostly concerned about preparing samples according to the WMA technology being used in the field and preparing/testing samples at temperatures according to the WMA reduced temperatures which is obvious. Idaho stated that: "Foamed WMA Plant produced Material is brought down below 200 □ F and then brought to HMA temps and tested as HMA. There is an additional

AASHTO T-165 test done with plant produced material for foamed WMA.” Iowa stated that: “We compact assurance testing to 240 □ F for WMA regardless of technology or compaction temp. (275 □ F for HMA)”

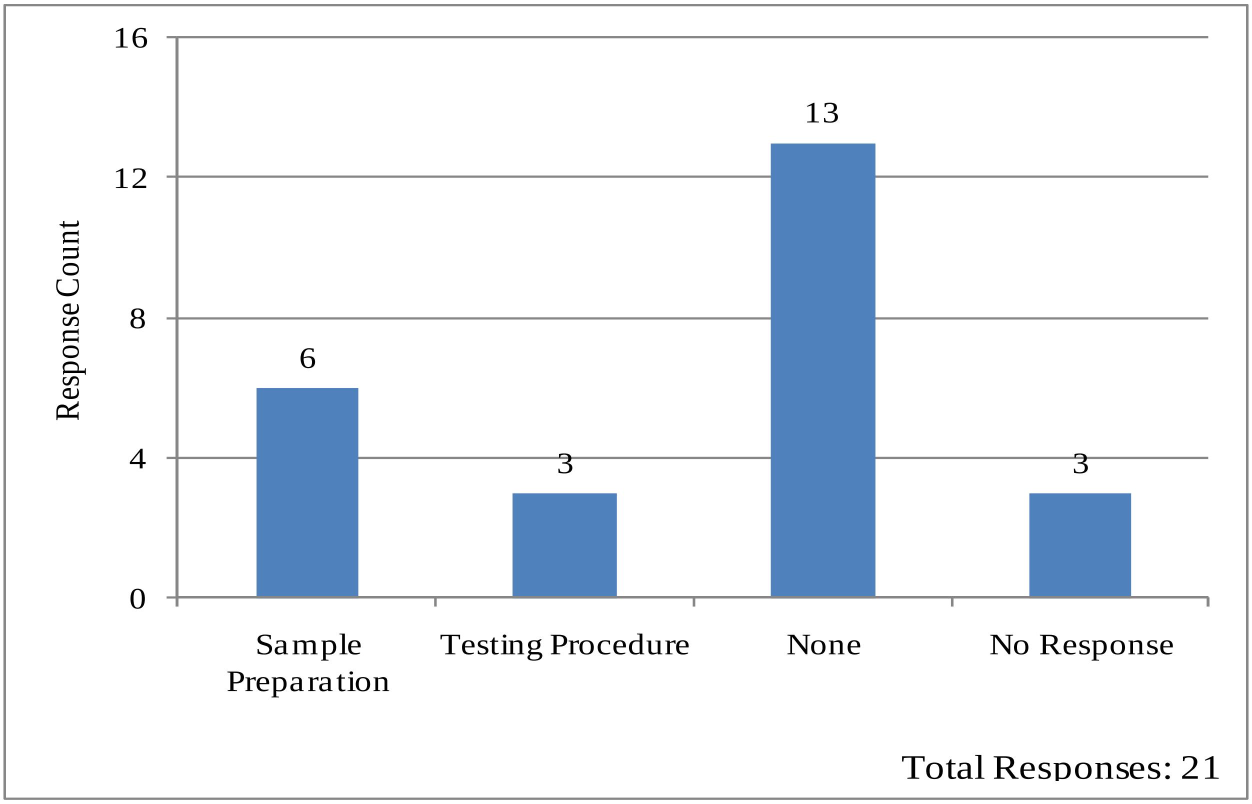

Figure 3.30. Modifications in lab assurance testing for WMA compared to HMA

The survey continued with modifications that the agencies may have in their quality control plan for WMA compared to HMA and as Figure 3.31 shows most agencies follow the same plan for both types of mixes. The modifications on quality control plan for WMA as compared to HMA was discussed. Vermont requires that the quality control plan has a section on the WMA technology to be used, New York mandates that the “Production, Testing and Compaction Details" document made by the WMA technology provider be followed by the mixer producer so as to ensure that everyone is utilizing the technology properly, Maine requests that “the contractor has to determine the technology-specific production and placement temperature range”. As the figure represents, of the 21 respondents only four have modifications and as the comments further explains these modifications are not significant.

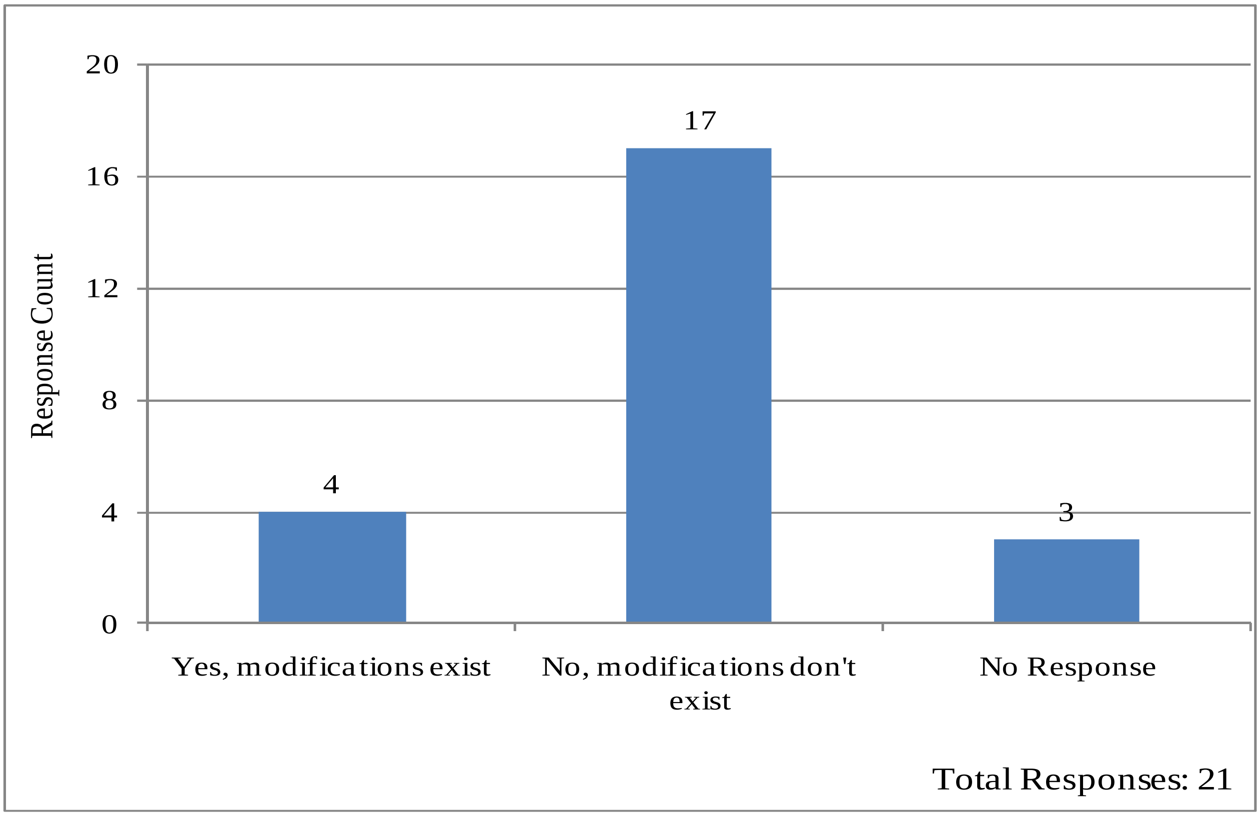

Figure 3.31. Modifications in WMA quality control plan compared to HMA

The other topic of interest was that whether agencies are using test sections to evaluate the constructability and performance of current WMA technologies or not. Figure 3.32 shows the results. As can be seen from the figure, of the 20 responses 14 indicates having test sections to evaluate the performance of WMA.

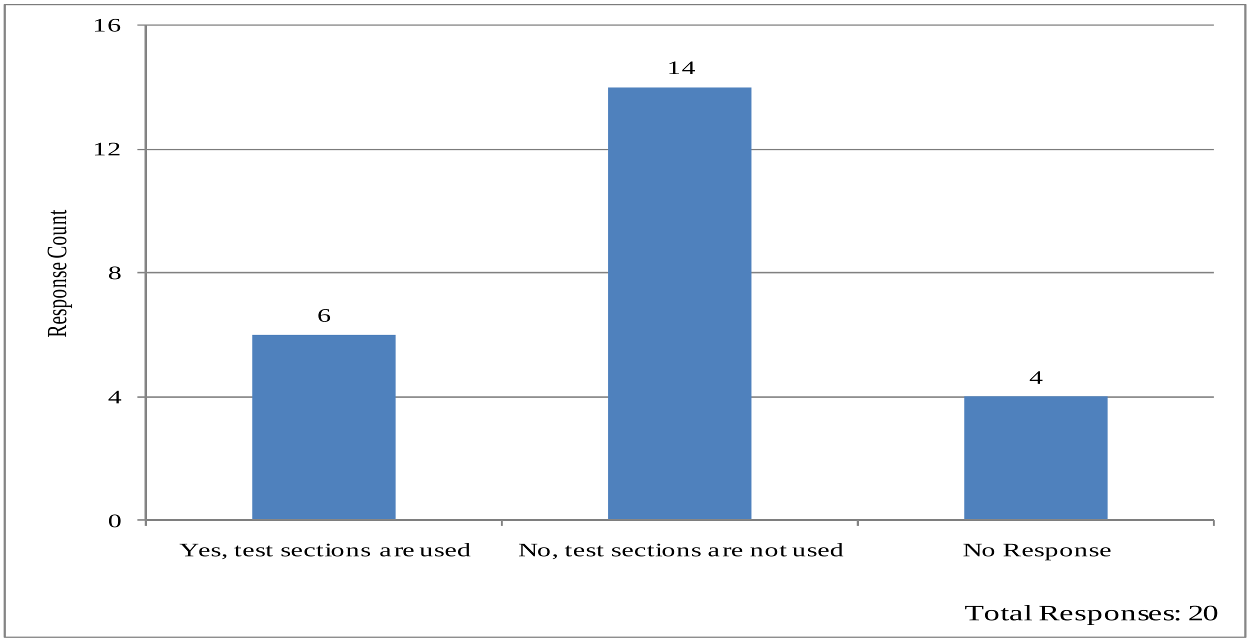

Figure 3.32. Use of test section for WMA evaluation

The final question was to find out what would be the reaction of the agency in case of using non-approved items by the contractors, Figure 3.33 shows the distribution of the responses.

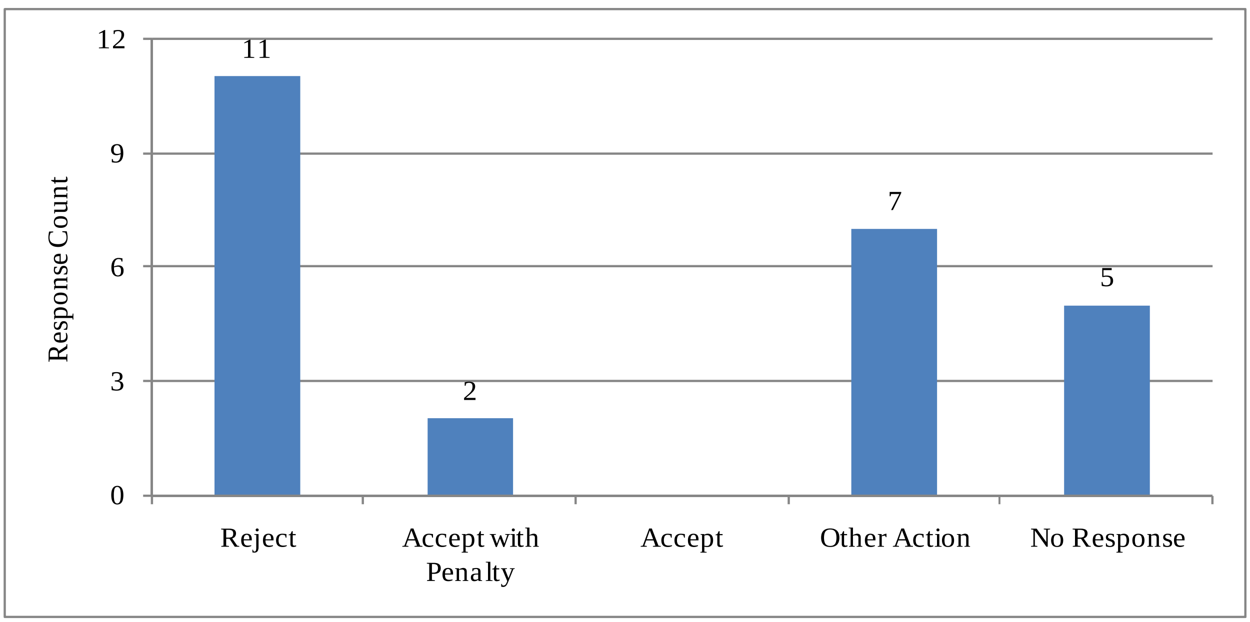

Figure 3.33. Agency's action in case of using non-approved items by the contractor

3.7. Summary of Survey Analysis

As the results of the survey shows, current state of agencies experience with respect to WMA is primitive. Most projects are conducted with foaming processes and organic additives have been the least favorite. As the results of the survey shows, rutting and moisture susceptibility is the main concern of the practitioners. Most agencies do not have any specification for WMA and currently they are following the regulations and specifications they traditionally used for HMA projects. Lab testing and sample preparations are mostly done similar to HMA and in few cases special notice is given to moisture susceptibility evaluation. Agencies have not modified their quality control and assurance schedule for the WMA sections compared to HMA and most are still in preliminary steps of experimenting with WMA and monitoring its performance to implement their findings in possible future specification or special provision. Some DOTs have list of approved processes and also a procedure for approval of new technologies that are not in the list.

CHAPTER 4. EXPERIMENTAL DESIGN AND DATA COLLECTION ON PERFORMANCE OF WMA

4.1. Introduction

To evaluate performance of WMA compared to HMA, data are collected from DOTs regarding their experiments. In this chapter sample preparation and testing procedure followed by each agency in their study are presented. The analysis of the collected data and tests results are done in the next chapter. As rutting and moisture susceptibility are widely recognized as main concerns in use of WMA, the focus in this chapter is on test results related to these two.

Heating the binder in mixing and construction phase causes aging and decrease in flexibility. Due to lower temperatures in construction of WMA, less aging occurs and the binder will not be as stiff as HMA. Therefore, WMA mixes are more flexible than HMA and have higher flow values. WMA mixes being more flexible is advantageous in construction phase because the mix will be more workable but at the same time WMA would be more susceptible to rutting (permanent deformation), that is why a rutting has always been a concern in WMA researches.

Another issue that is widely considered is the moisture susceptibility of WMA. Due to lower temperatures in mixing and construction, aggregates may not get fully dried and moisture could exist in the mix. Moreover, in foaming processes we intentionally add water to the mix in form of water sprays. Existence of small amounts of water in form of a thin film around aggregates or even partially between asphalt and aggregates could weaken the bond between aggregates and asphalt and result in stripping.

In this chapter results of experiments conducted by some DOTs regarding rutting and moisture susceptibility are presented and analyzed.

4.2. Summary of Experiments

For rutting, tests results of experiments conducted by three states were collected: Georgia, North Dakota, and Ohio. For Moisture susceptibility the results of experiments by four states were used: Georgia, Iowa, Michigan, and Ohio. Georgia and Ohio actually did both tests on the WMA mixes they had.

Georgia DOT evaluated three types of WMA technologies by comparing sections with HMA control (Tsai et al, 2010). The three WMA tested were Evotherm, Rediset, and CECABASE and were made the same way as control HMA: using Superpave. All were made as sections in a 9.5 mm depth overlay project. With dosage of 0.6% for Evotherm, 0.2% of Rediset, and CECABASE at 0.44% at temperatures of 260, 280 and 260 □ F respectively and HMA at 315. The samples were tested at 64 □C for rutting according to Georgian Standard (GDT 115) for rutting susceptibility test (similar to AASHTO method for testing with APA). The moisture susceptibility was conducted according to T 283 in which tensile strength of samples were measures in two conditions: dry (unconditioned) and wet (conditioned according to T 283 procedure).

In Iowa, moisture susceptibility of Evotherm and Sasobit were tested by taking samples from a pilot study. Evotherm was added at 4% and Sasobit at 1.5%. Specimen heights were at 2.5 in and were tested according to T 283. Binder used in the project was PG 58 -22.

In Michigan three WMA technologies were compared to HMA in moisture susceptibility (Zhanping et al, 2011). Evaluation was done according to AASHTO T 283. The SuperpaveTM specification was followed in the mix preparation. For the WMA mixture, samples were batched and mixed in the lab using the aggregate and binder same as the control mixture. ADVERA® WMA was added at the rate of 0.15%, 0.25% and 0.35% based on the mixture weight during the mixing process. All WMA mixtures were mixed at 100°C, 115°C and 130°C, and compacted at 100°C, 115°C and 130°C, respectively. All the mixtures (HMA and WMA) were compacted using the 86 gyration numbers. For Sasobit, WMA was made with 0.5%, 1.5%, 3.0% (based on binder weight) produced under the same at temperature of 100°C, 115°C and 130°C. And for Cecabse WMA was made with 0.2%, 0.35% and 0.5%.

In the study conducted by North Dakota DOT (Suleiman, 2011), WMA and HMA control section were part of a 1.5 in overlay. WMA was produced using Evotherm 3G and samples with 6 in diameter were tested using APA at 58 □C and 8000 cycles and 100 psi pressure.

In the study conducted in Ohio (Abbas et al. 2011), foaming WMA was used which was produced by WLB10 at 30 □F lower than HMA which was constructed as control. Rut depths were calculated at different loading cycles (5, 500, 1000, and 8000) according to AASHTO TP 63-07 using APA. For moisture susceptibility samples were tested according to AASHTO T 283.

4.3. Rutting

Rutting occurs in the early years of the pavement in service and at high temperatures. It has always been a major concern regarding the performance of WMA. Therefore, rutting evaluation has been the main area in many WMA studies. The collected data from some of DOTs are presented here followed by graphs and tables for data analysis and discussion. Mostly rutting is evaluated according to AASHTO TP 63-06 by using Asphalt Pavement Analyzer device, some DOTs might have small modification in testing procedure and as long as binder content, aggregate blending and gradation, and sample preparation are not the same between DOTs the results are not to be compared to each other but to be used to make general conclusions about rutting in WMA.

4.3.1. Evaluation of Evotherm, Rediset, and Cecabse RT by Georgia Department of Transportation (DOT)

In a pilot study in Geogia, GDOT placed WMA test sections using three WMA mixes: Evotherm, Rediset WMA, Cecabe RT WMA, and a 9.5 mm Superpave control mix. All of the sections were part of a 9.5 mm Superpave mix overlay construction project on State Route 42 in Monroe County, Georgia.

4.3.1.1 Sample Preparation

The WMA mixes were produced using the same Superpave mix design used for producing the control mix, this was due to the fact that the dosage of additives were small and assumed not affecting the mix characteristics.

Evotherm was added at 0.6%, Rediset at 0.2%, and Cecabse RT at 0.44%. The mix temperatures were 260, 280, and 260 respectively and HMA was produced at 315 ◦F.

For Moisture Susceptibility tests, mixes were collected during construction and were formed into samples with air voids in 7.0±1.0%. The testing was conducted according to GDOT Standard (GDT66) and for each mix (3 WMA and 1 control) 6 samples were prepared which 3 were tested unconditioned and 3 tested after being conditioned.

To evaluate rutting susceptibility of each mix, APA test was conducted. Laboratory compacted samples were prepared from mixes collected during construction phase. The samples prepared had air voids ranges between 5.0±1.0%. The testing was conducted according to Georgia standard (GDT 115).

4.3.2. Evaluation of Evotherm by North Dakota DOT (NDDOT)

In an attempt to compare rutting of WMA with HMA, cores from a WMA study project near Valley City, ND were collected in which NDDOT has placed WMA overlays (1.5 in) using Evotherm 3G. The cores were 6 in diameter and the project title was “H-mdf-2-011(025)035. The project was built with a HMA control section from which control cores were taken and sent to laboratory for testing. 16 cores from WMA and 16 from HMA were taken, 2 at each location and 2 in each direction resulting in 4 cores at each spot.

4.3.2.1 Sample Preparation

The samples were to be tested by Asphalt Pavement Analyzer (APA) in order to evaluate the rutting resistance. Of the 32 samples, 24 were used for testing (keeping 8 in case of damaged samples or need of reruns). Half of the samples were to be tested under dry conditions and half under wet conditions.APA require specimens at 3 inches height therefore samples were cut from the bottom using a concrete saw leaving the top surfaces intact.

For preparation of dry samples, cores were heated to 58 ˚C (high temperature of the PG grade) for 6 hours and this temperature was maintained during the testing. For wet conditions, samples were placed in water bath at 58 ˚C for 24 hours prior testing and the test was conducted with samples submerged in water.

The test was conducted according to TP 63-03 “Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures”. The 24 cores were tested at 8000 loading cycles at 100 psi pressure and each APA test was consisted of 4 specimens (2 HMA and 2 WMA). A 9 mm rutting is considered as failure for class 29 or lower classification pavements.

4.3.3. Evaluation of Foamed WMA by Ohio DOT

In an attempt to evaluate the performance of WMA produced using foaming technologies, a study was conducted by Ohio DOT.

4.3.3.1 Sample Preparation

To produce WMA samples a laboratory scale asphalt binder device called WLB10 was used and the mixtures were produced at 30 □□ F lower than traditional HMA mixing and compaction temperatures. Water content for foaming was at 1.8%, which is the maximum value allowed by ODOT. Asphalt used in the experiment was PG 64-22. HMA mixture was also constructed as control. The samples were tested for rutting and moisture susceptibility. Rutting was evaluated according to APA testing procedure (AASHTO TP 63-07) and for moisture susceptibility AASHTO T 283 was used.

4.4. Moisture Susceptibility

WMA is produced at temperatures lower than traditional HMA therefore the concern that water may not be fully removed from aggregate and leave the mixture structure is logical and in fact one of the main concerns in using WMA, especially in foaming technologies in which water is actually added to the mix. Testing of WMA mixtures are currently conducted similar to HMA according to AASHTO T 283 and the results of some of the DOTs' experiment are presented here.

4.4.1. Evaluation of Evotherm, Rediset, and Cecabse RT by Georgia DOT

Project objective and sample preparation are discussed in previous section (rutting of Evotherm, Rediset, and Cecabse RT by Georgia DOT). In here results of moisture susceptibility test are presented.

4.4.2. Evaluation of Evotherm and Sasobit by Iowa DOT

Iowa Department of Transportation conducted a project to evaluate moisture susceptibility of WMA compared to HMA. Two WMA technologies were used with a HMA control section: Evotherm and Sasobit. From each section 6 samples were taken and were tested according to AASHTO T-283.

4.4.2.1. Sample Preparation

The test is performed by compacting specimens to an air void level of six to eight percent. Three specimens are selected as a control and tested without moisture conditioning, and three more specimens are selected to be conditioned by saturating with water undergoing a freeze cycle, and subsequently having a warm-water soaking cycle. The specimens are then tested for indirect tensile strength by loading the specimens at a constant rate and measuring the force required to break the specimen. The tensile strength of the conditioned specimens is compared to the control specimens to determine the tensile strength ratio (TSR).

For laboratory-batched mixtures, 6 in diameter and 2.5 in thick specimens were used. After mixing, the mixture is placed in the pans and spread to about 1 in. (25 mm) thick. The mix is then cooled to room temperature for 2 ± 0.5 hours. The mixture is placed in the oven for 2 hours at 275 ± 5°F (135 ± 3°C), and stirred every 60 ± 5 minutes to maintain conditioning.

4.4.3. Evaluation of Advera, CECABASE RT, and Sasobit by Michigan DOT

In a study conducted in Michigan Advera, CECABASE, and Sasobit were used in construction of samples on which TSR test was conducted according to AASHTO T 283.

4.4.3.1. Sample Preparation

For Advera, in asphalt mixture testing, the mixture design used in the study was based on specifications for a local asphalt mixture used in Michigan. The (nominal maximum aggregate size is 12.5mm and the designed traffic level is less than 3 million ESALs based on the current

SuperpaveTM asphalt mixture design procedure. A PG58-34 binder was used for both control and WMA mixtures. For control mixture, the sample was batched and mixed using a bucket mixer in the lab. The mixtures were then heated in an oven for two hours (short-term aging) until the control mixtures reached the compaction temperatures (153°C). The SuperpaveTM specification was followed in the mix preparation. For the WMA mixture, samples were batched and mixed in the lab using the aggregate and binder same as the control mixture.

ADVERA® WMA was added at the rate of 0.15%, 0.25% and 0.35% based on the mixture weight during the mixing process. All WMA mixtures were mixed at 100°C, 115°C and 130°C, and compacted at 100°C, 115°C and 130°C, respectively. All the mixtures (HMA and WMA) were compacted using the 86 gyration numbers.

For Sasobit, WMA was made with 0.5%, 1.5%, 3.0% (based on binder weight) were produced under the same environment at temperature of 100°C, 115°C and 130°C. And for Cecabse WMA was made with 0.2%, 0.35% and 0.5%.

4.4.4. Evaluation of Foamed WMA by Ohio DOT

Project objective and sample preparation are discussed in previous section (rutting evaluation of foamed WMA by Ohio DOT). In here results of moisture susceptibility test are presented.

CHAPTER 5. DATA ANALYSIS ON PERFORMANCE OF WMA

5.1. Introduction

In this chapter data collected experiments discussed in the previous chapter are presented and analyzed. It should be noted that each agency's experiment may be focused on specific technologies and certain performance indices, therefore the results of all agencies' testing may not be comparable.

5.2. Rutting Test Results

5.2.1. Results of study on Evotherm, Rediset, and CECABSE RT by Georgia DOT

Table 5.1. Rut values for HMA – Georgia DOT

Sample	1	2	3	4	5	6
Height (mm)	75.0	75.0	75.0	75.0	75.0	75.0
Gmb (no units)	2.362	2.35	2.352	2.351	2.352	2.355
Voids (%)	5.2	5.7	5.6	5.7	5.6	5.5
Rut value (mm)	5.13	5.76	4.64	5.07	7.17	6.93
Temperature 64 C		Average Rut Value (mm)				5.78

Table 5.2. Rut values for Evotherm – Georgia DOT

Sample	1	2	3	4	5	6
Height (mm)	75.0	75.0	75.0	75.0	75.0	75.0
Gmb (no units)	2.352	2.353	2.354	2.355	2.346	2.35
Voids (%)	5.1	5.1	5.0	5.0	5.4	5.2
Rut value (mm)	5.24	5.84	5.32	6.16	7.91	8.85
Temperature 64 C		Average Rut Value (mm)				6.55

Table 5.3. Rut values for Rediset – Georgia DOT

Sample	1	2	3	4	5	6
Height (mm)	75.0	75.0	75.0	75.0	75.0	75.0
Gmb (no units)	2.350	2.350	2.346	2.356	2.353	2.359
Voids (%)	5.6	5.6	5.8	5.4	5.5	5.3
Rut value (mm)	4.92	6.05	5.64	6.49	5.49	6.18
Temperature 64 C			Average Rut Value (mm)			5.79

Table 5.4. Rut values for CECABSE RT – Georgia DOT

Sample	1	2	3	4	5	6
Height (mm)	75.0	75.0	75.0	75.0	75.0	75.0
Gmb (no units)	2.345	2.348	2.350	2.354	2.346	2.344
Voids (%)	5.3	5.2	5.1	5.0	5.3	5.4
Rut value (mm)	6.15	6.33	5.08	5.00	6.40	6.60
Temperature 64 C			Average Rut Value (mm)			5.93

Table 5.5. Comparison of average rut values – Georgia DOT

Section	Rut Value (mm)
HMA	5.78
Evotherm	6.55
Rediset	5.79
Cecabse RT	5.93

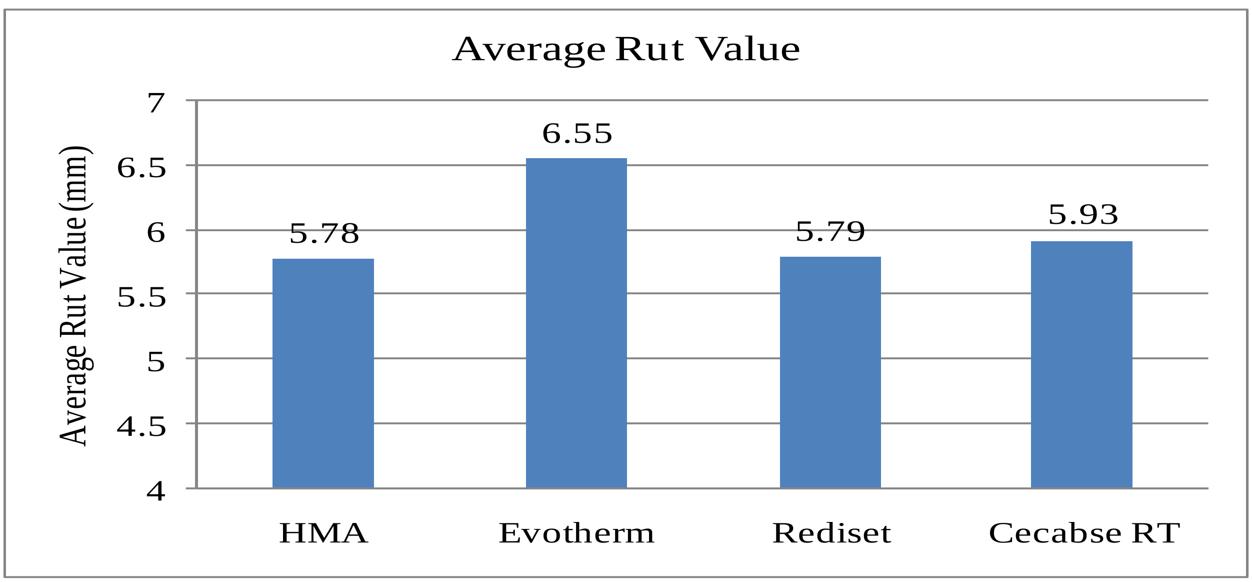

Figure 5.1. Comparison of average rut values – Georgia DOT

As the results show, all three WMA mixtures had acceptable performance regarding rutting susceptibility. The values of rut depth are close to the control section (HMA) with Evotherm having the highest rut depth value among all 4 sample types, the other three having really close rut values.

5.2.2. Results of study on Evotherm by North Dakota DOT

Table 5.6 and 5.7 show the results of the test conducted at NDDOT for the dry and wet conditions respectively. The results are further presented in Figures 5.2, 5.3, and 5.4.

Table 5.6. Rut values for dry condition – ND DOT

	Core #	Rut Value (mm)
WMA	21	8.08
	23	8.83
HMA	1	6.55
	3	8.73
WMA	25	9.12
	27	9.36
HMA	9	7.37
	11	8.11
WMA	29	9.25
	31	8.76
HMA	13	8.34
	15	8.07

Table 5.7. Rut values for wet condition– ND DOT

	Core #	Rut Value (mm)
WMA	18	9.95
	20	9.05
HMA	2	6.45
	4	7.63
WMA	22	8.1
	24	8.45
HMA	6	6.19
	8	5.49
WMA	30	7.72
	32	8.16
HMA	14	5.63
	16	8.34

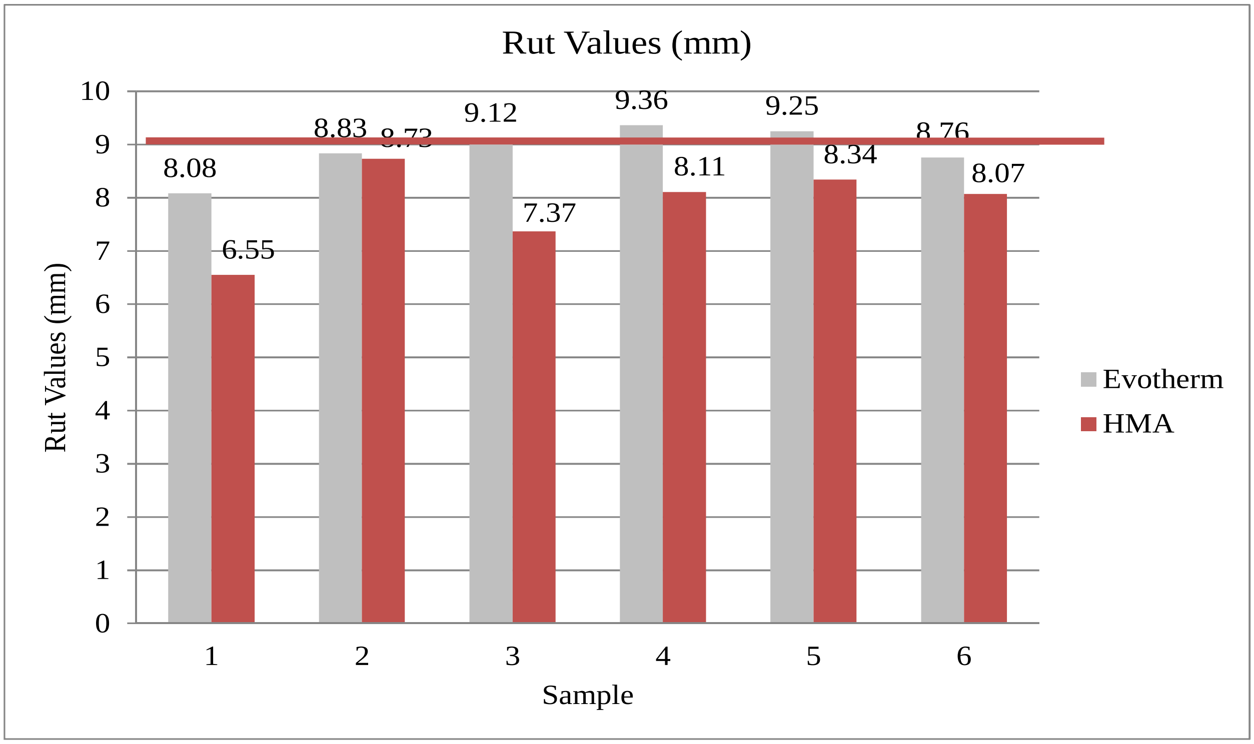

Figure 5.2. Comparison of rut values in dry condition – ND DOT

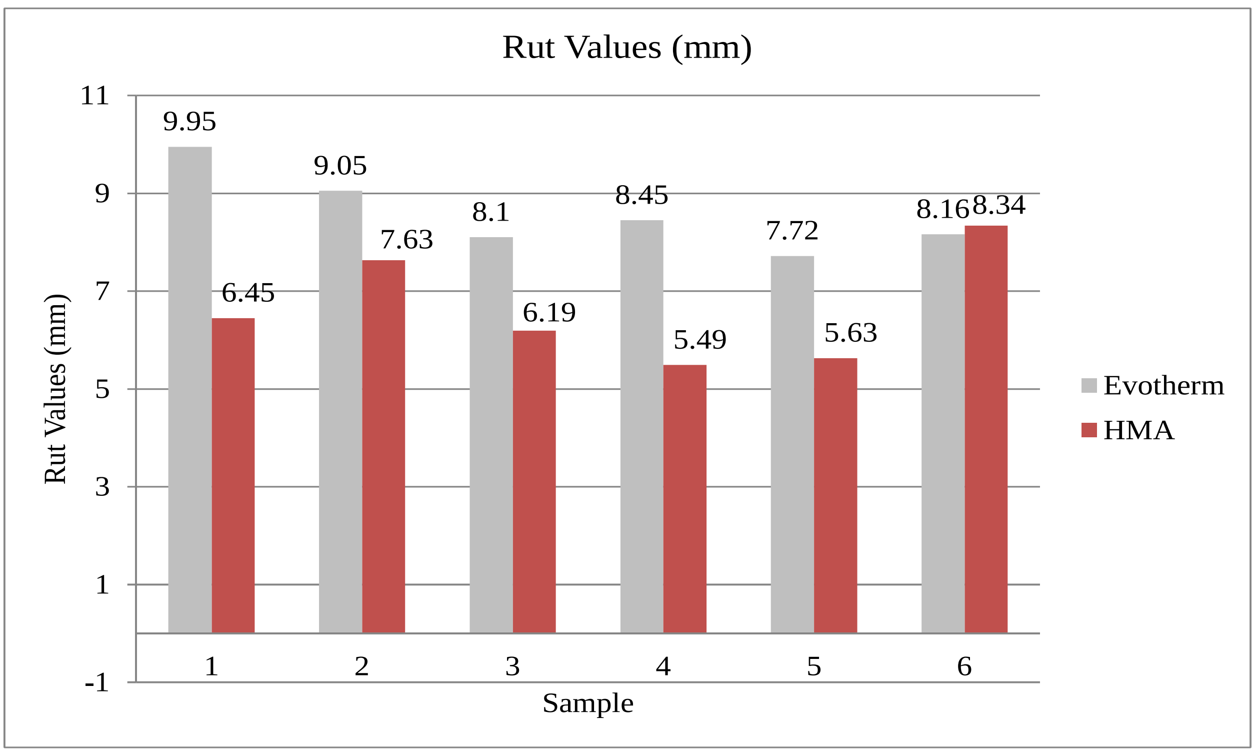

Figure 5.3. Comparison of rut values in wet condition – ND DOT

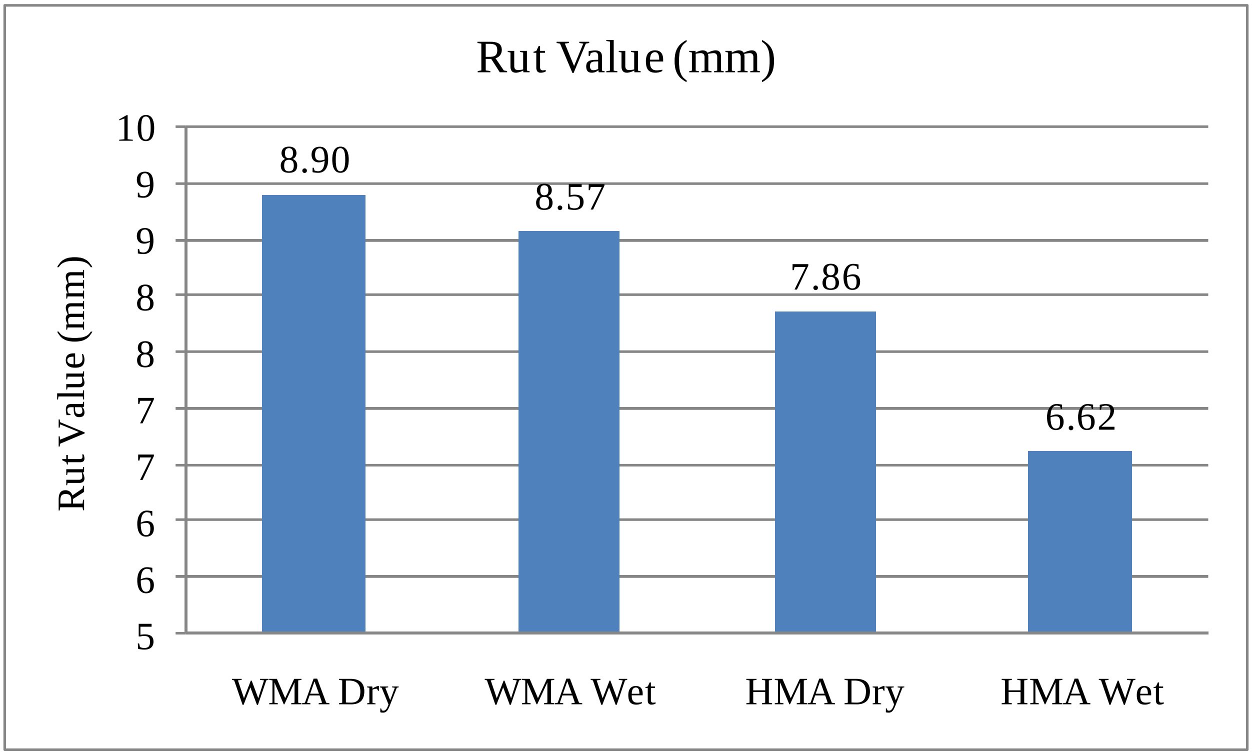

Figure 5.4. Comparison of average rut values – ND DOT

As the results show, WMA samples have higher rut values compared to HMA and of the 24 samples tested, 5 samples did not satisfy the maximum 9mm limit on rut value and all the 5 samples were WMA. This shows the necessity to conduct further tests in North Dakota prior to start using Evotherm in WMA projects. Also as the results show dry sample have higher rut values compared to conditioned samples.

5.2.3. Results of study on Foamed WMA by Ohio DOT

The results of study by Ohio DOT are presented in Tables 5.8 and 5.9, for HMA and WMA respectively. The average rut depth values are further presented in Tables 5.10 and 5.11. Figure 5.5 compares the results by using bar chart.

Table 5.8. APA test results for HMA samples – Ohio DOT

			Rut Depth at Each Slot (in)		
		Specimen	A	B	C
Cycle	5	Slot 1	0.0000	0.0000	0.0000
		Slot 2	0.0000	0.0000	0.0000
		Slot 3	0.0000	0.0000	0.0000
		Slot 4	0.0000	0.0000	0.0000
	500	Slot 1	0.1275	0.1295	0.0995
		Slot 2	0.1210	0.1310	0.1170
		Slot 3	0.1445	0.1390	0.1520
		Slot 4	0.1400	0.1495	0.1630
	1000	Slot 1	0.1530	0.1690	0.1380
		Slot 2	0.1475	0.1710	0.1540
		Slot 3	0.1885	0.1785	0.1980
		Slot 4	0.1765	0.1950	0.2060
	8000	Slot 1	0.3384	0.3369	0.2554
		Slot 2	0.3209	0.3479	0.2909
		Slot 3	0.3799	0.4254	0.3654
		Slot 4	0.3599	0.3889	0.3679

Table 5.9. APA test results for WMA sample – Ohio DOT

			Rut Depth at Each Slot (in)		
		Specimen	A	B	C
Cycle	5	Slot 1	0.0000	0.0000	0.0000
		Slot 2	0.0000	0.0000	0.0000
		Slot 3	0.0000	0.0000	0.0000
		Slot 4	0.0000	0.0000	0.0000
	500	Slot 1	0.2120	0.2005	0.2075
		Slot 2	0.2180	0.2460	0.2285
		Slot 3	0.2210	0.2145	0.2045
		Slot 4	0.2300	0.1970	0.2045
	1000	Slot 1	0.2700	0.2610	0.2660
		Slot 2	0.2805	0.2939	0.2940
		Slot 3	0.2890	0.2635	0.2825
		Slot 4	0.2524	0.2540	0.2600
	8000	Slot 1	0.6609	0.5694	0.6139
		Slot 2	0.6284	0.6519	0.6484
		Slot 3	0.6659	0.5994	0.5804
		Slot 4	0.5739	0.5244	0.4854

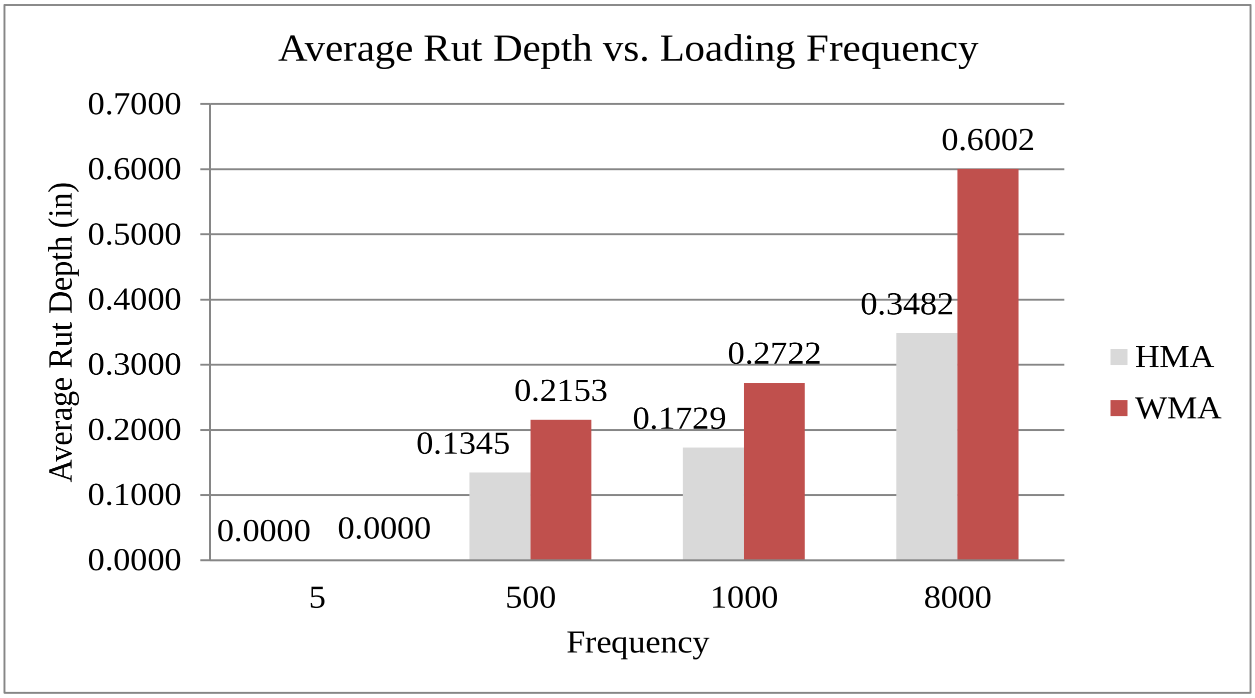

Figure 5.5. Comparison of WMA and HMA in APA test – Ohio DOT

Table 5.10. Average rut depth for HMA – Ohio DOT

		Average Rut Depth (in)			
	Specimen	A	B	C	Average of Samples
Cycle	5	0.0000	0.0000	0.0000	0.0000
	500	0.1333	0.1373	0.1329	0.1345
	1000	0.1664	0.1784	0.1740	0.1729
	8000	0.3498	0.3748	0.3199	0.3482

Table 5.11. Average rut depth for WMA – Ohio DOT

		Average Rut Depth (in)			
	Specimen	A	B	C	Average of Samples
Cycle	5	0.0000	0.0000	0.0000	0.0000
	500	0.2203	0.2145	0.2113	0.2153
	1000	0.2730	0.2681	0.2756	0.2722
	8000	0.6323	0.5863	0.5820	0.6002

As the results show WMA sample have higher rut depth compared to HMA in all frequencies and at 8000 the rut depth of WMA is about twice of HMA, being more than 15.2 mm which could be of concern.

5.3. Moisture Susceptibility Test Results

5.3.1. Results of study on Evotherm, Rediset, and Cecabse RT by Georgia DOT

Table 5.12. TSR values for HMA – Georgia DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Binder Content%	5.46	5.46	5.46	5.46	5.46	5.46
Voids (%)	7.077	7.823	7.485	7.355	7.444	7.191
Gmb (no units)	2.316	2.298	2.306	2.309	2.307	2.313
Stability lbs.	3886	3847	3967	3880	4415	4447
Spec. Ht. (mm)	95.0	95.0	95.1	95.0	95.0	95.0
Tensile Strength psi	110.237	109.131	112.417	110.067	125.244	126.152
	Average Tensile Strength		110.6	Average Tensile Strength		120.5
	Average Air Voids		7.5	Average Air Voids		7.3
	Average Gmb		2.307	Average Gmb		2.310
	TSR % (80% min.)		108.94			

Table 5.13. TSR values for Evotherm – Georgia DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Binder Content%	5.81	5.81	5.81	5.81	5.81	5.81
Voids (%)	7.156	6.628	6.882	6.801	6.774	6.749
Gmb (no units)	2.301	2.315	2.308	2.310	2.311	2.312
Stability lbs.	3384	2836	2803	3578	3215	3693
Spec. Ht. (mm)	95.0	95.0	95.1	95.0	95.0	95.0
Tensile Strength psi	95.997	80.451	79.431	101.500	91.202	104.762
	Average Tensile Strength		85.3	Average Tensile Strength		99.2
	Average Air Voids		6.9	Average Air Voids		6.8
	Average Gmb		2.308	Average Gmb		2.311
	TSR % (80% min.)		116.25			

Table 5.14. TSR values for Rediset – Georgia DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Binder Content%	5.88	5.88	5.88	5.88	5.88	5.88
Voids (%)	6.671	7.006	6.704	6.549	6.757	7.026
Gmb (no units)	2.324	2.315	2.323	2.327	2.322	2.315
Stability lbs.	3133	2499	2506	3163	3127	3191
Spec. Ht. (mm)	95.0	95.0	95.1	95.0	95.0	95.0
Tensile Strength psi	88.876	70.891	71.015	89.727	88.706	90.522
	Average Tensile Strength		76.9	Average Tensile Strength		89.7
	Average Air Voids		6.8	Average Air Voids		6.8
	Average Gmb		2.321	Average Gmb		2.321
	TSR % (80% min.)		116.54			

Table 5.15. TSR values for CECABASE RT – Georgia DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Binder Content%	5.83	5.83	5.83	5.83	5.83	5.83
Voids (%)	6.815	6.777	6.875	6.805	6.870	6.731
Gmb (no units)	2.308	2.309	2.307	2.308	2.307	2.310
Stability lbs.	3268	2695	2597	3208	3054	3020
Spec. Ht. (mm)	95.0	95.0	95.1	95.0	95.0	95.0
Tensile Strength psi	92.706	76.451	73.594	91.004	86.635	85.671
	Average Tensile Strength		80.9	Average Tensile Strength		87.8
	Average Air Voids		6.8	Average Air Voids		6.8
	Average Gmb		2.308	Average Gmb		2.308
	TSR % (80% min.)		108.47			

Table 5.16. Comparison of average tensile strength and TSR – Georgia DOT

	Average Tensile Strength (psi)		
	Unconditioned	Conditioned	TSR (%)
HMA	110.595	120.488	108.9
Evotherm	85.293	99.155	116.3
Rediset	76.927	89.652	116.5
Cecabase	80.917	87.770	108.5

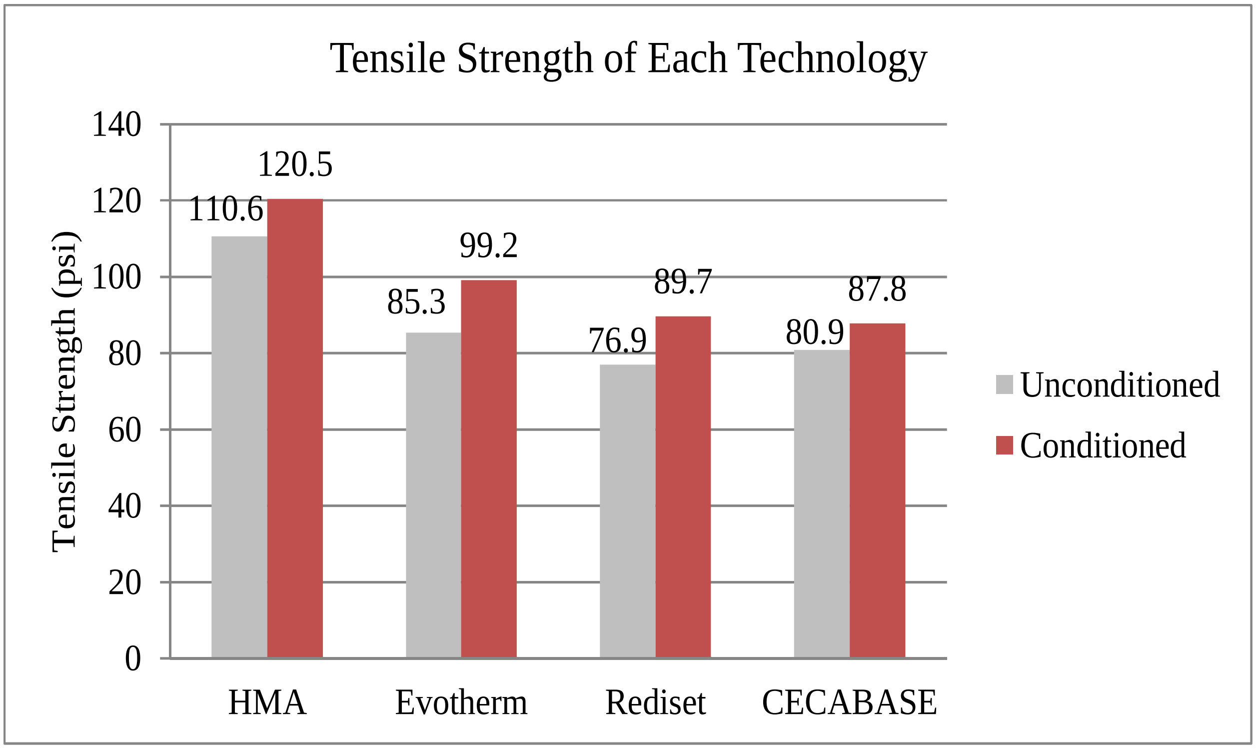

Figure 5.6. Comparison of tensile strength of sections - Georgia DOT

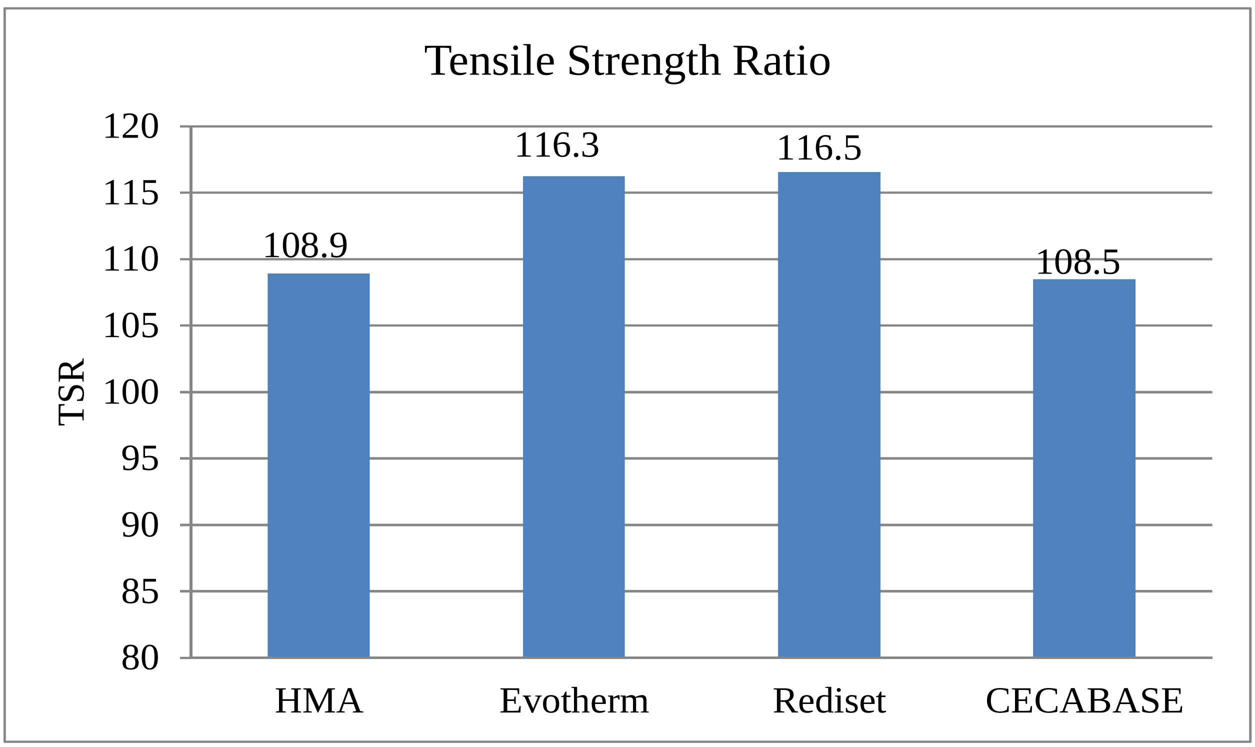

Figure 5.7. Comparison of TSR of sections - Georgia DOT

The results of this study conducted by Georgia DOT were unexpected in all aspects. Conditioned samples had higher tensile strength of unconditioned samples which is not normally observed, furthermore of the three WMA technologies two (Evotherm and Rediset) showed higher TSR values of HMA. The only results which were same as what was expected was that HMA sample had higher tensile strength compared to their WMA counterparts. An explanation for these results is that with fine or tender mixes conditioning could actually stiffen the samples resulting in TSR values higher than 100%.

5.3.2. Results of study on Evotherm and Sasobit by Iowa DOT

As discussed earlier, TSR values of 6 cores taken from each of the three sections were calculated. The results could be found in the following tables and graphs.

Table 5.17. TSR values for HMA – Iowa DOT

	Conditioned			Unconditioned		
Specimen	1	3	4	2	5	6
Gmb (no units)	2.265	2.267	2.264	2.261	2.273	2.263
Voids (%)	6.971	6.889	7.012	7.135	6.642	7.053
Vol. Voids (in^3)	116.911	115.354	117.663	119.873	111.075	118.422
SSD Wt. (lb)	3890.5	3885.5	3891			
% Sat. (70-80%)	77.923	77.327	78.105			
Load lbs.	2636	2766	2777	3205	3404	3265
Spec. Ht. (in.)	3.799	3.799	3.799	3.799	3.799	3.799
Tensile Strength psi	74.827	78.517	78.830	90.979	96.628	92.682
	Average Tensile Strength		77.4	Average Tensile Strength		93.4
	Average Air Voids		7.0	Average Air Voids		6.9
	Average Gmb		2.265	Average Gmb		2.266
				TSR (80% min.)		82.8

Table 5.18. TSR values for Evotherm – Iowa DOT

	Conditioned			Unconditioned		
Specimen	1	2	3	4	5	6
Gmb (no units)	2.249	2.246	2.249	2.247	2.249	2.245
Voids (%)	6.891	7.015	6.891	6.974	6.891	7.056
Vol. Voids (in^3)	116.352	118.779	116.428	117.980	116.386	119.430
SSD Wt. (lb)	3890.8	3895.2	3890.9			
% Sat. (70-80%)	79.844	77.455	78.676			
Load lbs.	2285	2345	2369	3391	3477	3584
Spec. Ht. (in.)	3.831	3.831	3.831	3.831	3.831	3.831
Tensile Strength psi	64.330	66.019	66.695	95.468	97.889	100.901
	Average Tensile Strength		65.7	Average Tensile Strength		98.1
	Average Air Voids		6.9	Average Air Voids		7.0
	Average Gmb		2.248	Average Gmb		2.247
				TSR (80% min.)		67.0

Table 5.19. TSR values for Sasobit– Iowa DOT

	Conditioned			Unconditioned		
Specimen	1	2	3	4	5	6
Gmb (no units)	2.286	2.280	2.285	2.279	2.280	2.284
Voids (%)	6.783	7.027	6.824	7.068	7.027	6.864
Vol. Voids (in^3)	112.899	117.190	113.605	117.933	117.302	114.264
SSD Wt. (lb)	3885.7	3887.8	3887.2			
% Sat. (70-80%)	71.037	73.300	73.676			
Load lbs.	2564	2425	2681	3406	3511	3387
Spec. Ht. (in.)	3.780	3.780	3.780	3.780	3.780	3.780
Tensile Strength psi	73.162	69.196	76.501	97.188	100.184	96.646
	Average Tensile Strength		73.0	Average Tensile Strength		98.0
	Average Air Voids		6.9	Average Air Voids		7.0
	Average Gmb		2.284	Average Gmb		2.281
				TSR (80% min.)		74.4

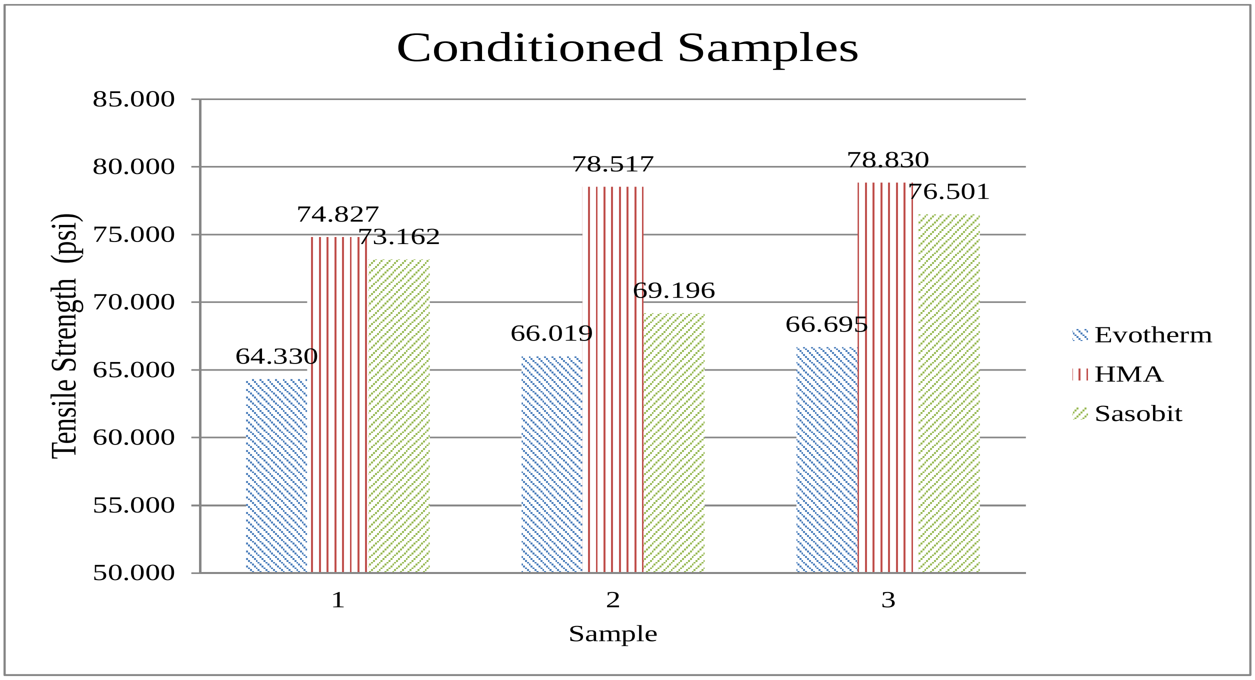

Figure 5.8. Comparison of Tensile Strength of conditioned samples – Iowa DOT

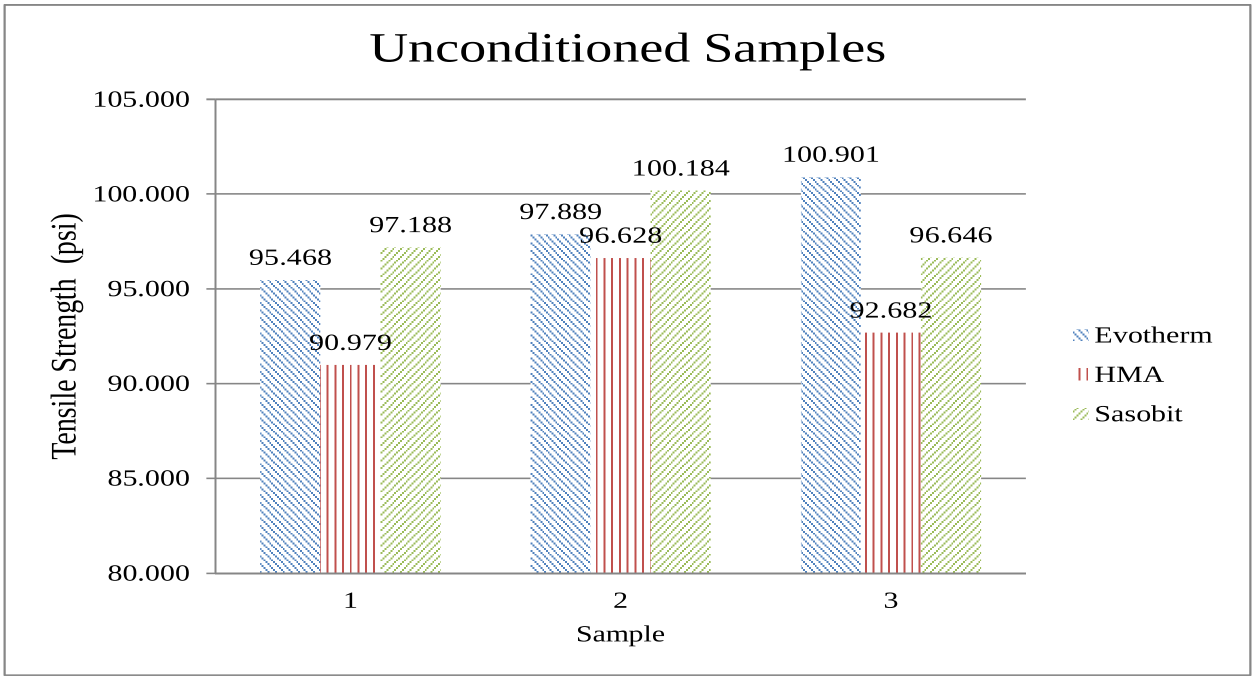

Figure 5.9. Comparison of Tensile Strength of unconditioned samples – Iowa DOT

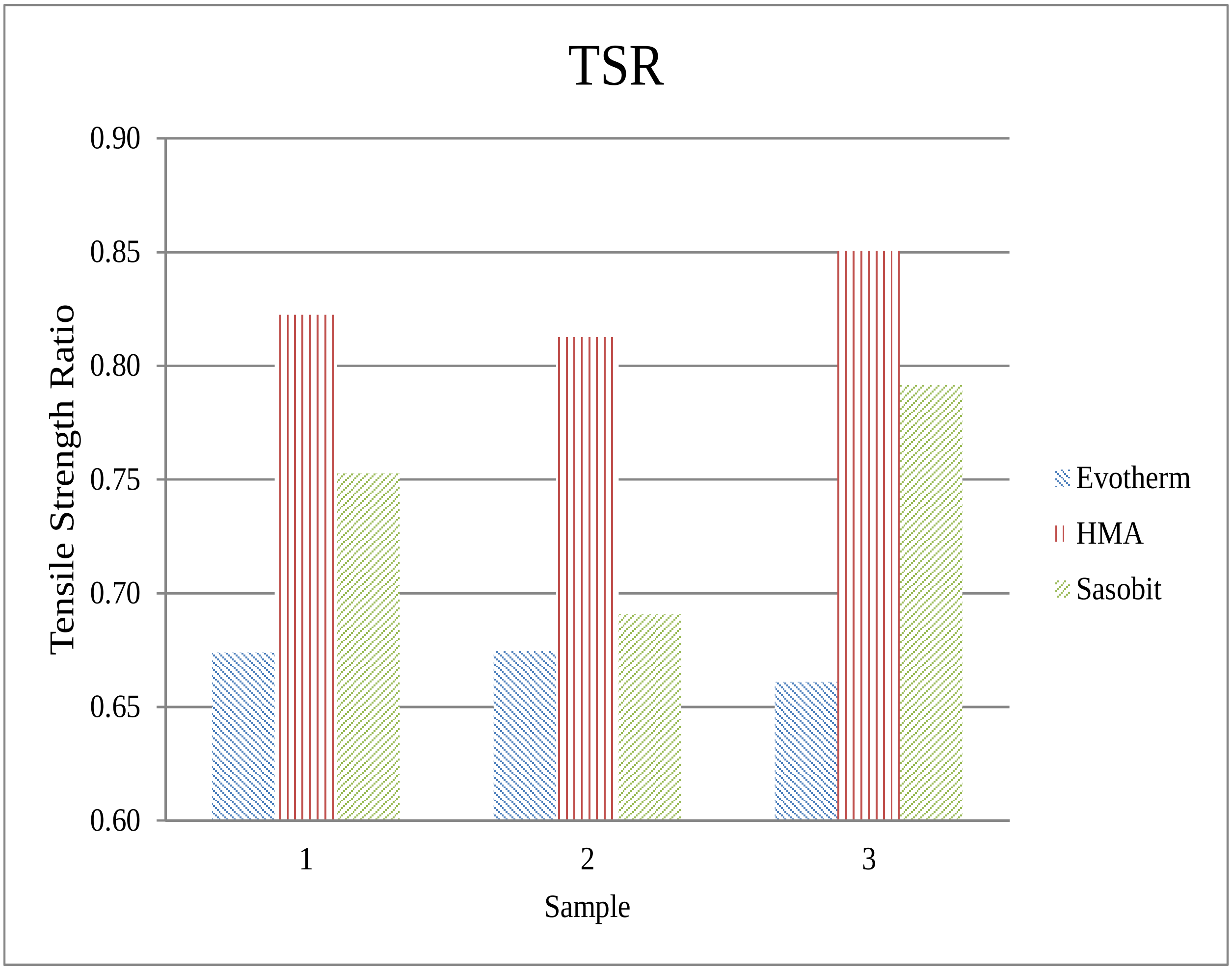

Figure 5.10. Comparison of TSR of each section – Iowa DOT

As the test results show, and considering a minimum TSR value of 0.8 required for this test to ensure the mixture is not susceptible to moisture, none of the two WMA mixes satisfy this requirement although Sasobit has a better performance than Evotherm. None of the samples from the WMA mixes passed the requirement and this verifies a main concern regarding moisture susceptibility of WMA as long as it is produced at lower temperature the chances of water remaining in the mix is higher. What is note worthy here is that unconditioned samples of WMA have higher tensile strength than the control samples (HMA) but the conditioned ones have lower strength.

5.3.3. Results of study on Advera, CECABASE RT, and Sasobit by Michigan

Table 5.20. Performance of Advera in T 283 test – Michigan DOT

Sample	Dry Tensile Strength	Moist. Tensile Strength	TSR
HMA	717	651	0.91
0.15 Advera 130	395	258	0.65
0.25 Advera 130	370	346	0.94
0.35 Advera 130	399	386	0.97
0.15 Advera 115	399	372	0.93
0.25 Advera 115	406	360	0.89
0.35 Advera 115	389	323	0.83
0.15 Advera 100	1038	740	0.71
0.25 Advera 100	628	549	0.87
0.35 Advera 100	447	360	0.81

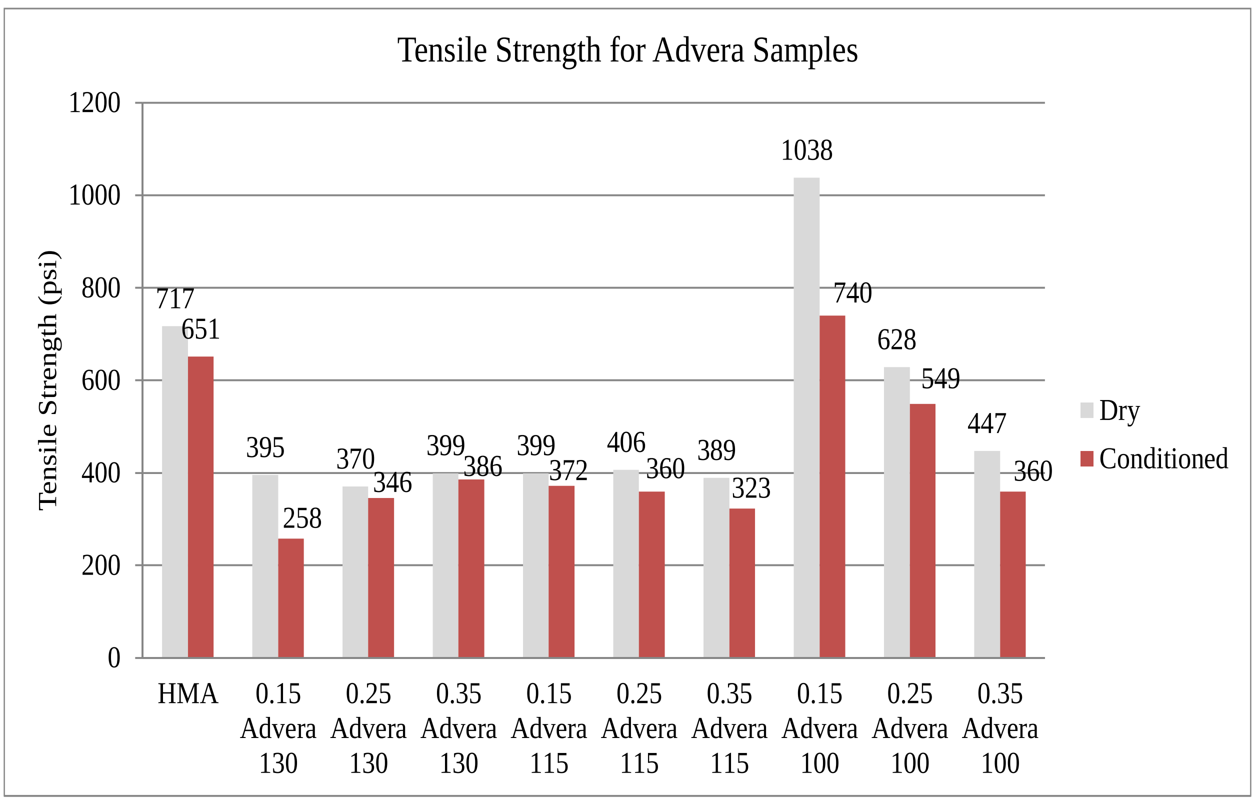

Figure 5.11. Tensile strength of Advera – Michigan DOT

Table 5.21. Performance of Sasobit in T 283 test – Michigan DOT

Sample	Dry Tensile Strength (psi)	Moist. Tensile Strength (psi)	TSR
HMA	717	651	0.91
0.5 Sasobit 130	430	449	1.04
1.5 Sasobit 130	436	432	0.99
3 Sasobit 130	447	422	0.94
0.5 Sasobit 115	421	386	0.92
1.5 Sasobit 115	429	397	0.93
3 Sasobit 115	452	419	0.93
0.5 Sasobit 100	592	538	0.91
1.5 Sasobit 100	421	378	0.90
0.5 Sasobit 100	393	337	0.86

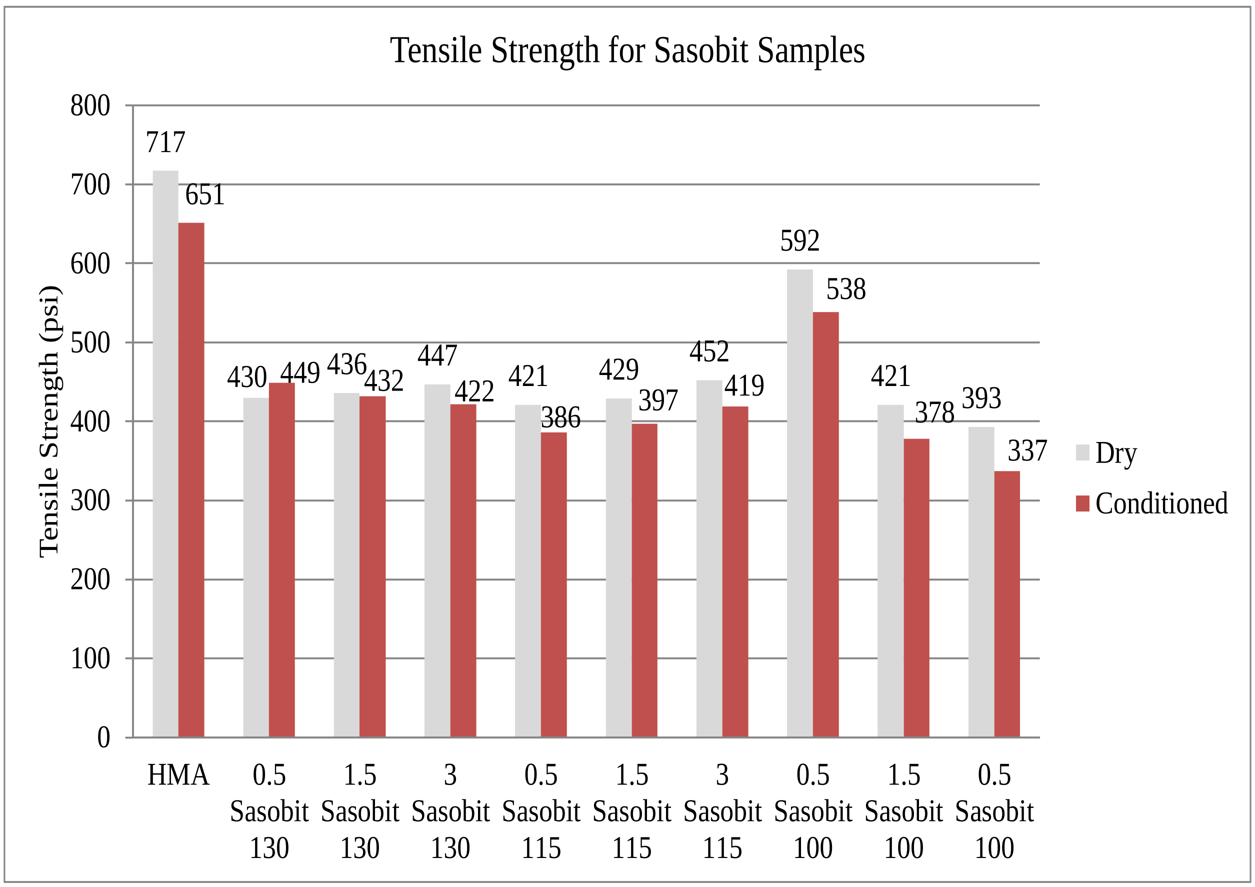

Figure 5.12. Tensile strength of Sasobit – Michigan DOT

Table 5.22. Performance of Sasobit in T 283 test – Michigan DOT

Sample	Dry Tensile Strength (psi)	Moist. Tensile Strength (psi)	TSR
HMA	717	651	0.91
0.2 Ceca 130	512	534	1.04
0.35 Ceca 130	503	521	1.04
0.5 Ceca 130	513	489	0.95
0.2 Ceca 115	414	408	0.99
0.35 Ceca 115	512	472	0.92
0.5 Ceca 115	522	463	0.89
0.2 Ceca 100	426	391	0.92
0.35 Ceca 100	609	570	0.94
0.5 Ceca 100	420	430	1.02

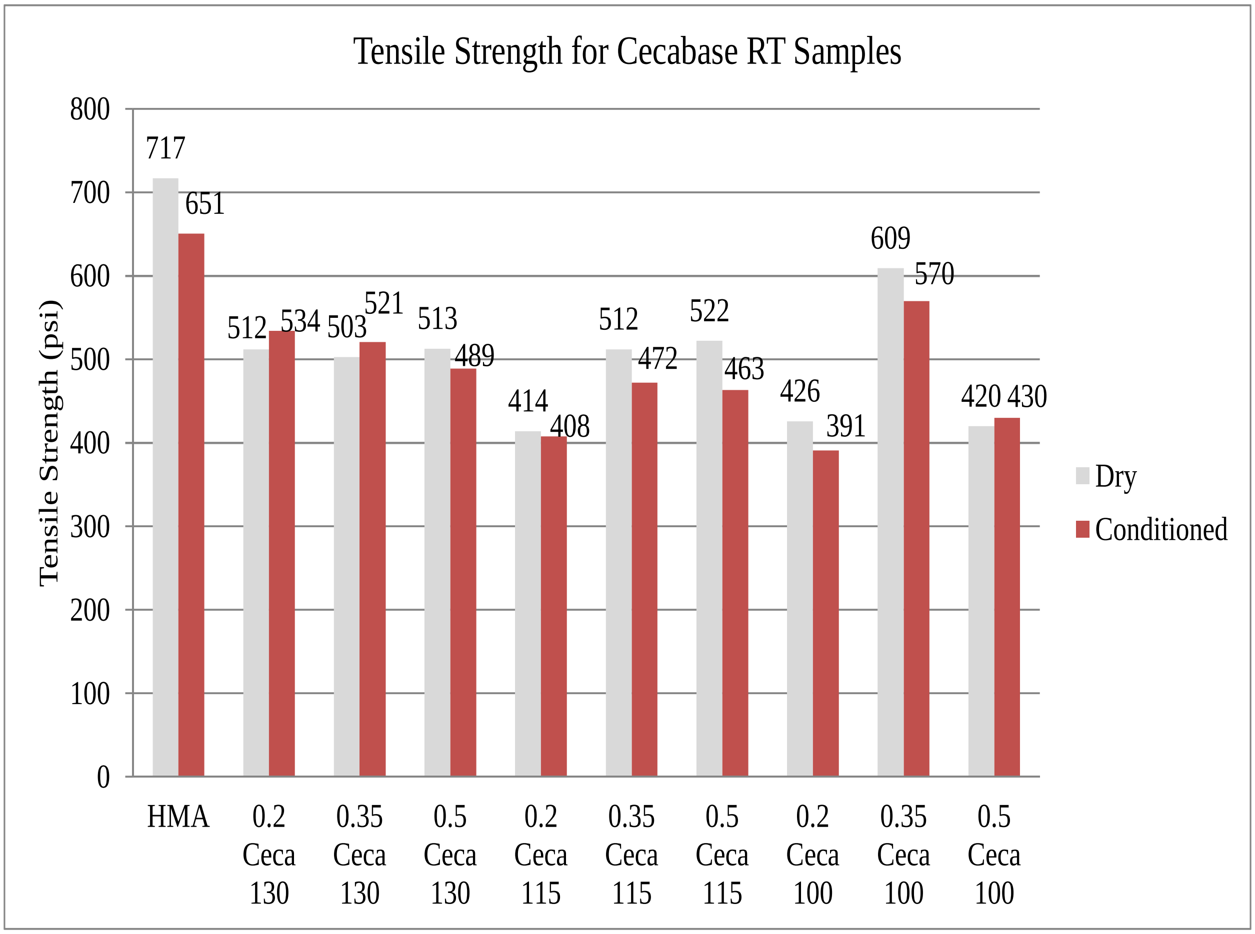

Figure 5.13. Tensile strength of CECABASE RT – Michigan DOT

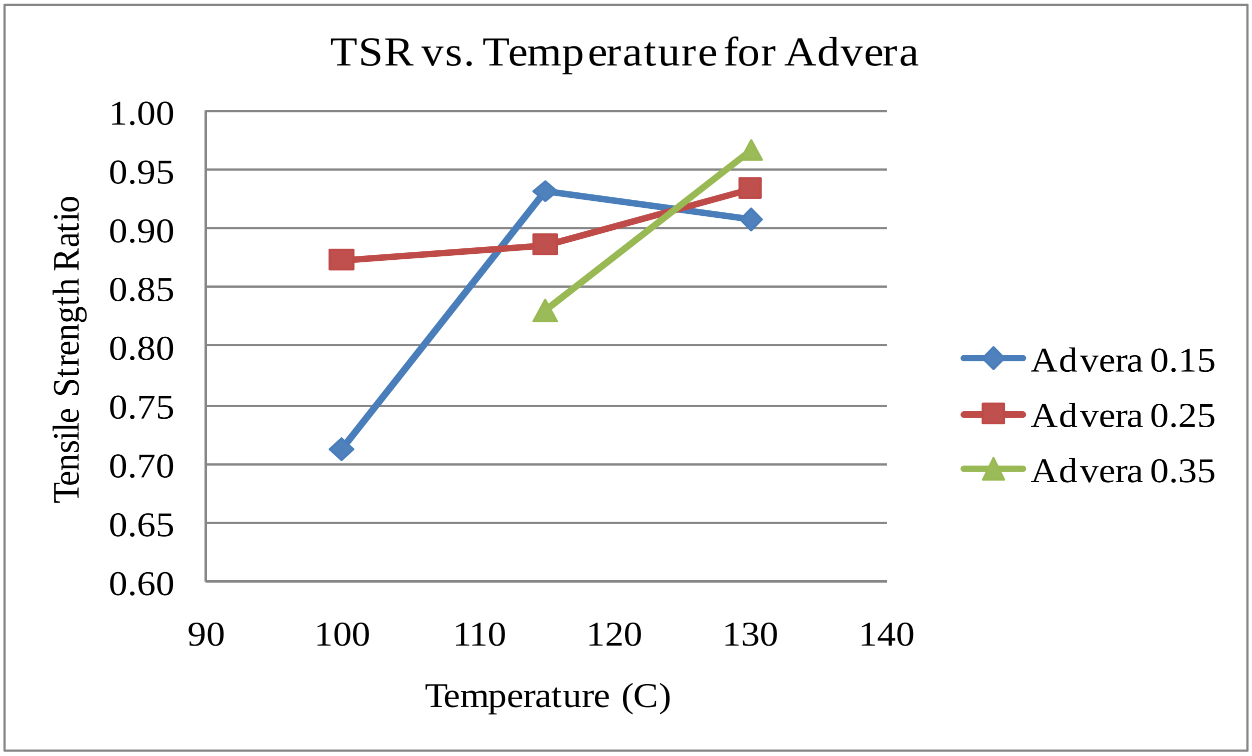

Figure 5.14. TSR vs. Temperature for Advera – Michigan DOT

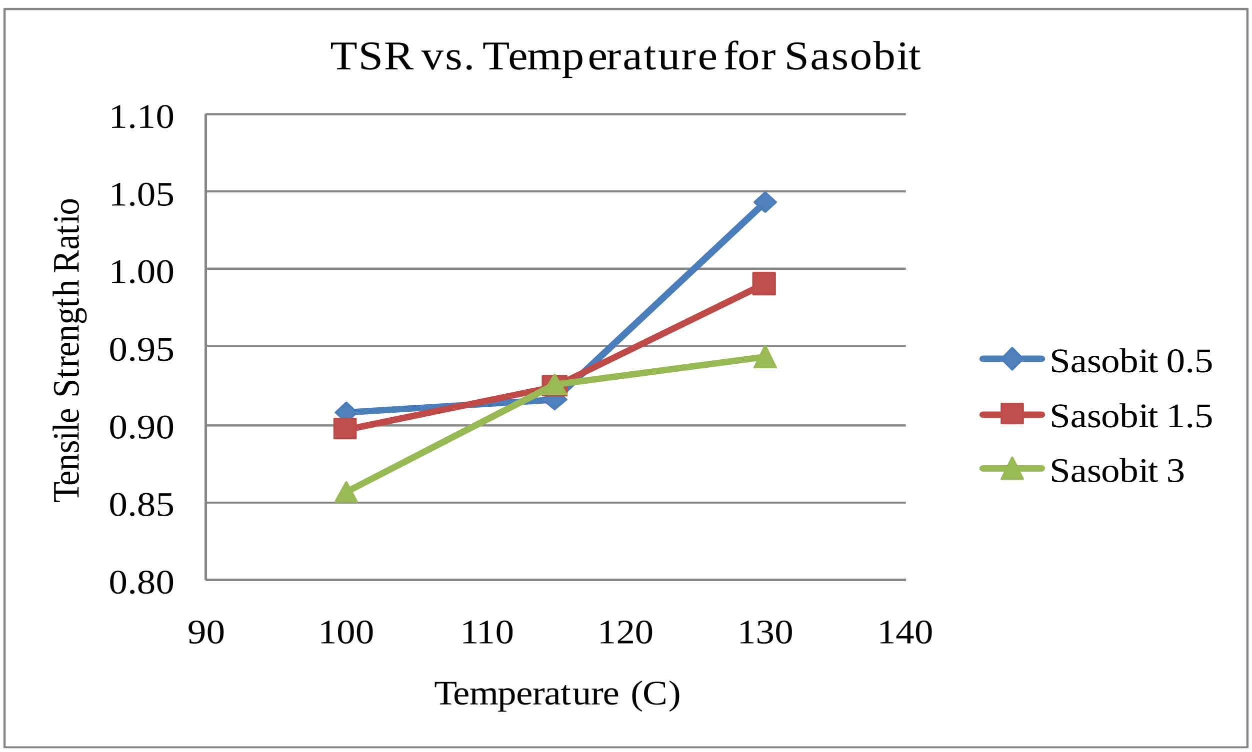

Figure 5.15. TSR vs. Temperature for Sasobit – Michigan DOT

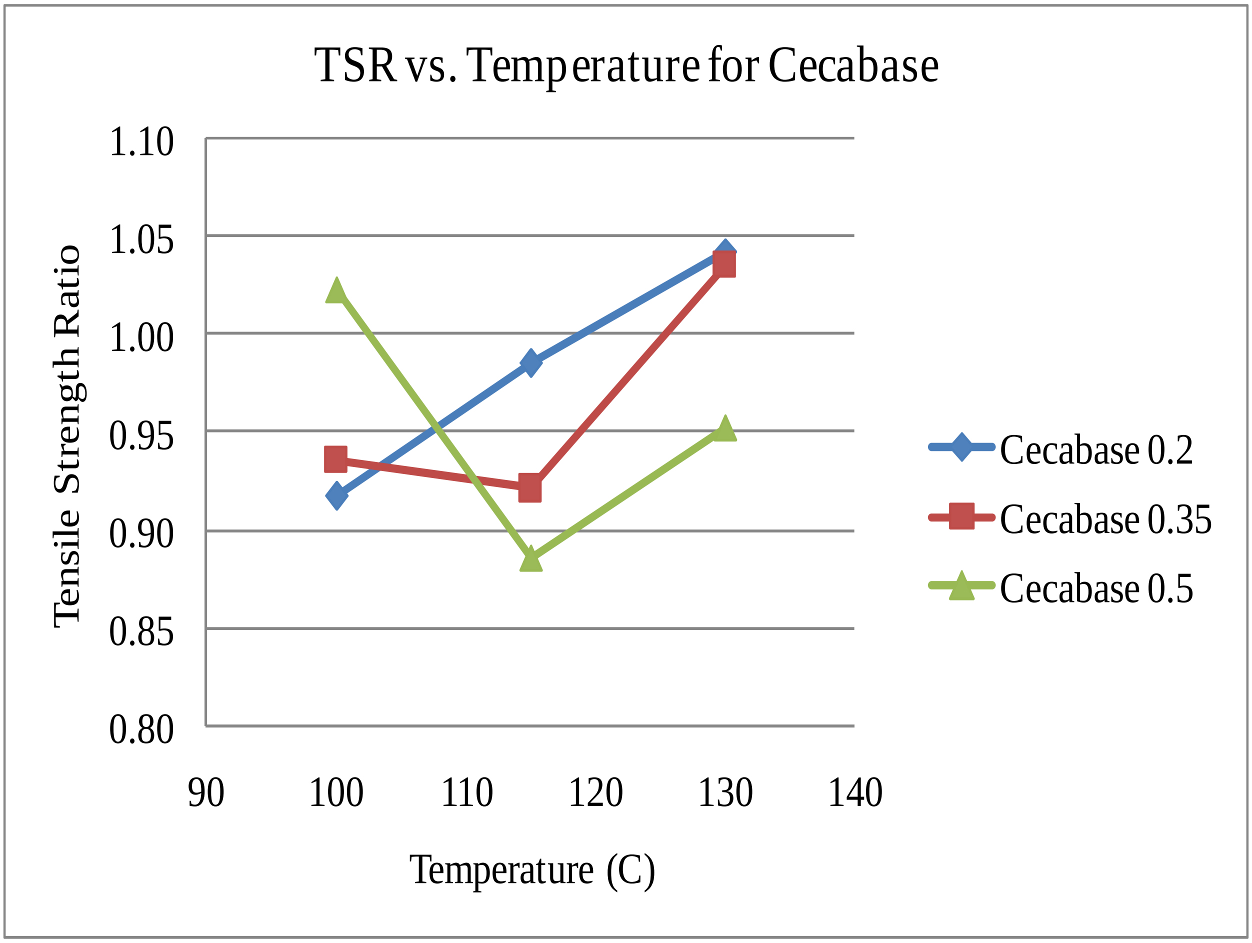

Figure 5.16. TSR vs. Temperature for CECABASE – Michigan DOT

The results could be discussed from two viewpoints: tensile strength of WMA compared to HMA and TSR values of WMA vs. HMA. The results show that in almost all cases tensile strength of WMA sample were lower than HMA control (in some cases much lower) which could be of concern. The TSR values shows good acceptable performance (above 0.8 in all cases except two: 0.15Advera130 and 0.15Advera100 which makes it safe to say that according to the test results of this study moisture susceptibility of WMA mixtures are acceptable and comparable to HMA. Further attention to the graphs shows in increase in temperature of testing results in an increase of TSR values for all three WMA technologies tested which is expected.

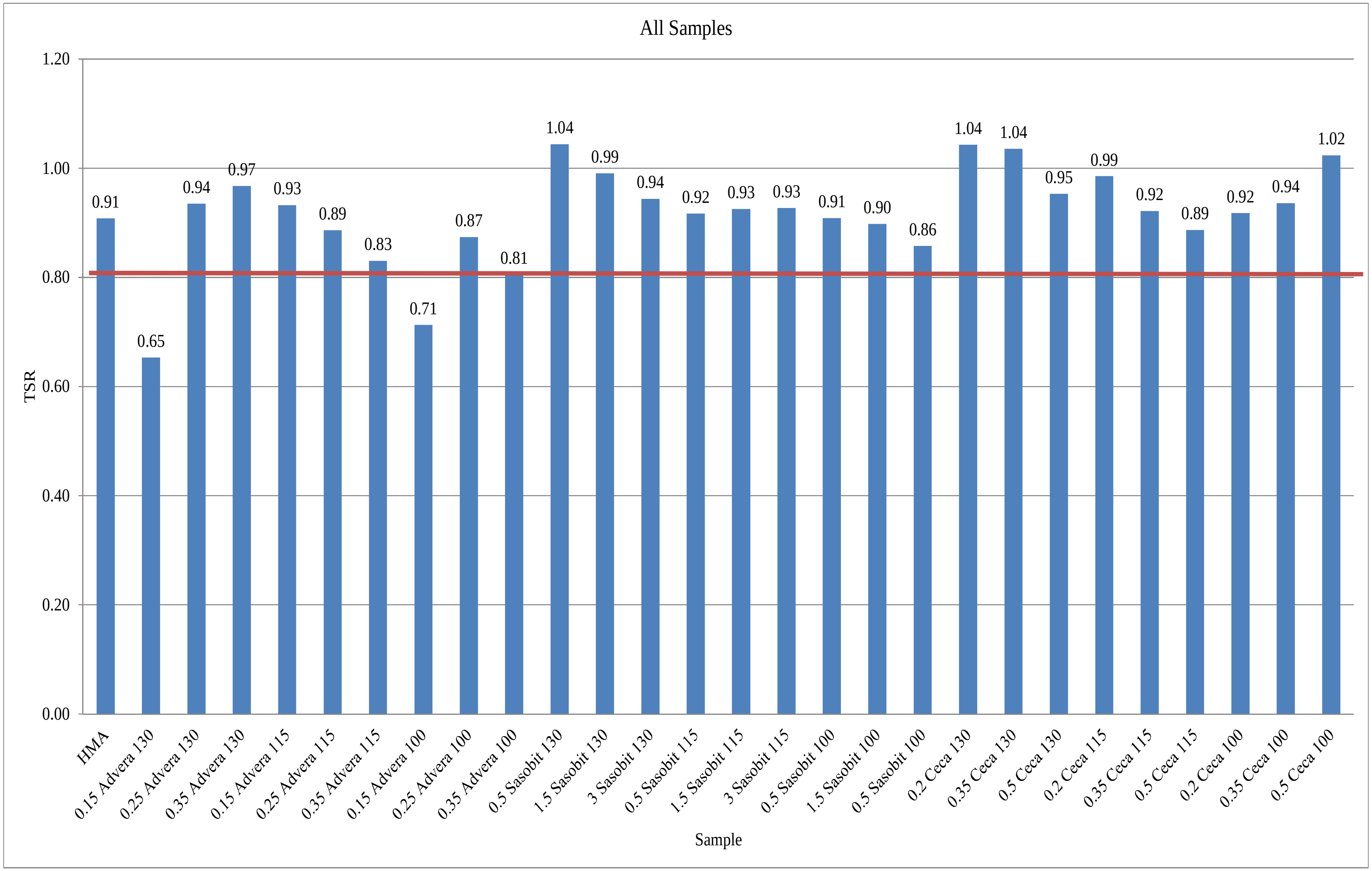

Figure 5.17. TSR values for all samples – Michigan DOT

5.3.4. Results of study on Foamed WMA by Ohio DOT

Table 5.23. Moisture Susceptibility of HMA samples – Ohio DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Voids (%)	6.6	7.5	6.5	6.6	6.6	7.5
Gmb (no units)	2.405	2.405	2.405	2.247	2.247	2.225
Stability (lbs)	2219	2208	2152	1900	1970	1852
Spec. Ht. (in)	2.70	2.71	2.68	2.67	2.68	2.69
Tensile Strength psi	130.8	129.7	127.8	113.3	117.0	109.6
	Average Tensile Strength		129.4	Average Tensile Strength		113.3
	Average Air Voids		6.9	Average Air Voids		6.9
	Average Gmb		2.405	Average Gmb		2.240
	TSR % (80% min.)		87.54			

Table 5.24. Moisture Susceptibility of WMA Samples – Ohio DOT

	Unconditioned			Conditioned		
Specimen	1	2	3	4	5	6
Voids (%)	7.1	7.0	6.8	7.3	6.8	7.1
Gmb (no units)	2.225	2.228	2.233	2.220	2.233	2.227
Stability (lbs)	1953	1958	1826	1673	1743	1531
Spec. Ht. (in)	2.73	2.70	2.73	2.72	2.71	2.71
Tensile Strength psi	113.9	115.4	106.5	97.9	102.4	89.9
	Average Tensile Strength		111.9	Average Tensile Strength		96.7
	Average Air Voids		7.0	Average Air Voids		7.1
	Average Gmb		2.229	Average Gmb		2.227
	TSR % (80% min.)		86.42			

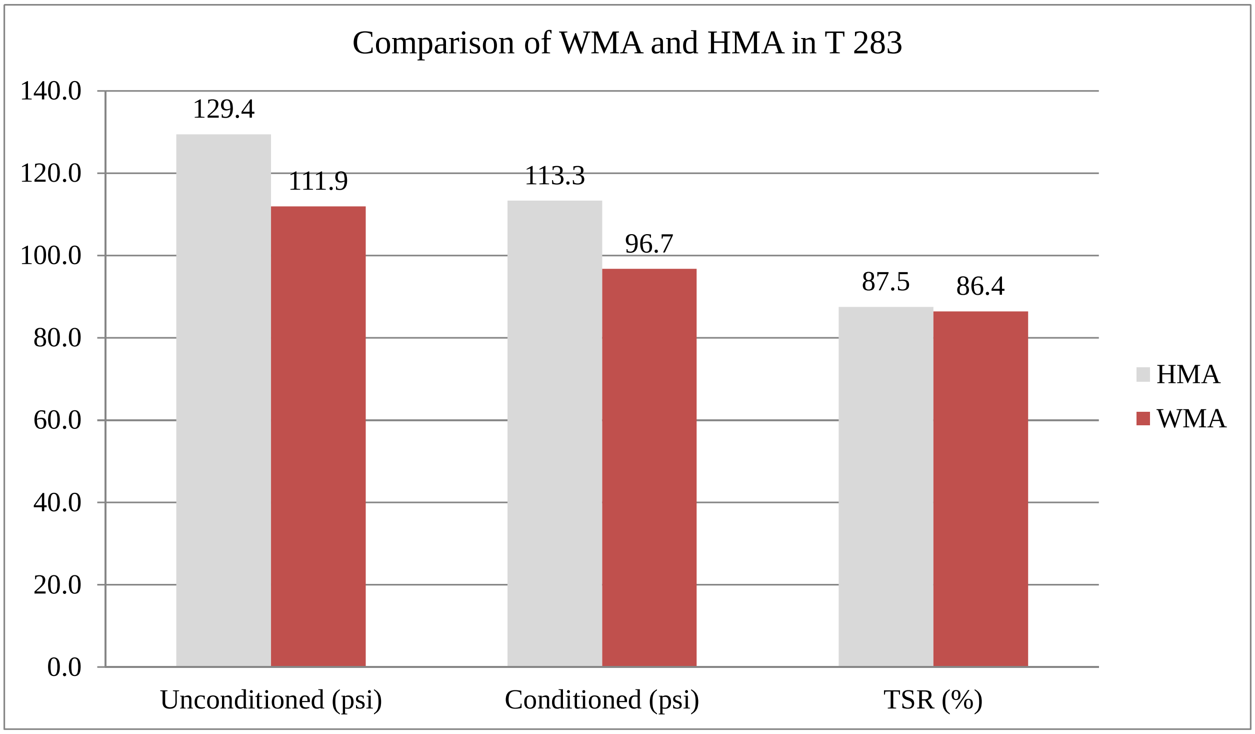

Figure 5.18. Comparison of WMA and HMA in T 283 test– Ohio DOT

The test results show good performance of foamed WMA compared to HMA. Close tensile strength of conditioned and unconditioned WMA with their HMA counterparts is interesting. HMA and WMA have close TSR values (87.5 vs. 86.4) and both satisfy the requirement of minimum 80% suggested by T 283. Therefore performance of WMA prepared by foaming is totally acceptable and similar to HMA according to this study.

5.4. Summary

In this chapter rutting and moisture susceptibility were introduced as two important issues to be considered in application of WMA. WMA is produced at lower temperatures therefore asphalt is not aged as much as HMA, furthermore additives cause the binder to behave softer. These two result in WMA mixtures to be more flexible and more flowable than HMA (in theory) resulting in conclusion that WMA should have higher rutting depth (permanent deformation).

Many studies are focused on comparison of WMA and HMA in rutting and a few whose data were available were analyzed and discussed in chapter. Test results of study conducted by Georgia DOT shows that Evotherm, Rediset, and Cecabse have rutting performance similar to the HMA control section specially Rediset and Cecabse (rut values of 5.79 and 5.93 compared to 5.78 for HMA). Among the three WMA technologies tested, Evotherm had the highest value but still was in the acceptable region for rut depth. Study on rutting performance of WMA conducted in North Dakota on Evotherm resulted in similar results, although WMA samples consistently had higher values of rut depth but still the results were within the acceptable range. Study on foamed asphalt conducted in Ohio showed high values of rutting depth for WMA, close to two times the rut depth for control HMA section and over the maximum limit for rutting which bring some concerns regarding WMA produced with their particular foaming device.

Lower mixing temperature of WMA could result in aggregates that are not totally dry which would results in a not perfect adherence between asphalt and aggregates. This water is also added directly in foamed WMA. Therefore stripping of aggregates from binder and failure of asphalt mixture structure is an issue that should be studied carefully. The results of Iowa experiment shows that sections constructed from Evotherm and Sasobit do not satisfy the requirement of minimum 0.8 in TSR. Therefore moisture susceptibility is a concern according to Iowa study. But the study at Michigan with Advera, Sasobit, and Cecabse showed that all the tested WMA technologies had acceptable performance (TSR higher than 0.8) except Advera at 0.15 dosage in two occasions (100 and 130 °C). It should be noted that in all cases WMA had lower tensile strength (dry or wet) compared to the HMA control. Foamed WMA studied by Ohio had similar performance with HMA in moisture test both having close TSR values.

Theoretically due to less aging of binder in WMA the mix is more flexible which is better for the long term performance and less fatigue is expected but not good for rutting. For moisture susceptibility adding water in foaming technologies and the unknown effect of chemical additives and waxes are the main concerns. As the data collected and analyzed in this chapter shows and according to the literature study conducted in the NDDOT report (Saboori, 2012) WMA performance in rutting and moisture susceptibility are comparable to HMA although there is not a high level of consistency in the results of different studies. This could be attributed to extensive number of technologies that are available, the reliability and performance of different technologies are not guaranteed and the sensitivity of each technology to the local conditions is not fully understood. Therefore it seems logical to locally test each technology prior to approval and monitor the performance to have a more secure approach to WMA.

CHAPTER 6. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Performance data of WMA in other states were collected and analyzed to be used in addition of survey results and literature study to recommend NDDOT approach to usage of WMA in their pavement projects. The project conducted literature study and collected data on the materials, construction and performance of WMA in neighboring states to determine the additives and processes that would perform best on NDDOT projects. Specific changes to current specifications and acceptance plans must follow manufacturer directions, lab testing, and field trials and performance.

6.1. Summary of Survey

Survey was designed to gather information, viewpoints, and experience of northern states' DOTs (due to similar climatic condition to North Dakota) regarding WMA. 24 questions were arranged in four 5 main categories: general observations, WMA technologies, mix design, specifications, and acceptance plan modifications.

In general observations sections, most DOTs preferred foaming processes and chemical additives rather than organic additives. Foaming processes initial costs are deemed high but in the long run the cost of additive (water) is very low compared to other types, therefore makes foaming processes favorable for the long run, on the other hand chemical additives normally do not require modifications to mix plant and have low initial cost but the cost of additives are higher. Although WMA would cost more in terms of additives and modifications to plant, saving in fuel cost and plant wear are addressed as advantage of WMA over HMA by the respondents. Regarding the yearly production, WMA production for most of the agencies was 5% to 20% of

HMA production of the states. In general, chemical additives advantages mentioned by the respondents were: adhesion promoter and improve compaction, easily replicated in the lab, utilization of higher percentages of RAP and RAS, and anti-stripping capabilities of chemical additives. Where for foaming processes: foaming installation costs are considered as a one-time, water will evaporate out of the mix and leave the asphalt intact with the least potential for changing asphalt properties, easier for a contractor to install on his hot plant, provides increased film thickness and compaction.

In WMA technologies section the results shows that in chemical additives, Evotherm™ is the most popular (29 projects out of total 32), the reduction in mixing temperature for chemical additives is mostly between 40-60ºF. The most significant distress observed for chemical additives is moisture damage (in 13 projects of 29 Evotherm projects). For foaming processes the most common technologies are the Double Barrel® Green, AQUABlack™, and Terex® WMA. Reductions in mixing temperature are mostly between 20-40ºF (foaming processes offer the lowest reduction values among WMA technologies). Of the three types of WMA technologies (chemical, foaming, and organic) most projects are conducted using foaming processes (122 projects, of which 44 was done using Double Barrel® Green). For organic additives Sasobit is the most common one and temperature reduction in mixing is between 20-40ºF.

Regarding modifications in mix design, agencies were asked about the modifications they have material selection, binder selection, aggregate structure design method, lab performance tests, required amount of anti stripping agents, and RAP and RAS requirements. Most agencies have no to minor modifications compared to their HMA specifications and are mostly preparing the samples according to the WMA manufacturer’s suggestion. Some minor modifications and comments in each category were: one of the agencies would adjust the binder content for the reduced absorption of WMA, in lab testing the specimens were required to be prepared at the temperature similar to field construction, for anti stripping agents most agencies had no modifications where only one agency required 1% to 1.5% lime to be added, RAP and RAS requirements were mostly similar expect for one agency that would not allow RAP in WMA mixes.

Regarding specifications and how the agencies have developed their specifications, 7 out of 21 respondents had separate specifications for WMA, 6 had list of approved processes and 6 had a procedure for approval of non-listed technologies. For developing their specifications agencies have based their effort on national reports and study, other states' specifications, and their own expertise.

In quality control and assurance aspects, agencies are mostly using the same specifications and methods they use for their HMA projects. The main difference is that lab testing and sample preparations are required to be done at temperatures similar to site construction and samples be made according to the same technology of WMA.

6.2. Summary and Conclusions of WMA Performance Data Analysis

Production of WMA at lower temperature has its advantages and disadvantages. Lower temperature means lower fuel cost and better stewardship towards environment. Additives that are used decrease viscosity of asphalt binder causing it to be more flexible than the binder with no additives at the same temperature which result in better workability of WMA mixtures. Lower compaction temperature means longer haul distances are possible for WMA as long as delivery temperature is not as sensitive as it is for HMA, also this allows to extend pavement projects more into cold seasons resulting in more time frame available for doing projects through the year. Considering all these advantages, the performance of WMA compared to HMA is still a big issue. Many studies have been conducted by researchers and agencies to study performance of WMA and many are still under investigation. Of many performance issues, rutting and moisture susceptibility are of more importance and have constantly been among issues under study in WMA. The reason behind this is the same facts that causes WMA advantages in construction raise concerns about its performance. WMA not being heated as much as HMA result in less aging of binder, moreover the additives help the binder in WMA mixes to always be more flowable and less viscous than the HMA counterpart. Rutting happens during early years of the service life of the pavement when asphalt mixture is not stiff enough and suffers permanent deformation under traffic. WMA mixes not being as stiff as HMA makes them easier to handle during construction and compaction but more susceptible to rutting. Regarding moisture susceptibility, as WMA mixtures are produced at lower temperatures, there is always this concern that aggregates are not fully dried and moisture still exists in the mixture that will lead to future separation of aggregates and binder around them and cause failure of the structure of the mix. This issue is more evident in foaming WMA mixes in which water is intentionally added to the mix.

As the collected data results show, the performance of WMA were satisfactory compared to HMA although in almost all cases WMA samples showed higher rutting values, lower tensile strength, and lower tensile strength ratios compared to HMA samples. Georgia experiment with Evotherm, Rediset, and Cecabse showed good performance of WMA mixtures in rutting specially for Rediset and Cecabse that had very close values compared to HMA. NDDOT study on Evotherm 3G showed WMA mixture had rut depth within acceptable range but higher than HMA control section. Ohio experience with foamed WMA resulted in high values of rutting, in some cases as high as twice as HMA control section. The results of moisture susceptibility tests were more alerting (WMA having satisfactory performance although HMA performance was better, except Georgia experiment which had contradictory results of TSR higher than 100% and WMA performing better). Iowa sections built with Evotherm and Sasobit did not satisfy the requirement of minimum 0.8 in TSR. The study at Michigan with Advera, Sasobit, and Cecabse showed that all the tested WMA technologies had acceptable performance (TSR higher than 0.8) except Advera at 0.15 dosage in two occasions (100 and 130 □C). It should be noted that in all cases WMA had lower tensile strength (dry or wet) compared to the HMA control. Foamed WMA studied by Ohio had similar performance with HMA in moisture test both having close TSR values.

6.3. Recommendations for WMA Implementation in North Dakota

6.3.1. NDDOT WMA Selection or Approval Process

Most DOTs develop their own list of approved WMA technologies. Not all technologies would succeed in ND considering extreme weather conditions as well as different petroleum resources. It is recommended that a short list of approved processes be developed that consists of those processes most frequently used in ND that have had acceptable performance. The list shall be updated on a routine basis. New technologies that have been successful in other states can be evaluated on a limited basis with the assistance of research effort. NAPA has had many pilot studies done in this regard whose publications could be used as a starting point subjected to further evaluation. It is recommended that NDDOT base their selection of approved processes on local evaluation including lab and field testing. NDSU WMA Report, Appendix C, (Saboori, 2012) provides approved list of processes of all states that have such list.

Additional specification requirements shall be added for each approved technology/additive based on local evaluation. As will be discussed later, the following areas will require testing modifications: temperature acceptance, moisture susceptibility, and binder selection. Further research will indicate the details of needed mix design modifications including lab mixing and compaction temperatures and aging requirements. Considering the fact that new technologies and methods of WMA production are coming out each year, developing an approval procedure for new WMA technologies is recommended. Samples of other states approval process are attached in NDSU WMA Report, Appendix C, (Saboori, 2012).

The trade-off between cost and performance among different WMA technologies must be based on life-cycle-cost analysis that is based on long-term performance monitoring of different WMA technologies. Added cost of WMA is based on contractors' practices and decisions to use specific technology/equipment. At this time, a suggestion by a contractor to use a specific technology may not be acceptable because NDDOT must first adopt practices and specifications for WMA technologies.

6.3.2. Additives or Processes Appropriate for Use on NDDOT Projects

Most DOTs have had experiences with foamed processes and chemical additives while use of organic additives has been limited. DOTs of northern states are at early stages of experimenting with WMA and in most cases they have minimum modifications in their WMA specs and testing compared to HMA and are mainly following manufacturer's recommendation. The suggestions of NCHRP 691 study on WMA mix design are mostly directed toward agencies' preferences and implementation based on local testing and experiments. NDDOT experience with foaming technologies will be expanded with future new projects. It is too early to judge which process seems to be more suitable.

The following recommendations are made based on the survey results: the survey results show that foaming processes are most favored (among which Double Barrel Green is the most widely used) and after that are chemical processes (with Evotherm being mostly used). This could be a good starting point for NDDOT although the importance of local testing and evaluation in the actual climatic condition cannot be neglected; the advantage of using the Double Barrel and Evotherm is that as long as other DOTs are years ahead in laying down their WMA sections, updates of the performance of other projects could be of use for NDDOT.

6.3.3. Specification Changes for WMA Compared to HMA

This study provides details current WMA specifications and documents experience of other states in implementing WMA technologies. Following the survey conclusions that most states do not require additional testing for WMA projects as compared to HMA project, no immediate changes to current acceptance testing are recommended. But specific concerns are considered for future WMA implementation. The main items of concern of WMA future specifications that must be evaluated based on local conditions are: (1) temperature control, (2) moisture sensitivity, and (3) selection of binder grade. A key element in WMA future implementation is testing applicability for production and acceptance quality. Special effort should be directed to the verification of the applicability of current HMA testing on WMA mixes. There is also the possibility of conducting local testing to verify characteristics of new technologies and requirements for new specifications.

Specific changes to current specifications and acceptance plans must follow manufacturer directions, lab testing, and field trials and performance. Research at the early stages of WMA implementation would evaluate the steps and practices by other DOTs in using manufacturer's recommendation in mix design and construction. Lab studies on mix design and evaluation at lowered temperatures will help evaluate different technologies and additives. Comparisons of mix performance of different additives, for example moisture susceptibility, in the lab will help verify/develop special requirements and specifications for WMA as compared to HMA specifications. Testing equipment shall not be altered or changed as long as all DOTs are using the same testing equipment they use for HMA. The same note is advised in NCHRP 691, but some of the requirements could be modified such as TSR acceptance values.

Based on the survey results and the review of current research, selection of WMA binder grades may need revisions, particularly for softer binders that will not be aged enough during the mix production and construction stages. Moisture susceptibility testing and acceptance criteria will be close to that of HMA but more restrictive. NCHRP study also showed that HMA and WMA performance were similar and not much modification is required. What is inevitable is the construction of test sections and the running of lab experiments on selected WMA technologies that are to be implemented. Projects with high traffic are more likely to have modified binder grading but considering current knowledge there is not enough information to recommend changes related to moisture testing requirements. The survey suggests that anti stripping or lime is being used by most agencies.

It is recommended to take one step at a time and not to rush into using RAP and RAS as long as full performance of WMA using conventional ingredients is not fully understood. Although RAP use shall not be neglected in pavement projects due to environmental and sustainability concerns, it is not beneficial to add another element to our experiment that increases the complexity. It is also recommended that NDDOT sponsor well designed experiments and extensive lab research on the performance of WMA constructed using local aggregates and laid in ND climate.

6.4. Recommendations for Future Research

The widespread demand for Warm Mix Asphalt in North America requires more in-depth information on materials, additives, testing plans, and mix design considerations. As discussed earlier, additional testing requirements are recommended in the following areas: temperature acceptance, moisture susceptibility, and binder selection. Further research will indicate the details of needed mix design modifications including lab mixing and compaction temperatures and aging requirements. Additional studies are recommended in the following areas:

6.4.1. Applicability of HMA Testing on WMA

The objective of the proposed study is to examine the applicability of current hot mix testing, including Superpave testing, on warm mixes and the potential to accurately characterize moisture susceptibility. Laboratory study to evaluate the moisture susceptibility of plant-produced warm mix asphalt (WMA) is proposed. WMA mixture samples will be obtained at asphalt plant and compared to hot-mix asphalt (HMA) samples through laboratory performance tests. In addition to traditional AASHTO T283 freeze and thaw (F-T) and tensile strength ratio (TSR), Superpave indirect tension (IDT) tests, dynamic modulus test, Asphalt Pavement Analyzer (APA), and Hamburg wheel tracking test are recommended to evaluate asphalt mixtures subjected to F-T moisture conditioning.

6.4.2. Comparison of Moisture Susceptibility of WMA Technologies

The objective of this study is to compare the moisture susceptibility of the two widely used warm-mix asphalt (WMA) approaches: foaming and emulsion technologies. It is recommended that the study evaluates the constructability of both technologies through monitoring trial pavement sections of the two WMA technologies and their hot-mix asphalt (HMA) counterpart. Plant-mixed loose mixtures from the field will be collected at the time of paving and will be evaluated in the laboratories by conducting various experimental evaluations of the individual mixtures. Recommended testing includes AASHTO T283 freeze and thaw (F-T) and tensile strength ratio (TSR), Superpave indirect tension (IDT) tests, dynamic modulus test, Asphalt Pavement Analyzer (APA), and Hamburg wheel tracking test. The testing will be focused on susceptibility of WMA to moisture conditioning as compared to the HMA controls. Early-stage field performance data will be collected for years after placement to confirm rutting and cracking performance from both the WMA and HMA sections, and that field data agree with laboratory evaluations.

6.4.3. Laboratory Evaluation of WMA containing High Percentages of RAP

The objective of this study is to evaluate the rutting resistance, moisture susceptibility, and fatigue resistance of warm-mix asphalt (WMA) mixtures containing high percentages of reclaimed asphalt pavement (RAP) through laboratory performance tests. WMA mixtures can be plant produced, with selected foaming technologies in the US. RAP content will range from 0 to 60%. Laboratory performance tests include asphalt pavement analyzer (APA) rutting test, Hamburg wheel tracking test, tensile strength ratio (TSR) test, Superpave indirect tension (IDT) tests, and possibly, beam fatigue test. WMA mixtures will be compared to HMA mixtures containing same RAP contents.

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APPENDIX A. SURVEY FORM[2]

[2] This survey was designed by a research team consisted of Arash Saboori and Mohyeldin Ragab working under supervision of Professor Magdy Abdelrahman. Arash was the lead graduate student in the project responsible for organizing the tasks and distributing assignments required to achieve the deliverables between the team. Mohy was assigned to help in parts of literature study phase, design of survey, collecting data and developing graphs.

Warm Mix Asphalt Survey for North Dakota

Introduction, Contact Details and Legal Notice

The purpose of this questionnaire is to gather information from DOTs regarding their experiences with WMA and the specifications they use for WMA projects. The result of this questionnaire will help the research group in development of a guideline for process approval and specification for WMA projects in North Dakota.

Introduction

The use of Warm Mix Asphalt (WMA) allows savings in energy usage. This is achieved through foamed asphalt or through the use of additives to reduce asphalt apparent viscosity at the low mixing temperature and to improve the workability of the mixture, so that asphalt coats aggregate efficiently. WMA has the potential of efficient compaction, reduced thermal segregation, and extended service life. However, concerns related to the mixing processes and additives used in the WMA production exist. For example, the potential for moisture damage and early rutting may be higher because aggregate may not be sufficiently dried. To fully understand WMA, many research projects are under investigation. At the same time, the experience obtained from actual projects is of great importance and could lead to valuable insight to performance of WMA, which is the aim of this study.

Contact Details

NDSU research group would be more than happy to receive your emails or calls if you have any questions or would like to submit any documents or information related to the survey.

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Legal Notice

By participating in this survey you are giving permission to the research group to use your questionnaire results in their analysis and publish the results. The information obtained from this survey is considered as NDDOT property and can be published or re-produced in any format and in any media.

Warm Mix Asphalt Survey for North Dakota

General Observation

1. Compare WMA to HMA in the following categories based on your agency experience. Please explain your choices in the comment box.

	Advantageous	Same	Disadvantageous
Bidding	◯	◯	◯
Contractor's Willingness	◯	◯	◯
Constructability	◯	◯	◯
Performance	◯	◯	◯
Maintenance	◯	◯	◯
Cost	◯	◯	◯

Comments

2. How much was the WMA and HMA approximate production (tonnage/year) based on the average of last 5 years?

3. How is WMA bidding cost compared to HMA?

	%	More/Same/Less
WMA bidding cost is		

4. What is the approximate range of additional costs ($/ton) for WMA production at:

4.1 Cost of Additives

Refinery

Field Location

4.2 Total Cost Including Processing

Refinery

Field Location

Warm Mix Asphalt Survey for North Dakota

5. Is it possible to provide information/data/documentation for some of your agency projects/experiences with WMA? (please provide it through web link, email, or post)

6. If you had to pick one WMA process, what would it be? Please explain why.

Warm Mix Asphalt Survey for North Dakota

Technologies

7. For each of the three main processes below please specify the followings:

In how many of your agency projects was the technology implemented?

How much reduction in mixing temperature could you achieve compared to HMA projects?

Have you observed moisture damage and/or rutting on your warm mix projects? If yes, in how many projects did you observe them? If there were other distresses, please list them in the comment box.

7.1 ~~~ CHEMICAL PROCESSES ~~~

	Number of Constructed Projects	Mixing Temperature Reduction Achieved (F)	Number of Projects with Moisture Damage	Number of Projects with Rutting
CECABASE® RT				
Evotherm ™				
HyperTherm™/QualiTherm				
Rediset™WMX				

Please list other technologies and/or other distresses not listed above

Warm Mix Asphalt Survey for North Dakota

7.2 ~~~ FOAMING PROCESSES ~~~

	Number of Constructed Projects	Mixing Temperature Reduction Achieved (F)	Number of Projects with Moisture Damage	Number of Projects with Rutting
Accu-Shear™				
Advera® WMA				
AQUABlack™ WMA System				
AquaFoam				
Aspha-Min®				
Double Barrel® Green				
Eco-Foam II				
LEA (Low Emission Asphalt)				
Meeker Warm Mix				
Terex® WMA System				
Tri-Mix Warm Mix Injection System				
Ultrafoam GX2™ System				
WAM Foam				

Please list other technologies and/or other distresses not listed above

7.3 ~~~ ORGANIC ADDITIVES ~~~

	Number of Constructed Projects	Mixing Temperature Reduction Achieved (F)	Number of Projects with Moisture Damage	Number of Projects with Rutting
Astech PER®				
Sasobit®				
SonneWarmix™				
Thiopave™				
TLA-X™ Warm Mix				

Please list other technologies and/or other distresses not listed above

Warm Mix Asphalt Survey for North Dakota

Mix Design

8. In your WMA Material Selection, which of the items below has been modified compared to HMA mix design? (please explain in the comment box)

- [ ] Binder Selection
- [ ] Aggregate Properties
- [ ] Volumetric Parameters (VMA & VFA)
- [ ] Recycled Asphalt Pavement (content/gradation)
- [ ] Additives (types/percentage)
- [ ] No Modifications of Any Items

Comments

9. In your WMA Binder Selection, which of the items below has been modified compared to HMA mix design? (please explain in the comment box)

- [ ] Binder Content
- [ ] Binder Grade
- [ ] Binder Preparation/Testing
- [ ] No Modifications of Any Items

Comments

10. In your WMA Design Aggregate Structure, which of the items below has been modified compared to HMA mix design? (please explain in the comment box)

Add "Aggregate Sources" and "Other Aggregate Properties, Please specify in the space below"
Remove "Aggregate Patching, Aggregate Mixing, Aggregate Conditioning, Volumetric Parameters"

- ☐ Aggregate Sources
- ☐ Nominal Maximum Aggregate Size
- ☐ Trial Gradations
- ☐ Aggregate Compaction
- ☐ No Modifications of Any Items

Other Aggregate Properties, Please specify in the space below

11. In your WMA Lab Performance Tests, which of the testing below has been modified compared to HMA mix design? (please explain in the comment box)

	Specimen Preparation	Testing and Procedure
Rutting	☐	☐
Thermal Cracking	☐	☐
Fatigue	☐	☐
Moisture Sensitivity	☐	☐
No Modifications of Any Items	☐	☐

Comments

12. Compared to HMA, does your agency require to modify the amount of anti-stripping agent used for WMA? If yes, please specify how? Also if any other type of additives are required for WMA, please specify in the comment box.

◯ Yes

◯ No

Comments

13. For which of the following does your agency have different requirements (percentage/processing/testing) compared to HMA? Please specify in the comment box below.

	Yes	No
RAP (Reclaimed Asphalt Pavement)	◯	◯
RAS (Reclaimed Asphalt Shingles)	◯	◯

Comments

14. If Modifications are made, does the design for WMA depend on the WMA technology used? (if yes, please explain how)

◯ Yes

◯ No

Comments

-

Warm Mix Asphalt Survey for North Dakota

Specification

15. What are the mechanisms for developing warm mix asphalt in your agency? In the comment box, please provide your most recent documents/web links for each of the items below. (either copy the web link(s) or email us the document)

- [ ] Separate specification developed for WMA
- [ ] Approved list of processes
- [ ] Approval process for non-listed processes proposed

Other (please specify)

16. How did you develop your agency specification or approval procedure? (in the comment box please specify the reference your agency used for the first two choices)

- [ ] Based on national studies/guidelines (such as NCHRP reports)
- [ ] Based on other DOTs specifications
- [ ] Developed by your own agency

Comments

17. Do you have a list of NOT PERMITTED (WMA technologies, additives, etc...) in any section of your specification? (If yes, please list the Not Permitted items in the comment box below)

- ( ) Yes
- ( ) No

Comments

Warm Mix Asphalt Survey for North Dakota

Acceptance Plan

18 Compared to HMA, for which of the WMA acceptance plan components do you have modifications? Please explain in the comment box. Also, could you provide us with your agency acceptance plan for WMA (through web link, email, or hard copy).

	Yes	No
Acceptance sampling type	◯	◯
Quality characteristics	◯	◯
Specification limits	◯	◯
Quality level goals	◯	◯
Risk	◯	◯
Pay factors	◯	◯

Comments (links or other information)

19. Compared to HMA, in which of the following do you have modifications in temperature monitoring for WMA? Please specify in the comment box.

- ☐ Mixing
- ☐ Construction/Compaction
- ☐ None

Comments

20. Is the WMA sampling schedule for quality assurance different from HMA? (If yes, please explain in the comment box)

- ◯ Yes
- ◯ No

Comments

21. For lab assurance testing, in which of the following do you have modifications compared to HMA? Please specify in the comment box.

- ☐ Sample preparation
- ☐ Testing procedure
- ☐ None

Comments

22. Compared to HMA, does your agency have any modifications on Quality Control Plan? If yes, please explain in the comment box.

- ◯ Yes
- ◯ No

Comments

23. Do you use test sections to evaluate construction/performance of WMA technologies? If yes, what are the approval process and the tests?

- ◯ Yes
- ◯ No

Comments

24. In case of using non-approved technologies, additives, or modifiers by the contractor, what would be the agency action? Please explain in the comment box.

- [ ] Reject
- [ ] Accept with penalty
- [ ] Accept

Other (please specify)

Warm Mix Asphalt Survey for North Dakota

Contact Information for Submitting Supplemental Information/Documents

NDSU research group would be more than happy to receive your emails or calls if you have any questions or would like to submit any documents or information related to the survey.

NDSU Contact:
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Fargo, ND 58108-6050
Tel. (701) 231-7249
Fax: (701) 231-6185
Email: m.abdelrahman@ndsu.edu

Please provide us with the additional information below

Years of Experience	
Position	
Email	
Telephone	
City	
State	

Note:

If you prefer to submit the survey again using the link provided, please clear your browsing history and cookies to remove any saved preferences.

APPENDIX B. RESPONSES TO THE SURVEY[3]

The tables in Appendix B represent the responses to the questions in the survey (Appendix A). Therefore, numbering of the tables corresponds with the number of the respective question in the survey.

[3] The content of this section are the results of a survey designed by a research team consisted of Arash Saboori and Mohyeldin Ragab working under supervision of Professor Magdy Abdelrahman. Arash was the lead graduate student in the project responsible for organizing the tasks and distributing assignments required to achieve the deliverables between the team. Mohy was assigned to help in parts of literature study phase, design of survey, collecting data and developing graphs.

Table B.1. Comparison between WMA and HMA

State	Bidding	Contractor's Willingness	Constructability	Performance	Maintenance	Cost
Colorado						
Idaho	Same	Same	Advantageous	Disadvantageous	Disadvantageous	Same
Indiana	Same	Same	Advantageous	Same	Same	Same
Iowa	Disadvantageous	Advantageous	Advantageous	Same	Same	Disadvantageous
Kansas	Same	Same	Same	Same	Same	Same
Maine	Same	Same	Same	Same	Same	Disadvantageous
Manitoba, Canada	Advantageous	Advantageous	Advantageous	Same	Same	Same
Michigan	Same	Same	Same	Same	Same	Same
Minnesota	Same	Same	Advantageous	Same	Same	Disadvantageous
Missouri	Same	Same	Advantageous	Advantageous	Same	Same
Montana(1)	Same	Same	Same			Disadvantageous
Montana(2)		Disadvantageous	Advantageous			
Nebraska	Disadvantageous	Same	Same	Same	Same	Disadvantageous
Nevada(1)	Same	Same	Disadvantageous	Disadvantageous	Same	Same
Nevada(2)						
New Hampshire		Advantageous	Advantageous	Advantageous		
New York	Same	Same	Same			Disadvantageous
Ohio	Advantageous	Advantageous	Same	Same	Same	Advantageous
Oregon						
Saskatchewan			Disadvantageous			
South Dakota	Same	Disadvantageous	Same	Disadvantageous	Disadvantageous	Advantageous
Utah	Same	Disadvantageous	Same	Same	Same	Same
Vermont	Disadvantageous	Same	Same	Same	Same	Disadvantageous
Washington	Same	Advantageous	Same	Same	Same	Same

Table B.1. Comparison between WMA and HMA - comments section

State	Comments
Colorado	This is the first construction season that CDOT is allowing WMA processes in construction. We have no information on Q1 at this time.
Idaho	Performance is still an unknown. There may be the potential to strip and moisture susceptibility.
Indiana	WMA has permitted extending the time available to compact the HMA.
Iowa	In Iowa the cost of additives is about $2.25/mix ton for Evotherm and $4/ton for Sasobit, which is an increase to HMA. The water injection technology is only an initial investment cost; however, we require all WMA mixtures to undergo AASHTO T283 testing to satisfy a minimum 80% TSR. We do not require this on all HMA mixes, which leads to a potential added cost of an anti-stripping agent for all WMA technologies except Evotherm.
Kansas	We have WMA down for only one year and so far the performance has been the same. We don't specify that WMA must be used it is the contractor's option, and we have not seen a difference in bidding between the contractors that use WMA and contractors that use HMA.
Maine	Currently contractors are bidding HMA and utilizing warm-mix technologies as compaction aid (not lowering production temperatures). Projects bid with warm-mix technology are slightly more expensive than those with conventional HMA.
Manitoba, Canada	Manitoba Infrastructure and Transportation has constructed 2 WMA projects to date (with a 3rd scheduled for this season using water injection). We hosted a number of informational sessions for MIT staff Contractors prior to advertising our first WMA project; to educate all parties and address any concerns. We felt we recieved competitive bids for the first project, as it was used as part of a bigger reserach project. The second project was proposed by the Contractor to test the benefits of long haul (2 hours). Although the pavement has not been in service for very long, MIT was happy with the constructibility and performance thus far.
Michigan	We plan on taking an apporach where WMA is allowable at the contractor's option, therefore everything is considered the same.

Table B.1. Comparison between WMA and HMA - comments section - continued

State	Comments
Montana(1)	Montana DOT has only let 5 projects to date requiring WMA, to date only 3 of those jobs have been paved. These were paved within the last year so no information is available for performance and maintenance. The data base for cost comparison is pretty small. Several contractors have purchased equipment for WMA foaming application.
Montana(2)	We are still in the beginning phases of WMA ourselves. So far there has been both reluctance to use WMA and proactive requests to use WMA from our contracting community. Some of the larger contractors have purchased new hot plants in anticipation of wider use of WMA but we have only spec'ed it on 6 jobs so far. 3 last year and 3 this year so performance/maintenance data is not there yet. Compaction is aided on the road but older retrofitted plants have a hard time working at the reduced temperatures. I can't speak to any cost or bidding related issues.
Nebraska	Contractors seem interested in WMA, but there needs to be more innovation in finding cost effective solutions for many of the additives. At the moment, this seems to be one of the bigger hinderances for widespread use in Nebraska.
Nevada(1)	The main concerns that NDOT has with Warm Mix is early rutting due to uncertain optimum bitumen ratio and increased moisture sensitivity due to incomplete drying of aggregates.
Nevada(2)	We have not bid WMA in Nevada.
New Hampshire	Questions not responded to due to lack of data.
New York	Performance and Maintenance of WMA vs. HMA - We don't have enough history yet, hoiwever we do not expect to see the same or better. Cost - Our current WMA specification requires extra testing not normally done with our HMA mixtures, and our production quality incentives/disincentives do not apply to the WMA mixtures. These factors cause the current bid prices to be slightly higher ($1 - $5 per mix ton).
Ohio	Not enough information on performance yet. Since a new set of construction issues arise I rate constructability the same.
Oregon	Can't really address these as we have done only a couple of Warm Mix projects and most have been by a no cost change order.
Saskatchewan	Warm mix was found to have created more tender mixes, which is not a benefit in Saskatchewan as our mixes are already tender. As well, when used for blade patching, crews found it more difficult to work with. However, increased haul distances were an advantage.

Table B.1. Comparison between WMA and HMA - comments section - continued

State	Comments
Utah	UDOT's approach is to allow WMA but not require it. This allows the contractor to use the technology as it benefits them.
Vermont	We have not required WMA or bid it as an alternate but our specification would allow WMA useage. Contractors have not proposed WMA because of increased costs.
Washington	Use of WMA is optional to the Contractors but must be proposed and approved by WSDOT. Since WMA has only been used for a couple of years it is difficult to provide an accurate assessment of performance and maintenance.

Table B.2. Average WMA and HMA production in last 5 years

State	Comments
Colorado	Aside from small test sections 3 years ago, we have yet to complete a construction year with WMA projects.
Idaho	WMA avg over last 5 years 6,000 ton/yr. HMA avg over last 5 years 500,000 ton/yr.
Indiana	Indiana has had a permissive specification for the past three years. Annual HMA production could be estimated at 4 million tons with an average of 15 out of 100 plants equipped with foaming equipment. WMA production would therefore be in the realm of 500,000 tons or higher...we do not track WMA production tonnage.
Iowa	We are not permissive yet, so the WMA tonnage is limited and not representative of the true desire of WMA from the contractor's perspective. Iowa did 125,000 tons in 2010 which was about 4%. We expect this to increase when we are permissive in 2012.
Kansas	Last year was the first year we placed WMA and there were approximately 110,000 tons of WMA placed and around 1,100,000 tons of HMA placed.
Maine	Average Production: WMA - 50k Ton HMA - 750k Ton
Manitoba, Canada	Project advertised in 2009: 31,400 tonnes total project (23,550 was WMA) Project contstructed 2011: 81,000 tonnes total project (40,500 will be foamed WMA)
Michigan	0 tons of WMA. A contractor placed WMA on a project at their choice but I wouldn't consider it in answering this question.
Minnesota	50,000 WMA per year 1 million HMA per year
Missouri	In the last 5 years WMA has gone from almost 0% to 20% of the total production or almost 1 million tons. That should increase considerably for 2011 with more contractors using WMA.
Montana(1)	WMA - 25,600 tons based on 5 projects let. HMA - 25,800 tons based on average of 5 years. Although these averages are very close the individual project tonnages vary widely.
Montana(2)	
Nebraska	Around 2 Million Tons per year
Nevada(1)	Zero for State contracts.
Nevada(2)	WMA - 0 HMA - 600,000 tons
New Hampshire	This is the first paving season it is being utilized
New York	HMA - approx. tonnange per year - 3 million WMA - we are still in a experimental trial stages, but we have done approx. 225,000 tons of WMA in the last 5 years.
Ohio	In 2010 we produced 1.9 million WMA tons and almost 6 million total tons. Prior to that we ahd about 5.5 million total tons with WMA phasing in from 0 to 1.9 million tons in about 3 years.
Oregon	We have only done two WMA projects to date with a total tonage of about 10,000 ton. We average about 1,500,000 Tons of HMA
Saskatchewan	WMA production has been limited to trials in 2010. Some has been used for blade patching, some has been used on a thin lift overlay, a trial in which two additives will be evaluated was constructed, and one contractor was allowed to use WMA on paving job when work was occuring in December. Costs have been borne by the contractor/and or supplier at this point, so no information is available regarding bidding/costs.
South Dakota	only test sections of warm mix approx. 20,000 tons of 8 million tonns
Utah	5000
Vermont	HMA - 400,000 T/year WMA - 0
Washington	WMA approximately 75,000 tons. HMA approximately 4,800,000 tons.

Table B.3. WMA bidding cost compared to HMA

State	WMA bidding cost compared to HMA is	
Colorado		
Idaho		Same
Indiana		Same
Iowa	1 to 5 % Higher	More
Kansas		Same
Maine	6 to 10% Higher	More
Manitoba, Canada		
Michigan		Same
Minnesota	6 to 10% Higher	More
Missouri		Same
Montana(1)	6 to 10% Higher	More
Montana(2)		
Nebraska	15 to 20 % Higher	More
Nevada(1)	1 to 5 % Higher	Same
Nevada(2)		
New Hampshire		
New York	1 to 5 % Higher	More
Ohio	1 to 5 % Higher	
Oregon		
Saskatchewan		
South Dakota		
Utah		Same
Vermont		More
Washington		Same

Table B.4.1. Additional cost of WMA ($/ton) in cost of additives

State	Refinery	Field Location
Colorado		
Idaho	Unknown	
Indiana		
Iowa	we use foaming only.	0.00
Kansas		
Maine	n/a	n/a
Manitoba, Canada	unknown	
Michigan		
Minnesota		
Missouri	0.00	0 - except for initial equipment installation
Montana(1)		
Montana(2)	n/a	n/a
Nebraska		
Nevada(1)	depends on additive	depends on additive
Nevada(2)		
New Hampshire		
New York	$3-6/Liquid Ton	$8/Liquid Ton
Ohio		
Oregon		
Saskatchewan		
South Dakota		
Utah		
Vermont	Unknown	Unknown
Washington	N/A	N/A

Table B.4.2. Additional cost of WMA ($/ton) in total cost

State	Refinery	Field Location
Colorado		
Idaho		
Indiana	N/A	N/A
Iowa	2-4$/mix ton	
Kansas		
Maine	Unknown/Bid Specific	Unknown/Bid Specific
Manitoba, Canada		
Michigan	0	0- except for initial equipment installation
Minnesota	2	1.75
Missouri		
Montana(1)		
Montana(2)		
Nebraska		
Nevada(1)	n/a	n/a
Nevada(2)		
New Hampshire	unknown	
New York		
Ohio	0	0
Oregon		
Saskatchewan		
South Dakota		
Utah	unknown	
Vermont	$1-2 per ton	$1-2 per ton
Washington	Unknown	$25,000 - $50,000

Table B.5. Information/data/documentation of the agency projects/experiences with WMA

State	Response Text
Colorado	
Idaho	Nothing of great value. We have only limited information on one job. It was bid as HMA and Change Ordered to WMA at contractors request at no cost CO. Did meet all original HMA Superpave specifications and had reasonably good Pay factors based on Volumetrics and density. Spec for density is 91 to 96 percent (Correlated Nuke Gauge). Project completed 2010 mid summer in hot weather.
Indiana	Indiana is permissive with foaming asphalt only. We have not permitted any solid modifiers and have not been pressured by our Contractors to use them because of the substantial cost increase per ton of mixture.
Iowa	http://www.iowadot.gov/operationsresearch/reports/reports_pdf/hr_and_tr/reports/TR-599%20Final%20Report.pdf
Kansas	I will email some of the project results from our WMA projects.
Maine	Yes, however, projects have yet to be completed.
Manitoba, Canada	Contact:□ tara.liske@gov.mb.ca
Michigan	NA
Minnesota	http://www.dot.state.mn.us/mnroad/WMA/WMA%20Index.html
Missouri	Our first project is documented as part of NCHRP 09-47A and NCAT Report No. 10-02.
Montana(1)	deroberts@mt.gov
Montana(2)	
Nebraska	Yes, will email the information
Nevada(1)	None available at this time.
Nevada(2)	
New Hampshire	Not at this time. First paving season using this technology
New York	Yes, some info/data can be made available. We have various projects with various WMA technologies. Contact me with the type of information you are interested in.
Ohio	Emaililng a reprot from trials in 2008.
Oregon	
Saskatchewan	A paper will be published in the Canadian Technical Asphalt Association Proceedings, and a presentation will be given at the CSCE annual meeting
South Dakota	No
Utah	
Vermont	No data to date. First projects to be bid this year.
Washington	http://www.wsdot.wa.gov/Research/Reports/700/723.1.htm

Table B.6. Agencies' preferred WMA process

State	Response Text
Colorado	Chemical additive like Advera. CDOT is wary of foaming processes because of the lack of long-term, field performance information.
Idaho	Idaho's only WMA experience is with foaming asphalt (plant modification) Double Barrel Green.
Indiana	Indiana is permissive with foaming asphalt only. The equipment installation costs are considered a one-time annualized cost with pay-back to the contractor in the form of decreased fuel usage. The fuel savings have not approached the nationally reported value of 14% as many variables play into that number.
Iowa	As an owner I would choose Evotherm because it acts as an adhesion promoter as well as a compaction aid. A contractor would prefer water injection due to the one-time initial cost.
Kansas	Chemical Process. At this point we can't replicate the foaming process in the lab and we would be able to replicate the chemical process in the lab. Also the temperature drop can be more substantial with chemical processes, at this point with the foaming processes the contractors aren't really seeing a substantial savings in fuel costs.
Maine	For quality purposes, we feel that the synthetic wax WMA technologies are the best. However, we have only utilized EvoTherm and Water technologies in the State of Maine.
Manitoba, Canada	We only have experience with WMA additives: Sasobit, Evotherm and Advera. We will be constructed a foamed WMA project this season.
Michigan	Foaming/water injection. Least costly.
Minnesota	Evotherm, lower mixing temperatures, adhesion promoters, and anti-strip capabilities
Missouri	Experience has shown that chemical admixtures (Evotherm) provide the largest temperature reduction in addition to antistrip qualities and allowing higher percentages of RAP and RAS.
Montana(1)	foaming technology, water will evaporate out of the mix and leave the asphalt intact with the least potential for changine asphalt properties.
Montana(2)	
Nebraska	If a process could prove itself to lower the cost to produce asphalt while not losing anything in quality, that would be our choice. There is no clearcut leader in that, although the water injection methods may be the frontrunner.
Nevada(1)	Uncertain as of this date.
Nevada(2)	Foaming, easier for a contractor to install on his hot plant.
New Hampshire	At this point it would be the foaming method. No added cost, increased film thickness and compaction.

Table B.6. **Agencies' preferred WMA process – comments section**

State	Response Text
New York	NYSDOT does not favor any process over the other(s). NYSDOT has an approval process for each technology to follow in order for them to be put on our Approved List of WMA Technologies. Technologies that have been Approved are allowed to be used on entire WMA projects. Technologies that have not been Approved are limited to trial sections of 1000 tons or less.
Ohio	Foaming, no extra cost, significant emissions reduction.
Oregon	
Saskatchewan	Not enough information at this time.
South Dakota	chemical additives
Utah	unknown
Vermont	Probably waxes (Sasobit/Sonnewarm) because they can be added to the binder either at the HMA plant or at the refinery/terminal.
Washington	N/A

Table B.7.1. Agencies' experience with chemical processes

State	Number of Constructed Projects CECABASE® RT	Mixing Temperature Reduction Achieved (°F) CECABASE® RT	Number of Projects with Moisture Damage CECABASE® RT	Number of Projects with Rutting CECABASE® RT
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York	1	40-60		
Ohio				
Oregon				
Saskatchewan	1			
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.1. Agencies' experience with chemical processes - continued

State	Number of Constructed Projects Evotherm ™	Mixing Temperature Reduction Achieved (°F) Evotherm ™	Number of Projects with Moisture Damage Evotherm ™	Number of Projects with Rutting Evotherm ™
Colorado	1	20-40		
Idaho				
Indiana				
Iowa	6	40-60		
Kansas	4			
Maine	3	20-40		1
Manitoba, Canada	2	40-60		
Michigan				
Minnesota	3	40-60		
Missouri	15	40-60		
Montana(1)	1			
Montana(2)				
Nebraska	1	40-60		
Nevada(1)				
Nevada(2)				
New Hampshire	2	40-60		
New York	7	40-60		
Ohio	2	40-60		
Oregon				
Saskatchewan	3	20-40		
South Dakota	3	40-60		12
Utah	1	40-60		
Vermont				
Washington				

Table B.7.1. Agencies' experience with chemical processes - continued

State	Number of Constructed Projects HyperTherm™ /QualiTherm	Mixing Temperature Reduction Achieved (°F) HyperTherm™ /QualiTherm	Number of Projects with Moisture Damage HyperTherm™ /QualiTherm	Number of Projects with Rutting HyperTherm™ /QualiTherm
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York	1	40-60		
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.1. Agencies' experience with chemical processes - continued

State	Number of Constructed Projects Rediset™WMX	Mixing Temperature Reduction Achieved (°F) Rediset™WMX	Number of Projects with Moisture Damage Rediset™WMX	Number of Projects with Rutting Rediset™WMX
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.1. Agencies' experience with chemical processes - continued

State	Please list other technologies and/or other distresses not listed above
Colorado	
Idaho	Foaming Asphalt - Double Barrel Green
Indiana	Chemical processes are not currently permitted.
Iowa	
Kansas	
Maine	Moisture damage to the WMA projects is unknown to the date.
Manitoba, Canada	
Michigan	
Minnesota	
Missouri	
Montana(1)	
Montana(2)	
Nebraska	
Nevada(1)	
Nevada(2)	None.
New Hampshire	
New York	LEA - Lite - 4 Projects with approx 50 degree F temperature reduction. No damage to date.
Ohio	
Oregon	
Saskatchewan	No data regarding moisture damage/rutting is available at this time. Temperature reduction is based off of the trial
South Dakota	
Utah	
Vermont	None of these technologies have been used.
Washington	

Table B.7.2. Agencies' experience with foaming processes

State	Number of Constructed Projects Accu-Shear™	Mixing Temperature Reduction Achieved (°F) Accu-Shear™	Number of Projects with Moisture Damage Accu-Shear™	Number of Projects with Rutting Accu-Shear™
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska	1	20-40		
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Advera® WMA	Mixing Temperature Reduction Achieved (°F) Advera® WMA	Number of Projects with Moisture Damage Advera® WMA	Number of Projects with Rutting Advera® WMA
Colorado	1	20-40		
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada	1	40-60		
Michigan				
Minnesota				
Missouri	1	20-40		
Montana(1)				
Montana(2)				
Nebraska	1	40-60		
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio	3	40-60		
Oregon				
Saskatchewan	1	20-40		
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects AQUABlack ™ WMA System	Mixing Temperature Reduction Achieved (°F) AQUABlack ™ WMA System	Number of Projects with Moisture Damage AQUABlack ™ WMA System	Number of Projects with Rutting AQUABlack ™ WMA System
Colorado				
Idaho				
Indiana				
Iowa				
Kansas	15	20-40		
Maine				
Manitoba, Canada				
Michigan				
Minnesota	10	20-40		
Missouri	6	20-40		
Montana(1)	1			
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington	1	20-40		

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects AquaFoam	Mixing Temperature Reduction Achieved (°F) AquaFoam	Number of Projects with Moisture Damage AquaFoam	Number of Projects with Rutting AquaFoam
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota	2			
Utah				
Vermont				
Washington	1	20-40		

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Aspha-Min®	Mixing Temperature Reduction Achieved (°F) Aspha-Min®	Number of Projects with Moisture Damage Aspha-Min®	Number of Projects with Rutting Aspha-Min®
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri	1	20-40		
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Double Barrel® Green	Mixing Temperature Reduction Achieved (°F) Double Barrel® Green	Number of Projects with Moisture Damage Double Barrel® Green	Number of Projects with Rutting Double Barrel® Green
Colorado				
Idaho	1	20-40		
Indiana				
Iowa	5	20-40		
Kansas				
Maine	12	20-40		
Manitoba, Canada				
Michigan				
Minnesota				
Missouri	15	20-40		
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire	8	20-40		
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota	1			
Utah	1	20-40		
Vermont				
Washington	1	20-40		

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects LEA (Low Emission Asphalt)	Mixing Temperature Reduction Achieved (°F) LEA (Low Emission Asphalt)	Number of Projects with Moisture Damage LEA (Low Emission Asphalt)	Number of Projects with Rutting LEA (Low Emission Asphalt)
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York	12	80-100		
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Eco-Foam II	Mixing Temperature Reduction Achieved (°F) Eco-Foam II	Number of Projects with Moisture Damage Eco-Foam II	Number of Projects with Rutting Eco-Foam II
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Meeker Warm Mix	Mixing Temperature Reduction Achieved (°F) Meeker Warm Mix	Number of Projects with Moisture Damage Meeker Warm Mix	Number of Projects with Rutting Meeker Warm Mix
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Terex® WMA System	Mixing Temperature Reduction Achieved (°F) Terex® WMA System	Number of Projects with Moisture Damage Terex® WMA System	Number of Projects with Rutting Terex® WMA System
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri	4	20-40		
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire	8	20-40		
New York	3	20-40		
Ohio				
Oregon				
Saskatchewan				
South Dakota	1			
Utah				
Vermont	1	20-40		
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Tri-Mix Warm Mix Injection System	Mixing Temperature Reduction Achieved (°F) Tri-Mix Warm Mix Injection System	Number of Projects with Moisture Damage Tri-Mix Warm Mix Injection System	Number of Projects with Rutting Tri-Mix Warm Mix Injection System
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects Ultrafoam GX2™ System	Mixing Temperature Reduction Achieved (°F) Ultrafoam GX2™ System	Number of Projects with Moisture Damage Ultrafoam GX2™ System	Number of Projects with Rutting Ultrafoam GX2™ System
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington	3	20-40		

Table B.7.2. Agencies' experience with foaming processes - continued

State	Number of Constructed Projects WAM Foam	Mixing Temperature Reduction Achieved (°F) WAM Foam	Number of Projects with Moisture Damage WAM Foam	Number of Projects with Rutting WAM Foam
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.2. Agencies' experience with foaming processes - continued

State	Please list other technologies and/or other distresses not listed above
Colorado	I'm pretty sure Advera is a mineral additive, not a foaming process
Idaho	
Indiana	Indiana contractors have primarily focused on purchasing the Double Barrel Green system and the Gencor system for foaming. One contractor to date has purchased the Accu-Shear system and one contractor to date has acquired the AQUABlack system.
Iowa	
Kansas	We have not seen any mositure damage or rutting in any of the WMA projects, though the longest has been down for just a year.
Maine	Moisture damage to the WMA projects is unknown to the date. No rutting observed in these projects to date. All have been thin overlays.
Manitoba, Canada	
Michigan	first official project will be this summer
Minnesota	
Missouri	
Montana(1)	One other project utilized foaming technology but the specific system was not noted.
Montana(2)	
Nebraska	
Nevada(1)	
Nevada(2)	None.
New Hampshire	
New York	
Ohio	Contractors in Ohio use any of the above foaming equipment. I do not currently have a count of each type. Total is about 70 plants. We are not using other foam processes like WAM, LEA etc
Oregon	
Saskatchewan	No data is available on rutting/moisture damage at this time.
South Dakota	
Utah	
Vermont	
Washington	Since WMA has only been used for a couple of years it is difficult to provide an accurate assessment of performance and maintenance.

Table B.7.3. Agencies' experience with organic additives

State	Number of Constructed Projects Astech PER®	Mixing Temperature Reduction Achieved (°F) Astech PER®	Number of Projects with Moisture Damage Astech PER®	Number of Projects with Rutting Astech PER®
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.3. Agencies' experience with organic additives - continued

State	Number of Constructed Projects Sasobit®	Mixing Temperature Reduction Achieved (°F) Sasobit®	Number of Projects with Moisture Damage Sasobit®	Number of Projects with Rutting Sasobit®
Colorado	1	20-40		
Idaho				
Indiana				
Iowa	1	20-40		
Kansas				
Maine				
Manitoba, Canada	1	40-60		
Michigan				
Minnesota				
Missouri	8	20-40		
Montana(1)				
Montana(2)				
Nebraska	1	80-100		
Nevada(1)				
Nevada(2)				
New Hampshire				
New York	1	40-60		
Ohio	1	40-60		
Oregon				
Saskatchewan				
South Dakota	1			
Utah				
Vermont				
Washington	1	20-40		

Table B.7.3. Agencies' experience with organic additives - continued

State	Number of Constructed Projects SonneWarmix ™	Mixing Temperature Reduction Achieved (°F) SonneWarmix ™	Number of Projects with Moisture Damage SonneWarmix ™	Number of Projects with Rutting SonneWarmix ™
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine	2	20-40		
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.3. Agencies' experience with organic additives - continued

State	Number of Constructed Projects Thiopave™	Mixing Temperature Reduction Achieved (°F) Thiopave™	Number of Projects with Moisture Damage Thiopave™	Number of Projects with Rutting Thiopave™
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri	3	20-40		
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.3. Agencies' experience with organic additives - continued

State	Number of Constructed Projects TLA-X™ Warm Mix	Mixing Temperature Reduction Achieved (°F) TLA-X™ Warm Mix	Number of Projects with Moisture Damage TLA-X™ Warm Mix	Number of Projects with Rutting TLA-X™ Warm Mix
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.7.3. Agencies' experience with organic additives - continued

State	Please list other technologies and/or other distresses not listed above
Colorado	
Idaho	
Indiana	Organic additives are not currently permitted.
Iowa	Sasobit (1 project) no performance issues, though the TSR failed on both the WMA and HMA control section.
Kansas	
Maine	Each project less than one year old, no distress observed at this time.
Manitoba, Canada	
Michigan	
Minnesota	Planning on 1 project with Leadcap
Missouri	
Montana(1)	We have an experimental project in place that will begin in about 3 weeks that will utilize Sasobit additive.
Montana(2)	
Nebraska	
Nevada(1)	
Nevada(2)	None
New Hampshire	
New York	
Ohio	
Oregon	
Saskatchewan	
South Dakota	
Utah	
Vermont	
Washington	Since WMA has only been used for a couple of years it is difficult to provide an accurate assessment of performance and maintenance.

Table B.8. Modifications in WMA mix design compared to HMA

State	Binder Selection	Aggregate Properties	Volumetric Parameters (VMA & VFA)	Recycled Asphalt Pavement (Content/Gradation)	Additives (Types/Percentage)	No Modifications of Any Items
Colorado			Volumetric Parameters (VMA & VFA)			
Idaho						No Modifications of Any Items
Indiana						No Modifications of Any Items
Iowa	Binder Selection					
Kansas						No Modifications of Any Items
Maine						No Modifications of Any Items
Manitoba, Canada						No Modifications of Any Items
Michigan						No Modifications of Any Items
Minnesota						
Missouri						No Modifications of Any Items
Montana(1)				Recycled Asphalt Pavement (content/gradation)		
Montana(2)						
Nebraska					Additives (types/percentage)	No Modifications of Any Items
Nevada(1)	Binder Selection					
Nevada(2)						
New Hampshire						No Modifications of Any Items
New York						No Modifications of Any Items
Ohio						No Modifications of Any Items
Oregon						
Saskatchewan						No Modifications of Any Items
South Dakota						
Utah						No Modifications of Any Items
Vermont						No Modifications of Any Items
Washington						No Modifications of Any Items

Table B.8. Modifications in WMA mix design compared to HMA - comments section

State	Comments
Colorado	Lab volumetrics are run at standard super-pave temperatures; ergo, lab voids are typically below spec levels. We calculate an volumetric offset for each mix design, which is applied to the lab results and accounts for the higher compaction temperatures in the lab.
Idaho	
Indiana	Indiana has treated the foaming process as a drop-in technology. We do not require the contractor to fabricate the mix design or production control specimens at WMA temperatures. All gyratory fabricated specimens, including our acceptance samples, are made at HMA temperatures, which for us means 300F regardless of the production temperature.
Iowa	We have implemented NCHRP 9-43 recommendations to use proposed compaction temperature in the binder grade selection depending on the aging index.
Kansas	
Maine	Warm-mix is being evaluated in the same terms as HMA.
Manitoba, Canada	
Michigan	
Minnesota	Do not allow shingles on some projects.
Missouri	
Montana(1)	Our current warm mix bituminous surfacing specifications do not allow incorporation of recycled asphalt pavement.
Montana(2)	
Nebraska	Modifications may be made to type of antistrip used on the project.
Nevada(1)	
Nevada(2)	
New Hampshire	
New York	
Ohio	
Oregon	
Saskatchewan	No modifications have taken place at this time as WMA is in the early trial stages.
South Dakota	used manufacturers recommendations mix design and field volumetrics will be areas that need work
Utah	
Vermont	
Washington	

Table B.9. WMA binder selection modifications compared to HMA

State	Binder Content	Binder Grade	Binder Preparation/Testing	No Modifications of Any Items	Comments
Colorado				No Modifications of Any Items	
Idaho				No Modifications of Any Items	
Indiana				No Modifications of Any Items	
Iowa		Binder Grade			We suspect 0.1-0.2 in optimum binder content when specimens are fabricated using the WMA technology.
Kansas				No Modifications of Any Items	
Maine				No Modifications of Any Items	
Manitoba, Canada				No Modifications of Any Items	
Michigan				No Modifications of Any Items	
Minnesota				No Modifications of Any Items	
Missouri				No Modifications of Any Items	
Montana(1)				No Modifications of Any Items	
Montana(2)					
Nebraska				No Modifications of Any Items	
Nevada(1)	Binder Content				Adjusted for reduced absorption.
Nevada(2)					
New Hampshire				No Modifications of Any Items	
New York				No Modifications of Any Items	
Ohio				No Modifications of Any Items	
Oregon					
Saskatchewan				No Modifications of Any Items	No modifications have taken place at this time as WMA is in the early trial stages.
South Dakota	Binder Content		Binder Preparation/Testing		
Utah				No Modifications of Any Items	
Vermont				No Modifications of Any Items	
Washington				No Modifications of Any Items	

Table B.10. WMA aggregate structure modifications compared to HMA

State	Aggregate Sources	Nominal Maximum Aggregate Size	Trial Gradations	Aggregate Compaction	No Modifications of Any Items	Other Aggregate Properties
Colorado					No Modifications of Any Items	
Idaho					No Modifications of Any Items	
Indiana					No Modifications of Any Items	
Iowa						
Kansas					No Modifications of Any Items	
Maine					No Modifications of Any Items	
Manitoba, Canada					No Modifications of Any Items	
Michigan					No Modifications of Any Items	
Minnesota					No Modifications of Any Items	
Missouri					No Modifications of Any Items	
Montana(1)					No Modifications of Any Items	
Montana(2)						
Nebraska					No Modifications of Any Items	
Nevada(1)					No Modifications of Any Items	
Nevada(2)						
New Hampshire					No Modifications of Any Items	
New York					No Modifications of Any Items	
Ohio					No Modifications of Any Items	
Oregon						
Saskatchewan					No Modifications of Any Items	No modifications have taken place at this time as WMA is in the early trial stages.
South Dakota						
Utah					No Modifications of Any Items	
Vermont					No Modifications of Any Items	
Washington					No Modifications of Any Items	

Table B.11. WMA lab performance tests modifications compared to HMA

State	Rutting-Specimen Preparation	Rutting-Testing and Procedure	Thermal Cracking-Specimen Preparation	Thermal Cracking-Testing and Procedure
Colorado				
Idaho				
Indiana				
Iowa				
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota				
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.11. WMA lab performance tests modifications compared to HMA - continued

State	Fatigue-Specimen Preparation	Fatigue-Testing and Procedure	Moisture Sensitivity-Specimen Preparation	Moisture Sensitivity-Testing and Procedure
Colorado				
Idaho			Specimen Preparation	Testing and Procedure
Indiana				
Iowa			Specimen Preparation	
Kansas				
Maine				
Manitoba, Canada				
Michigan				
Minnesota			Specimen Preparation	
Missouri				
Montana(1)				
Montana(2)				
Nebraska				
Nevada(1)				
Nevada(2)				
New Hampshire				
New York				
Ohio				
Oregon				
Saskatchewan				
South Dakota				
Utah				
Vermont				
Washington				

Table B.11. WMA lab performance tests modifications compared to HMA - continued

State	No Modifications of Any Items-Specimen Preparation	No Modifications of Any Items-Testing and Procedure
Colorado	Specimen Preparation	Testing and Procedure
Idaho		
Indiana	Specimen Preparation	Testing and Procedure
Iowa		Testing and Procedure
Kansas	Specimen Preparation	Testing and Procedure
Maine	Specimen Preparation	Testing and Procedure
Manitoba, Canada		
Michigan		
Minnesota		
Missouri	Specimen Preparation	Testing and Procedure
Montana(1)	Specimen Preparation	Testing and Procedure
Montana(2)		
Nebraska	Specimen Preparation	Testing and Procedure
Nevada(1)	Specimen Preparation	Testing and Procedure
Nevada(2)		
New Hampshire	Specimen Preparation	Testing and Procedure
New York	Specimen Preparation	Testing and Procedure
Ohio	Specimen Preparation	Testing and Procedure
Oregon		
Saskatchewan	Specimen Preparation	Testing and Procedure
South Dakota		
Utah	Specimen Preparation	Testing and Procedure
Vermont	Specimen Preparation	Testing and Procedure
Washington		

Table B.11. WMA lab performance tests modifications compared to HMA - continued

State	Comments
Colorado	Lab volumetrics are run at standard super-pave temperatures; ergo, lab voids are typically below spec levels. We calculate an volumetric offset for each mix design, which is applied to the lab results and accounts for the higher compaction temperatures in the lab.
Idaho	AASHTO T 165 done at test strip, in addition to being done at design, with plant produced material.
Indiana	
Iowa	We require the specimens are fabricated with the WMA technology (except foaming at this point since no contractor has a foaming table).
Kansas	
Maine	
Manitoba, Canada	MIT does not conduct performance tests as part of our mix design
Michigan	None at this time
Minnesota	Lower compaction temperature.
Missouri	
Montana(1)	
Montana(2)	
Nebraska	
Nevada(1)	We will modify to match proposed field mixing and compacting temps.
Nevada(2)	
New Hampshire	
New York	
Ohio	
Oregon	
Saskatchewan	No modifications have taken place at this time as WMA is in the early trial stages.
South Dakota	
Utah	
Vermont	
Washington	To date only the Sasobit additive was evaluated during mix design analysis, all other WMA technologies have been used during production with no mix design evaluation.

Table B.12. WMA anti-stripping agent modifications compared to HMA

State	Does your agency require to modify the amount of anti-stripping agent used for WMA?	Comments
Colorado	No	
Idaho	No	
Indiana	No	Our mix design procedures incorporate AASHTO T-283. We do not conduct stripping tests on production samples. Indiana, overall, does not have stripping sensitive aggregates and overall we see very little use of anti-stripping materials.
Iowa	No	The dosage is not prescribed for neither HMA nor WMA. It is optimized by evaluating TSR over 3 dosage rates.
Kansas	No	
Maine	No	Not at this time. Potential changes in the future.
Manitoba, Canada	No	
Michigan	No	
Minnesota	No	
Missouri	No	
Montana(1)	No	
Montana(2)		
Nebraska	Yes	Yes, currently we require 1.0% lime by weight of virgin aggregate. For evotherm or any other WMA with amine antistrip material no lime is added, but the contractor must find a way to meet 80% or greater on TSR. Most other additives still require 1.0% lime at this time, but this is still preliminary.
Nevada(1)	No	We already require 1.5% lime by 48-hour marination.
Nevada(2)		
New Hampshire		No additives required
New York	No	
Ohio	No	
Oregon		
Saskatchewan	No	1% lime is generally required in all Saskatchewan mixes regardless of mixing temperature.
South Dakota	No	
Utah	No	
Vermont	No	
Washington	No	

Table B.13. WMA RAP and RAS utilization modifications compared to HMA.

State	RAP (Reclaimed Asphalt Pavement)	RAS (Reclaimed Asphalt Shingles)	Comments
Colorado	No	Yes	
Idaho	No	No	
Indiana	No	No	Indiana has one set of standards for using recycled materials.
Iowa	No	No	
Kansas	No	No	
Maine	No	No	
Manitoba, Canada	No		MIT does not use RAS.
Michigan	Yes	Yes	
Minnesota	No	No	
Missouri	No	No	
Montana(1)	Yes	No	Asphalt Shingles are not allowed in either HMA or WMA at this point in time. RAP is allowed in HMA but not allowed in WMA.
Montana(2)			
Nebraska	No	No	
Nevada(1)	No	No	We allow 15% max RAP and do not allow Shingles.
Nevada(2)			
New Hampshire	No	No	
New York	No	No	
Ohio	No	No	
Oregon			
Saskatchewan	No	No	RAS is not used in Saskatchewan
South Dakota	No		
Utah	No		
Vermont	No	No	
Washington			Requirments are the same for use of RAP, WSDOT does not allow the use of RAS under current specifications.

Table B.14. Dependency of mix design on WMA technology

State	Does the design for WMA depend on the WMA technology used?	Comments
Colorado		
Idaho		
Indiana	No	
Iowa	Yes	All additives need to be included in the specimen fabrication. For the time being, contractors do not need a foaming table to do a foam design. We will require the raw materials be sent to our lab where we will foam the contractor's design and compare air voids. If we see a significant difference between the foamed and HMA designs we will eventually require contractors to foam their designs.
Kansas	No	
Maine	No	
Manitoba, Canada		No modifications have been made to date.
Michigan	No	
Minnesota	No	
Missouri		
Montana(1)	Yes	A mix design needs to be submitted for MDT approval for the specific WMA technology utilized.
Montana(2)		
Nebraska	No	
Nevada(1)	Yes	Depending on proposed mixing and compacting temps.
Nevada(2)		
New Hampshire		No modifications at this time
New York	No	
Ohio		
Oregon		
Saskatchewan		
South Dakota	Yes	
Utah	No	
Vermont	No	
Washington		N/A

Table B.15. Mechanism for WMA development

State	Separate specification developed for WMA	Approved list of processes	Approval process for non-listed processes proposed	Other (Please Specify)
Colorado		Approved list of processes	Approval process for non-listed processes proposed	
Idaho		Approved list of processes	Approval process for non-listed processes proposed	
Indiana				Indiana has a permissive specification as written into our Standard Specification for foamed asphalt only.
Iowa	Separate specification developed for WMA			No formal approval process. The technology needs to be approved by the Bituminous Engineer. We may eventually adopt an approach similar to Florida (provide results from previous paving histories for new technologies).
Kansas		Approved list of processes	Approval process for non-listed processes proposed	http://www.ksdot.org/burmatrres/pql/pql-04-03.pdf http://www.ksdot.org/burConsMain/specprov/2007/pdf/07-12002.pdf
Maine	Separate specification developed for WMA			Separate special provision developed for Warm-mix technology use.
Manitoba, Canada			Approval process for non-listed processes proposed	
Michigan				Same as HMA
Minnesota	Separate specification developed for WMA			WMA is also allowed under a permissive basis in our standard specification. MnDOT does not have an approved product list.

Table B.15. Mechanism for WMA development - continued

State	Separate specification developed for WMA	Approved list of processes	Approval process for non-listed processes proposed	Other (please specify)
Missouri				Contractors are choosing the tried and tested processes and tend to shy away from others.
Montana(1)	Separate specification developed for WMA			We have a separate special provision for WMA.
Montana(2)				
Nebraska	Separate specification developed for WMA	Approved list of processes	Approval process for non-listed processes proposed	We are still drafting the specification. Any process may be used, but if it is not on the approved list it will need to go through a trial/research project.
Nevada(1)				We intend to approve specific processes by specific Contractors.
Nevada(2)				
New Hampshire		Approved list of processes		
New York	Separate specification developed for WMA	Approved list of processes	Approval process for non-listed processes proposed	
Ohio				We only allow foaming. HMA Specs allow use of WMA except where restricted in specific mix types. Contractors can propose other processes but so far have not.
Oregon				
Saskatchewan				Nothing at this time.
South Dakota	Separate specification developed for WMA			Research project
Utah				Same as Hot Mix
Vermont				Project Special Provision modifying sections of HMA specification. Currently being developed.
Washington				Use of WMA is optional to the Contractors but must be proposed and approved by WSDOT.

Table B.16. WMA specification/approval procedure

State	Based on National Studies/Guidelines (Such as NCHRP Reports)	Based on Other DOTs Specifications	Developed by Your Own Agency	Comments
Colorado	Based on national studies/guidelines (such as NCHRP reports)		Developed by your own agency	
Idaho	Based on national studies/guidelines (such as NCHRP reports)		Developed by your own agency	NCHRP Report 691 under study for implementation
Indiana			Developed by your own agency	
Iowa	Based on national studies/guidelines (such as NCHRP reports)		Developed by your own agency	
Kansas		Based on other DOTs specifications		For now since our experience with WMA has been limited we have used Texas's experience with WMA. Once we have gathered more of our own information we will re-evaluate the steps to get pre-approved.
Maine			Developed by your own agency	May adopt New England agency guidelines for approval process and approved products list.
Manitoba, Canada			Developed by your own agency	
Michigan			Developed by your own agency	Agency and HMA Industry developed
Minnesota	Based on national studies/guidelines (such as NCHRP reports)	Based on other DOTs specifications	Developed by your own agency	
Missouri			Developed by your own agency	
Montana(1)	Based on national studies/guidelines (such as NCHRP reports)	Based on other DOTs specifications		Also based on MDT research of local Federal Lands projects utilizing WMA.
Montana(2)				
Nebraska		Based on other DOTs specifications	Developed by your own agency	We surveyed other DOT specifications and then for that brought in what was pertinent for our specification and local experiences.
Nevada(1)				Not developed yet.
Nevada(2)				
New Hampshire		Based on other DOTs specifications		
New York			Developed by your own agency	
Ohio			Developed by your own agency	
Oregon				

Table B.16. WMA specification/approval procedure - continued

State	Based on national studies/guidelines (such as NCHRP reports)	Based on other DOTs specifications	Developed by your own agency	Comments
Saskatchewan				No agency spec or approval process at this time. Trials are approved on a case by case basis.
South Dakota	Based on national studies/guidelines (such as NCHRP reports)	Based on other DOTs specifications	Developed by your own agency	will use all three to develop spec for state
Utah			Developed by your own agency	
Vermont			Developed by your own agency	
Washington			Developed by your own agency	Worked with Washington Asphalt Pavement Association to develop review and approval process based on nationally recognized processes.

Table B.17. Non-permitted technologies

State	Do you have a list of NOT PERMITTED (WMA technologies,	Comments
Colorado	No	Currently, some foaming processes are limited to 5,000 tons per project for test sections.
Idaho	No	
Indiana	No	
Iowa	No	Although our lab results with Advera are not encouraging
Kansas	No	
Maine	No	
Manitoba, Canada	No	
Michigan	No	
Minnesota	No	
Missouri	No	
Montana(1)	No	We don't specifically list technologies that we permit, instead we have listed technologies that we do allow.
Montana(2)		
Nebraska	No	
Nevada(1)	No	
Nevada(2)		
New Hampshire	No	
New York	No	If the WMA technology is on our approved list, then it can be used for an entire WMA project. Technologies that have not been put on our Approved List are limited to 1000 ton trial sections.
Ohio	No	
Oregon		
Saskatchewan	No	
South Dakota		not determined at this time
Utah	No	
Vermont	No	
Washington	No	

Table B.18. **Modification in acceptance plan compared to HMA**

State	Acceptance Sampling Type	Quality Characteristics	Specification Limits	Quality Level Goals	Risk	Pay Factors
Colorado	No	No	No	No	No	No
Idaho		Yes				
Indiana	No	No	No	No	No	No
Iowa	No	No	No	No	No	No
Kansas	No	No	No	No	No	No
Maine	No	No	Yes	No	No	No
Manitoba, Canada						
Michigan	No	No	No	No	No	No
Minnesota	No	No	No	No	No	No
Missouri	No	No	No	No	No	No
Montana(1)	No	No	No	No	No	No
Montana(2)						
Nebraska	No	No	No	No	No	No
Nevada(1)	No	No	No	No	No	No
Nevada(2)						
New Hampshire	No	No	No	No	No	No
New York	No	No	No	No	No	Yes
Ohio	No	No	No	No	No	No
Oregon						
Saskatchewan	No	No	No	No	No	No
South Dakota						
Utah	No	No	No	No	No	No
Vermont	No	No	No	No	No	No
Washington						

Table B.18. **Modification in acceptance plan compared to HMA - comments section**

State	Comments (Links or Other Information)
Colorado	
Idaho	
Indiana	Indiana expects all foamed asphalt to meet the HMA criteria.
Iowa	
Kansas	
Maine	Modification to specification limits is for mixing and placement temperatures as determined by the manufacturer recommendations.
Manitoba, Canada	n/a
Michigan	
Minnesota	Only difference is laboratory compaction temperatures.
Missouri	
Montana(1)	
Montana(2)	
Nebraska	
Nevada(1)	
Nevada(2)	
New Hampshire	
New York	Under our current experimetal work plan for WMA, the plant recieves no incentives/disincentives for mixture quality.
Ohio	
Oregon	
Saskatchewan	Acceptance is the same as HMA at this time.
South Dakota	not deermined at this time
Utah	
Vermont	
Washington	No modifications required. http://www.wsdot.wa.gov/biz/construction/word/wmaproposal.docx

Table B.19. Modifications in temperature monitoring compared to HMA

State	Mixing	Construction/Compaction	None	Comments
Colorado			None	
Idaho				
Indiana			None	
Iowa	Mixing	Construction/Compaction		WMA plant temp is proposed as part of the mix design. The design is done at this temperature. Production temp cannot drop more than 10F below the target temp. The max temp for WMA is 280F.
Kansas		Construction/Compaction		For HMA maximum density needs to be achieved by 175 F and for WMA by 165 F.
Maine	Mixing	Construction/Compaction		
Manitoba, Canada	Mixing	Construction/Compaction		
Michigan		Construction/Compaction		
Minnesota			None	
Missouri			None	
Montana(1)			None	
Montana(2)				
Nebraska			None	It is based on manufactures recommendation.
Nevada(1)			None	
Nevada(2)				
New Hampshire			None	
New York	Mixing	Construction/Compaction		Monitoring of the Temperature does not change. The mixing and compaction temperatures are as recommended by the WMA technology provider.
Ohio	Mixing	Construction/Compaction		We compact field specimens at 30 degrees less than the HMA design temp. We target about 30 degrees less at the pavement depending on conditions.
Oregon				
Saskatchewan	Mixing			WMA is mixed at a lower temperature, so plant operators must be aware of this, and adjust temperatures accordingly.
South Dakota	Mixing	Construction/Compaction		
Utah			None	
Vermont			None	Monitoring protocols are the same, only lower temperatures.
Washington			None	

Table B.20. Modifications in QA sampling schedule compared to HMA

State	Is the WMA sampling schedule for quality assurance different from HMA?	Comments
Colorado	No	
Idaho	No	
Indiana	No	
Iowa	Yes	Only in the realm of AASHTO T283. We normally only sample T283 for HMA on interstates and quartzite mixes; however, we will sample T283 for all WMA mixes above 3M ESALS.
Kansas	No	
Maine	No	
Manitoba, Canada	No	
Michigan	No	
Minnesota	No	
Missouri	No	
Montana(1)	No	
Montana(2)		
Nebraska	No	
Nevada(1)	No	
Nevada(2)		
New Hampshire	No	
New York	No	
Ohio	No	
Oregon		
Saskatchewan	No	
South Dakota	No	
Utah	No	
Vermont	No	
Washington	No	

Table B.21. Modifications in lab assurance testing compared to HMA

State	Sample preparation	Testing procedure	None	Comments
New Hampshire			None	
New York	Sample preparation			Laboratory samples are compacted at the WMA compaction temperature recommended by the WMA technology provider. One of our Approved technologies recommends conditioning the mixture in an oven prioir to any QC/QA laboratory testing.
Ohio	Sample preparation			30 degrees less compaction temp for WMA.
Oregon				
Saskatchewan			None	
South Dakota	Sample preparation	Testing procedure		
Utah			None	
Vermont			None	
Washington			None	

Table B.22. Modifications in QC plans compared to HMA

State	Compared to HMA, does your agency have any modifications on Quality Control Plan?	Comments
Colorado	No	
Idaho	No	
Indiana	No	
Iowa	No	
Kansas	No	
Maine	Yes	Contractor has to determine the technology-specific production and placement temperature range.
Manitoba, Canada	No	
Michigan	No	
Minnesota	No	
Missouri	Yes	Specify WMA temperature for mixing and compaction.
Montana(1)	No	
Montana(2)		
Nebraska	No	
Nevada(1)	No	
Nevada(2)		
New Hampshire	No	
New York	Yes	As part of a WMA technologies approval, the technology must write a "Production, Testing and Compaction Details" document. This document must be followed by the mixture producer to ensure that everyone using this technology is using it in the proper way. We require the mix producers to state in their Quality Control Plans that they will follow the "Details" writen by the technology provider.
Ohio	No	
Oregon		
Saskatchewan	No	
South Dakota	No	
Utah	No	
Vermont	Yes	Need to include section on the WMA technology to be used.
Washington	No	

Table B.23. **Test sections for evaluation of WMA performance**

State	Do you use test sections to evaluate	Comments
Colorado	No	
Idaho	No	We perform Test Strips on all projects HMA or WMA with no changes to either however we do not place control sections for WMA projects.
Indiana	No	
Iowa	Yes	We use test strips for both HMA and WMA. We verify density is being achieved with higher specification limits. If compaction is not achieved then a change in mix or rolling pattern may be needed.
Kansas	No	
Maine	Yes	Use of HMA control-strips to compare performance of WMA.
Manitoba, Canada	Yes	Distress survey of each test sections (rutting, cracking, ride)
Michigan	No	
Minnesota	No	Some sections at MnROAD
Missouri	No	
Montana(1)	No	Currently we have one research project to be constructed where we have one control paving section utilizing HMA and 3 other WMA technologies that we will be able to compare during construction and compare results following construction.
Montana(2)		
Nebraska	Yes	We allow the use of both WMA and HMA on a project, requiring at least 1000 tons of each material be placed, and then evaluate testing as we do with HMA and continue to monitor the road, visually evaluating it against the HMA and

Table B.23. **Test sections for evaluation of WMA performance - continued**

State	Do you use test sections to evaluate construction/performance of WMA technologies?	Comments
Nevada(1)	No	
Nevada(2)		
New Hampshire	No	
New York	Yes	We do allow trial sections to be built on NYSDOT roadways, but we do not require it. The approval process allows trial sections to be built in other states, cities, counties, etc. We follow up with the project owner on performace, construction, etc.
Ohio	No	We had condcuted trials a few years ago. We not longer construct test sections but may for a new technology.
Oregon		
Saskatchewan	Yes	Approval for test sections is conducted on a case by case basis. Tests at this point have included mechanistic testing of lab produced samples, some moisture susceptibility testing, and control sections established on WMA trials.
South Dakota		
Utah	No	
Vermont	No	
Washington	No	

Table B.24. Agency's reaction in case of use of non-approved WMA technologies

State	Reject	Accept with Penalty	Accept	Other (Please Specify)
Colorado	Reject	Accept with penalty		
Idaho	Reject			
Indiana				Cost added per ton of mixture for additives or modifiers has prohibited their use or request for use in Indiana.
Iowa	Reject			
Kansas	Reject			
Maine	Reject			All technologies must be approved prior to use by the contractor.
Manitoba, Canada				We would investigate the product and approve prior to use.
Michigan	Reject			Only allowing foaming/water injection at this time.
Minnesota	Reject			
Missouri				What is "non-approved?" If it is that the contractor used a recognized process without noticification, the mixture would be accepted based on testing and acceptable placement.
Montana(1)	Reject			
Montana(2)				
Nebraska	Reject			
Nevada(1)	Reject			
Nevada(2)				
New Hampshire				Require verification before use.
New York				If a producer seeks prior consent to use a non-approved technology, we are open to limited trials of 1000 tons or less. If a producer uses a non-approved technology without our consent, then the pavement section will be rejected.
Ohio	Reject			
Oregon				
Saskatchewan				At this time, no standard response exists. The ministry is open to new technologies, if the contractor/supplier shares some of the risk. However, it is unlikely a contractor would be allowed to proceed if they switched additives during construction.
South Dakota				
Utah				This issue should be performance based. Mix tests can be used to sort out the major sources of distress. If performance is demonstrated to be poor in labratory testing, penalties should be assessed accordingly. If a mix is executed contrary to design, it should not be accepted.
Vermont		Accept with penalty		Would likely accept with penalty if contractor can demonstrate no significant adverse effect. However, we monitor at the plant and would not allow production to begin if a non-approved used. Technology must be identified in WMA design.
Washington				N/A