THE SUITABILITY OF WARM MIX ASPHALT

FOR USE IN NORTH DAKOTA

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ABSTRACT

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Compared to hot mix asphalt (HMA), warm mix asphalt (WMA) offers several potential benefits, including reduced fossil fuel use and increased workability. The research presented in this paper examined the suitability of WMA for use in North Dakota, through review of previous research and experiences of North Dakota and other states, including those with similar weather to North Dakota. This review suggested that North Dakota and its neighboring states are looking to similar types of WMA to suit their varying needs. While more than one type of WMA may be suitable for use in North Dakota's climate, there could be some types that work better than others depending on aggregate sources, traffic volume and loads, and overlay versus new construction. North Dakota should continue to try various types of WMA and determine which additives or processes work best in the areas of the state's greatest need.

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CHAPTER 1. INTRODUCTION

In 2010, the North Dakota Department of Transportation (NDDOT) let its first two warm mix asphalt (WMA) paving projects, both of which utilized chemical additives. While the NDDOT continues to evaluate the suitability of different types of WMA for use in North Dakota, a recent survey of the asphalt paving contractors in North Dakota, discussed later, indicated that most contractors are capable of producing WMA mixes with either foaming processes, or chemical additives, or both. However, the contractors expressed that they would be open to any WMA processes or additives that NDDOT may specify on individual asphalt paving projects.

WMA has many potential benefits over hot mix asphalt (HMA). These benefits include (Horner, 2010):

- Reduced emissions and reduced exposure to workers
- Lowered CO_2 emissions
- Lowered energy consumption at HMA plant (up to 20%)
- Decreased asphalt binder aging
- Increased plant production and less wear on HMA plant
- Allows for longer haul distances
- Could extend the paving season to allow cool weather paving
- Acts as a compaction aid

One benefit that could be of particular interest to some North Dakota contractors is the potential for an extended paving season. Since North Dakota's paving season is limited by cold weather, the ability to pave into colder temperatures could extend the paving season and allow more work to be done. Kristjansdottir (2006) points out that:

> "When it comes to cold weather paving considerations, important factors to consider are compactability, moisture susceptibility, and binder grade. Compactability is indeed well accounted for by the warm mix methods, since they all reduce the viscosity of the asphalt and have the capability of increasing compaction and thereby reducing permeability. …many of the advantages gained when WMA is produced at regular HMA temperatures are particularly beneficial for cold weather conditions, e.g. extended paving season, easier compaction during extreme weather conditions and easier compaction for stiff mixes."

Other states have already adopted WMA as an acceptable alternative to HMA in many situations. While these states have policies governing the acceptable use of WMA, they tend to have differing viewpoints on determining what is "acceptable." The states that have adopted WMA typically either have a "loose" adoption policy or a "restrictive" adoption policy. States with a "loose" policy are more hands-off when it comes to evaluating a new WMA technology. "Loose" states leave it up to the contractor to prove that the specific type of WMA the contractor wants to use has a good performance history on prior projects, with minimal testing performed by the states prior to use. States with a "strict" policy of adoption are more hands-on and involved in the process. "Strict" states usually perform testing on a product before letting a contractor use it in the field. Once the states are satisfied with the product's performance, they place it on a list of acceptable materials that any contractor can use for future projects. Although states are taking these differing approaches for the evaluation of WMA, both methods are providing promising results. Experiences that other states, particularly those with similar weather to North Dakota, have had with WMA could be useful to North Dakota.

Objectives and Scope

The objective of this paper was to examine the suitability of WMA technologies for use in North Dakota. To accomplish this objective, a literature review was conducted on performance characteristics and costs of different types of WMA. Several state DOTs' practices and procedures for evaluating different types of WMA were surveyed as well as their experiences with WMA paving, including those of North Dakota and its neighboring states. Input was also obtained from North Dakota asphalt paving contractors through a questionnaire survey. Together, these results were used to formulate conclusions that can be used to help evaluate the suitability of WMA for use in North Dakota for a particular situation or condition.

Structure of Paper

This paper has been organized into six chapters. The first chapter introduces the topic of WMA in North Dakota. The second chapter presents background information on WMA and the results of a literature review on the performance of WMA. The third chapter describes the methodology used to conduct the research presented in this paper. The fourth chapter reports on other state DOTs' efforts to implement the use of WMA and presents the approaches they are using in evaluating different WMA processes and additives. The fifth chapter describes North Dakota's efforts for adopting WMA, including the results of NDDOT's first WMA projects and their plan for future projects, and discusses the results of the survey completed by six North Dakota asphalt paving contractors. The sixth chapter concludes this paper by summarizing the observations made during the course of research and making suggestions for further research.

CHAPTER 2. LITERATURE REVIEW AND BACKGROUND

Review of WMA Technologies

Warm mix asphalt is produced in a similar fashion to HMA. The difference between the two lies in additional agents added to the mix, explained below in this section. These additives make the asphalt less viscous at a lower temperature and better able to coat the aggregate.

The Asphalt Paving Association of Iowa (APAI) has defined warm mix asphalt on its website as "Hot-Mix Asphalt that is produced at temperatures 35° F–100° F cooler than normal production HMA temperatures. This temperature reduction is done through the use of techniques that reduce the viscosity of the asphalt cement allowing coating of the aggregate at lower production temperatures (Asphalt Paving Association of Iowa, 2011)." To achieve the reduced viscosity and coating at lower temperatures, an additive of some sort needs to be added to the mix, sometimes requiring special equipment. Currently, there are 22 different WMA technologies being marketed in the United States (Bukowski, 2011). The different types of WMA technologies can be divided into four categories: Water-Based Additives, Water-Bearing Additives, Chemical Additives, and Organic Additives (Perkins, 2009).

Water-Based Additives

The most common type of water-based systems in the United States involves injecting water into the hot binder through pressurized nozzles. Other methods of using water to create WMA include mixing damp aggregate with a hot binder. The reaction between the hot binder and moisture turns the water into steam and creates bubbles that get caught in the binder, resulting in a foaming action. This foaming action causes a rapid expansion in volume and a decrease in viscosity, which allows the aggregate to be coated at a lower temperature. These types of WMA technologies that involve equipment to inject water into the binder require significant modifications to the plant as well as additional equipment. Examples of this technology include the following:

- Astec Double Barrel Green
- Ultrafoam GX
- Aquablack WMA
- Terex Warm Mix Asphalt System
- Low Energy Asphalt

Water-Bearing Additives

Water-bearing WMA technologies are additives that consist of synthetic zeolites, which are crystalline structures. These zeolites contain around 18-21% water by mass and, when added to the mix at small dosages, cause a similar foaming action to that of water-based agents. The water is released from the crystalline structure when the temperature is around the boiling point of water. Because the foaming action starts to occur around the boiling point of water, it is possible for the binder to coat the aggregate at a lower temperature than that of HMA. There are currently only a few types of water-bearing additives, and they are similar in nature. They are Advera and Aspha-min. These two products do not require much, if any, modification to the asphalt plant.

Chemical Additives

Chemical additives are typically emulsions that contain a variety of chemicals that are helpful to create a mix at a lower temperature. The chemicals often contain anti-stripping agents, surfactants, and polymers to increase the workability and covering of an aggregate. The chemical additive can be used as an emulsion or be mixed with the bitumen during the mix process. Some examples of chemical additives include:

- Evotherm DAT
- Evotherm 3G
- Rediset WMX
- Revix
- Cecabase RT

Organic Additives

The most common type of organic additive is Sasobit, a paraffin wax. The wax comes in small pellets and is added to the mix at a rate of about 3-4% by weight of the bitumen. The wax has a melting point around the boiling point of water and, when mixed with the asphalt, reduces viscosity. This reduction in viscosity allows the binder to coat the aggregate at lower temperatures than that of HMA. When the temperature of the binder/wax mixture drops below the boiling point of water, the wax solidifies into lattice structures. These lattice structures help resist deformation and add stability. However, it has been shown that this added rigidity can have undesirable effects on low-temperature binder properties by reducing the m-value (Hurley and Prowell, 2005).

This adverse effect is caused by the stiffer binder not being able to relieve the stresses caused by a rapid cool down in binder temperature, which can result in thermal cracking in field applications. The suitability of the organic additive Sasobit for cold weather regions like North Dakota will be discussed in Chapter 5.

Performance of WMA

When looking at performance characteristics of WMA, it is important to consider many of the same characteristics that are used for HMA. The Superpave mix design methods of HMA specify performance grade (PG) of asphalt binder based on the field performance of asphalt's resistance to rutting, thermal cracking, and fatigue cracking. Another key performance indicator of an asphalt mix is resistance to moisture-induced damage or how susceptible a mix is to moisture damage. In fact, there have been several research efforts that investigated moisture susceptibility of WMA, collectively pointing to general tendency.

Moisture Susceptibility – Laboratory Samples

Moisture susceptibility is a bigger issue with WMA than it is with HMA. The main reason for this issue is the reduced production temperatures used in WMA. The higher temperatures required for HMA do a better job of drying the aggregate as it is produced. If an aggregate source has excess moisture saturation, the lower temperatures from WMA may be insufficient in drying the aggregate, allowing water to get in the way of the bond between the aggregate and asphalt. One possible remedy for this problem is covering the aggregate stockpile to prevent it from becoming saturated from rain (Prowell, 2007).

As a result, it would be beneficial to perform moisture testing when the aggregate source selected for WMA production has been subject to moist conditions. If the aggregate proves to have more than the wanted moisture content, it may be desirable to add an anti-stripping agent to the mix.

Most testing on the moisture susceptibility of asphalt is done using the tensile strength ratio (TSR), which is determined according to AASHTO T 283 *Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage.* The test is performed by compacting specimens to an air void level of 6-8%. Three specimens are chosen as a control and tested dry, and three more specimens are chosen to be saturated with water undergoing a freeze cycle and subsequently having a warm-water soaking cycle. The samples are then tested for indirect tensile strength by loading the specimens at a constant rate and measuring the force required to break the sample. The tensile strength of the conditioned specimens is compared to the control sample to determine the TSR. The AASHTO T 283 test can also be performed on field samples.

Commonly, an acceptable value for TSR testing is a value of .80 or greater. A lower value would indicate that the mix would be more susceptible to moisture damage and stripping. To remedy this problem, several steps can be taken. One solution would be to add a liquid anti-stripping agent to the mix, and another would be to add hydrated lime. Both of these methods would promote a better bond between the asphalt and aggregate. A third possible solution to raise the TSR value would be to alter the aggregate/mix design being used.

In one laboratory study (Sheth, 2010), it was found that all WMA samples had a lower TSR value than the control (Figure 1). This study indicates that using a WMA process to create a mix will increase the likelihood of moisture damage. However, in that study, it is important to note that not only did the WMA samples not pass the TSR rating of .80, but the control HMA sample also had a value less than the minimum acceptable value. This information indicates that all samples were susceptible to moisture damage.

An additional point that can be observed from this test is that Advera and Aspha-min both had significantly lower TSR values than the other WMA samples. Both Advera and Aspha-min are water-bearing additives.

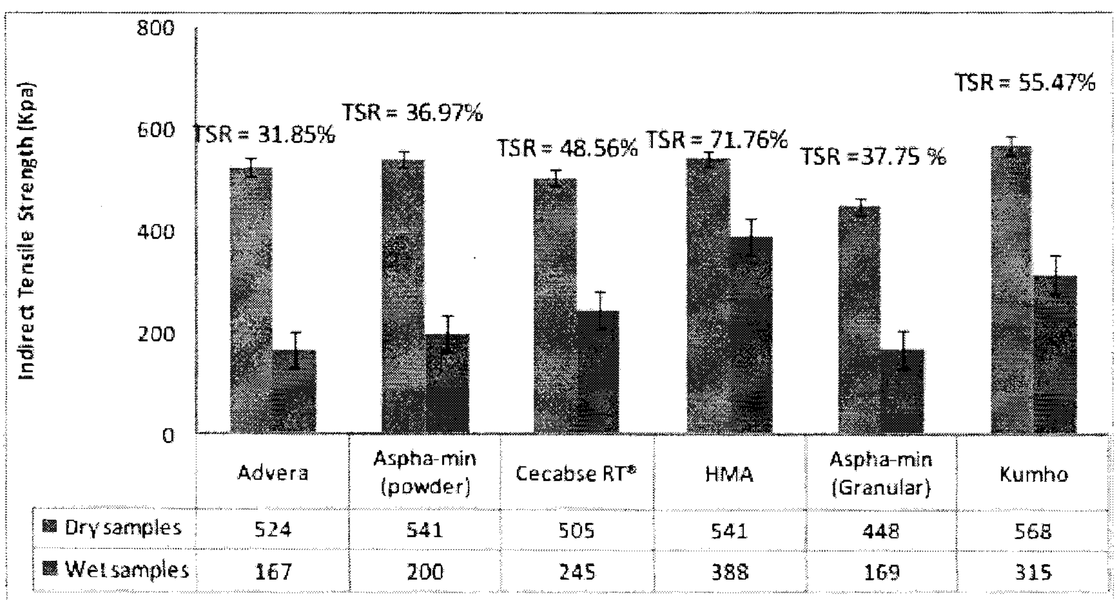

Figure 1. Sheth's TSR results (Sheth, 2010).

Another study (Hurley and Prowell, 2006) shows similar results to the previous study. In this study, only three of the nine samples had passing TSR values, which occurred at different compaction-temperature and aggregate-type combinations.

Again, the worst results were from the water-bearing additive Aspha-min. It is believed that these poor TSR values are the result of the binder being emulsified from the gradual release of water from the zeolites, which causes cohesive failure (Table 1).

Also worth noting is that the addition of hydrated lime did help increase the TSR value of Aspha-min. Although the TSR results did not pass the required minimum value of .80, it came very close.

Table 1. Hurley and Prowell's TSR Results (Hurley and Prowell, 2006)

Aggregate	Mix Type	Treatment	Stripping Inflection Point	TSR
Granite	Control	None	6500	1.16
Granite	Sasobit	None	3975	0.71
Granite	Aspha-min	None	3450	0.67
Granite	Evotherm	None	Not Observed	0.96
Granite	Aspha-min	1.5% Hydrated Lime	Not Observed	0.75
Granite	Sasobit	0.4% Antistripping Additive	Not Observed	0.94
Limestone	Control	None	2500	0.65
Limestone	Aspha-min	None	1700	0.51
Limestone	Sasobit	None	2900	0.91
Limestone	Evotherm	None	2550	0.62

Moisture Susceptibility – Field Samples

In one trial (Jones et al., 2008) performed on a test track in California, results showed that WMA had very comparable moisture sensitivity to that of the control HMA. The resulting TSR values (Table 2) for the WMA samples and control sample were all very close, indicating similar performance. Once again, the TSR values for all tested samples were below the required .80 minimum.

The results of this study did not really show any trend. The control, which had the lowest percentage of air voids, was not the best performer in the TSR category. Evotherm happened to have the highest percentage of air voids and was also the best performer in regards to TSR results (Jones et al., 2008).

Table 2. TSR Results from California Test Track (Jones et al., 2008)

Specimen	Stripping Inflection Point	TSR
Control	7.720	0.62
Advera	5.626	0.51
Evotherm	5.069	0.64
Sasobit	9.764	0.57

A field trial at the National Center for Asphalt Technology (NCAT) test track in Alabama (Prowell et al., 2006) showed a large difference in TSR values when comparing Evotherm WMA to the HMA control (Table 3). The control easily passed the .80 minimum TSR value while every sample of the WMA was less than half of the control.

This discrepancy could be the result of the control not being in the required air-void range that is specified. Because the air-void percentage of the HMA is lower than that of the WMA, the HMA may perform better than a mix with a higher air-void percentage.

Table 3. Evotherm TSR Results at NCAT Test Track (Prowell et al., 2006)

Mix Type	Avg. Air Voids (%)		Indirect Tensile Strength (psi)		TSR
	Unconditioned	Conditioned	Unconditioned	Conditioned	
HMA Control	4.6	4.4	104.1	98.0	0.94
Evotherm Surface	6.2	6.2	118.0	52.9	0.45
Evotherm Base	7.6	7.7	98.1	32.4	0.33
Evotherm Binder	8.0	8.1	106.9	40.6	0.38

The Florida Department of Transportation (FDOT) issued a report that included the performance of some of its WMA projects (Sholar et al., 2009). The FDOT has been pleased with performance so far. The state has tracked a couple of its WMA projects and reported the details (Table 4). The experience has shown that WMA has performed very close to the HMA control in the moisture susceptibility category as evidenced by the corresponding TSR values.

All of the previously mentioned studies on moisture susceptibility and many others are summarized in the Interim Report by the National Cooperative Highway Research Program (NCHRP) 09-47A. This report found that in most laboratory studies, WMA had lower TSR values than the control HMA (Kvasnak et al., 2009). The exception for this general rule is that Sasobit generally performed as well as, if not better than, the HMA control. Although laboratory testing has indicated the potential for moisture susceptibility, field trials have not shown the same propensity for moisture damage. This contradiction is one research task that NCHRP 09-47A will address upon its completion in 2013.

Table 4. FDOT WMA Comparison (Sholar et al., 2009)

Test Results for US-92 Project: Evotherm

Performance Measure	Mixture Type	
	HMA SP-12.5	WMA SP-12.5
Energy Ratio	1.66	1.64
APA Rut Depth (mm)	2.8	2.8
Tensile Strength Ratio (%)	70	65

Test Results for SR-11 Project: Double Barrel Green

Performance Measure	Mixture Type	
	HMA SP-12.5	WMA SP-12.5
Energy Ratio	1.7	1.85
APA Rut Depth (mm)	4.1	2.7
Tensile Strength Ratio (%)	61	58

As of now, the moisture susceptibility issue that is arising in the lab does not seem to be happening in the field trials (Kvasnak et al., 2009). This issue could be because, although WMA TSR values are typically slightly lower, the difference is often not significant. Another reason is that, even if WMA is more susceptible to moisture, it does not guarantee the mix will fail due to moisture. Mixes that are more susceptible to moisture must be subjected to moist conditions for a long enough period of time to be affected by the moisture.

Other Performance Characteristics

Rutting is another issue on which WMA testing has focused. This type of distress is a potential issue with WMA because of reduced aging in the binder during construction. Because the binder is not subjected to as high of temperatures, there is less oxidization taking place in the binder, resulting in a less stiff material. Because the binder is not as stiff as HMA, it could be more prone to rutting. In Interim Report I NCHRP 9-47A, a summary of the laboratory results from many studies states:

> "Several of the researchers evaluated different mixing temperatures and found that the rutting of the WMA decreased with increasing mixing temperature. The field produced WMA Hamburg results often indicated that the WMA, with the exception of Sasobit®, tended to rut more than the HMA. However, it should be noted that in many cases where the HMA passed the WMA still passed the criterion established in each study despite the increased rutting in the WMA." (Kvasnak et al. p.137, 2009)

Rutting is more likely to result in WMA because of the lower production temperatures. The additive typically does not contribute to the rutting potential, but the lower production temperature is the cause. As mentioned earlier, the exception to this rule is when using Sasobit and, sometimes, zeolite additives. Sasobit can actually add stiffness to the binder because of the wax additive's properties. When heated, the Sasobit wax melts and aids in decreasing the viscosity of the binder. When the Sasobit-mixed binder cools, the wax also cools and returns to its hardened state. This feature adds structure to the binder and causes it to be stiffer than it would normally be. It is also worth noting that, although the WMA binder was more susceptible to rutting than HMA in most studies, the additional susceptibility of WMA is only slight. In many cases, both the HMA and WMA passed the required specification.

One more performance characteristic used to categorize asphalt is its ability to resist thermal cracking. Commonly, a bending beam rheometer (BBR) is used to measure thermal cracking resistance. The NCHRP 09-47A report also found that BBR tests done on WMA indicate how most technologies improve resistance to thermal cracking, with the exception of Sasobit and occasionally some zeolite additives (Kvasnak et al., 2009). The same properties that make the WMA binder more susceptible to rutting also make WMA more resistant to thermal cracking. The lower production temperatures allow for less oxidization in the binder, resulting in a softer and less stiff binder. Thermal cracking is caused by the pavement contracting in cold temperatures; if the pavement cannot stretch quickly enough, it relieves the tensile stress by cracking. A soft and less-stiff binder is better able to stretch than a stiffer binder. Because Sasobit and some of the water-bearing zeolite additives add structure and stiffness to the binder, they can actually reduce the m-value of the binder, which is a measure of the ability of the binder to react to a sudden cooling and contracting of the pavement.

Fatigue cracking is also an important distress to consider. Estakhri et al. (2010) found through dynamic mechanical analysis of mix samples that WMA resists fatigue cracking better than HMA. However, Kvasnak et al. (2009) reported earlier that lab-produced WMA mixes commonly had shorter fatigue lives while field-produced WMA mixes had longer fatigue lives. One possible explanation for this inconsistency with a more recent finding is that due to issues associated with the scale of production, the laboratory testing did not accurately represent the actual conditions at the asphalt plant.

WMA Costs

The cost of a particular WMA technology can vary greatly depending on the type of product, additional equipment needed, amount of WMA being produced, and the amount of time over which the cost of the WMA technology is to be recovered. The initial costs for new equipment and installation for certain types of WMA technologies can be significant when compared to initial equipment costs of other technologies. Table 5 shows a recent cost breakdown for a variety of different WMA technologies.

In a study examining the cost of various WMA technologies available in the United States, it was found that water-based technologies of WMA technologies may be more cost effective when a large amount of mix is being produced, while chemical additive technologies may be more cost effective when WMA is being produced on a smaller scale (Bennert, 2008). For Bennert's study, WMA technologies were evaluated based on additional cost per ton for two different scenarios (Table 6). The first scenario assumed a small-scale production of WMA, with one contractor producing

Table 5. Cost Comparison of WMA (Swedeen, 2010)

Cost Element	WMA Technology						
	Organic Additive (Sasobit)	Water-bearing (Zeolites)	Water-based (Double Barrel Green)	Water-based (Ultrafoam GX)	Water-based (WAM-Foam)	Water-based (LEA)	Chemical Additive (Evotherm)
Equipment modification or installation			\$100,000-\$120,000	\$100,000-\$120,000	\$60,000-\$85,000	\$75,000-\$100,000	\$1,000-\$5,000
Royalties	None	None	None	None	\$15,000 first year, \$5,000 per plant, \$0.35 per ton	N/A	None
Material (Recommended dosage rate)	\$0.80/lb (1.5-3% by weight of binder)	\$0.60/lb (0.3% by weight of mix)	None (2% water to binder)	None (2% water to binder)	\$75 premium on soft binder (3% weight of binder)	None (0.5% coating additive weight of binder)	\$35-\$50 premium on binder (30% water, 70% AC)
Approximate increased cost of mix	\$2.00-\$3.00	\$3.60-\$4.00	None	None	\$0.27-\$0.35 Royalty	\$0.50-\$1.00 (depending on use of coating additive)	\$3.50-\$4.00

5,000 tons over a 5-day period for three different periods. The total tons of WMA produced in a year for scenario one is 15,000 tons. Scenario two assumed a large-scale production of WMA, producing 350,000 tons per year. Equipment costs and modifications to the plant were amortized over a 3-year period with a 12% compounded expected rate of return, and renting equipment was considered as an alternative when possible. For this study, equipment and additive costs were provided by the vendors, with freight costs calculated for shipment to a jobsite in New Jersey, Bennert's home state. It is also worth noting that the additional cost per ton reported did not include cost savings due to reduced fuel consumption, although Bennert (2008) did report that current data show a median average of 18% reduced fuel consumption to date.

A few things can be observed from looking at this comparison. The first important finding from this study is that, when producing a large quantity of WMA, water-based additives provide the lowest additional cost per ton. This lower cost is possible because there is not much, if any, additional cost for adding water to a mix. The only cost incurred is that of an upfront equipment installation. Although this upfront cost may seem significant at around $75,000-$120,000 (Swedeen, 2010), when spread over three years and over a million tons, the additional cost per ton is minimal. The three WMA technologies with the lowest cost per ton when the large-scale production scenario is used are Double Barrel Green, Low Energy Asphalt, and WAM Foam, all of which are water-based technologies. From the scenario using a small-scale production, the chemical additive Evotherm DAT is the lowest-cost alternative among those examined by Bennert (2008) – see Table 6.

Table 6. Cost Comparison of WMA at Different Scenarios (Bennert, 2008)

WMA Technology	Scenario	Equipment purchase	Equipment rental and mobilization per week	Additive cost per ton with freight	Anti-stripping agent deduct?	Estimated cost increase per ton
Advera	1	N/A	$6,900	$2.01	No	$3.39
	2	$130,000	N/A	$1.45	No	$1.62
Double Barrel Green	1	$90,000	N/A	$0.00	No	$2.81
	2	$90,000	N/A	$0.00	No	$0.12
EvothermTM DAT	1	$3,500	N/A	$2.25	Yes	$1.86
	2	$3,500	N/A	$2.25	Yes	$1.75
Low Energy Asphalt	1	$72,000	N/A	$0.88	Yes	$2.63
	2	$72,000	N/A	$0.88	Yes	$0.48
Rediset Terminal Blend	1	N/A	N/A	$3.48	Yes	$2.98
	2	N/A	N/A	$3.48	Yes	$2.98
Rediset Blown into Plant	1	N/A	$5,250	$2.85	Yes	$3.40
	2	$55,000	N/A	$2.85	Yes	$2.42
Sasobit Terminal Blend	1	N/A	N/A	$2.88	No	$2.88
	2	N/A	N/A	$2.88	No	$2.88
Sasobit Blown into Plant	1	N/A	$5,250	$2.28	No	$3.33
	2	$55,000	N/A	$2.28	No	$2.35
WAM-Foam	1	$100,000	N/A	$0.00	No	$3.12
	2	$100,000	N/A	$0.00	No	$0.13

[1] Advera addition rate is 0.25 percent by total weight of mix (5 lbs per ton).
[2] EvothermTM DAT addition rate is 0.25 percent by weight of binder.
[3] Rediset and Sasobit addition rate is 1.5 percent by weight of binder.
[4] Typical liquid anti-stripping additive addition rates are 0.25 to 0.50 percent weight of binder.

Summary

From the literature review discussed above, the following key observations were made:

- There are four main types of WMA: water-based additives, water-bearing additives, chemical additives, and organic additives.
- WMA technologies may affect the performance of the final mix. The organic additive Sasobit and the water-bearing zeolites could cause the mix to become more stiff, resulting in better rutting resistance but possibly requiring greater compactive efforts to achieve a specified pavement density, and negatively affecting resistance to thermal cracking.
- WMA may be found to have greater moisture susceptibility in the laboratory than in the field, e.g., once anti-strip or lime has been added.
- WMA is believed to improve resistance to fatigue cracking, but evidence does not always support this notion.
- Water-based additives are the most cost efficient when using large-scale production and recovering cost over a number of years. The chemical additive Evotherm was the least expensive option when using small-scale production.

In summary, the previous research efforts focused on evaluating certain types of WMA in particular performance characteristics. However, there have been few published efforts that synthesized varying performance characteristics of different types of WMA. To fill the gap, this research made one such attempt, and its outcome, presented in Table 7, formed the basis for evaluating all available types of WMA and identifying one particular type of WMA that may be best suited for use in North Dakota.

Table 7. Comparison of Field Performance Characteristics for Different Types of WMA

Criteria	WMA Type			
	Water-Based Additives	Water-Bearing Additives	Chemical Additives	Organic Additives
Rutting resistance	Slightly less than HMA, but still passes benchmark	Equal to or better than HMA	Slightly less than HMA, but still passes benchmark	Equal to or better than HMA
Thermal cracking resistance	Slightly better than HMA	Some zeolites can decrease resistance.	Slightly better than HMA	Sasobit can decrease resistance.
Fatigue cracking resistance	Longer fatigue life than HMA	Longer fatigue life than HMA	Longer fatigue life than HMA	Longer fatigue life than HMA
Moisture susceptibility	Almost equal to HMA	Almost equal to HMA	Almost equal to HMA	Almost equal to HMA
Cost for small scale production	$2.63-$3.12 additional cost per ton	$3.39 additional cost per ton	$1.86-$3.40 additional cost per ton	$2.88-$3.33 additional cost per ton
Cost for large scale production	$0.12-$0.48 additional cost per ton	$1.62 additional cost per ton	$1.75-$2.29 additional cost per ton	$2.35-$2.88 additional cost per ton

*Costs based on Table 6 (Bennert, 2008).

CHAPTER 3. METHODOLOGY

The objective of this paper was to investigate and analyze the suitability of different types of WMA for use in North Dakota. To achieve the research objective, several tasks were performed and generally followed the flow shown in Figure 2.

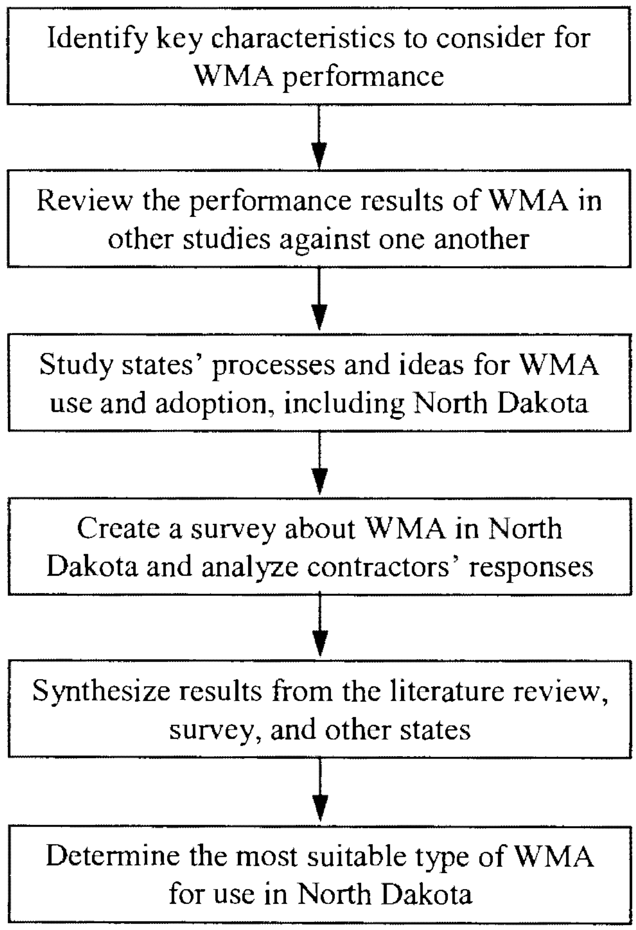

Figure 2. Research methodology.

Through the literature review, key performance characteristics that can be used to evaluate different WMA technologies were identified. There are already existing studies that tested these properties for many different types of WMA technologies.

Many of these studies evaluated more than one type of WMA technology at a time as well as a comparing the WMA data with a sample of HMA. To evaluate the different WMA technologies, they were compared against the performance of the HMA and other types of WMA in certain performance categories (Table 7). The data summarized in Table 7 are based on field trials for WMA rather than lab tests because field observations are considered to better represent real-world conditions.

To gain further understanding about the performance characteristics of WMA, several state DOTs were invited to share their experience using WMA and the evaluation process of WMA technologies for use in their states. This information was gathered with the intention of possibly applying some techniques from other state DOTs' WMA evaluation processes to North Dakota. Information was also gathered on North Dakota's limited experience with WMA which includes details from two field trials in 2010 and an outline of the NDDOT 2011 WMA paving plan.

The next step in the process was to gather feedback from experts in the North Dakota asphalt paving industry. This task was accomplished by creating an online survey and emailing it to contractors who regularly bid work from the NDDOT. The purpose of asking their opinions about WMA was to see if contractors would be willing to use WMA and to find out if they had any significant experiences with WMA.

Finally, all information from the literature, state DOTs, and ND contractor survey was synthesized to form the basis for evaluation that can be used in determining WMA technologies for potential implementation in North Dakota. It is noted that the findings and recommendations included in this Paper are primarily based on the author's observations from the literature review and his interpretation of state DOT engineers' and contractors' responses, rather than through laboratory testing or field observations.

CHAPTER 4. OTHER STATES' EFFORTS TO IMPLEMENT USE OF WMA

Neighboring State/Province Transportation Agencies' Experience

As of October 2010, at least 46 states, including North Dakota (described in Chapter 5), have started trial projects with WMA, and last year over 3 million tons of WMA was produced across the country (Limas, 2010). Since climatic conditions can significantly affect performance of asphalt pavements, the experiences that neighboring states and provinces with a similar climate have with WMA are reviewed in this section.

Minnesota

An engineer for the Minnesota Department of Transportation (Mn/DOT) provided the following general summary of the state's experience with WMA (T. Clyne, electronic correspondence, May 15, 2011).

- "The field performance of WMA has been similar to, or at times slightly better than, that of HMA. Rutting has not been an issue with WMA in Minnesota, nor has thermal or reflective cracking."
- "Mn/DOT has paved 4 WMA projects (below) to our knowledge. They all went relatively smoothly with little trouble. Early performance has been good. Many other counties, cities, and private developers have also done some warm mix work, most notably Crow Wing County in north-central MN."

- MnROAD, 2008
- TH 95, 2009
- TH 169, District 3, 2010
- TH 60, District 7, 2010
- TH 12, District 8, 2011 (planned)

At MnROAD, which is a roadway test section for the Mn/DOT located on I-94, six test cells of WMA were placed for evaluation in 2008 (Johnson et al., 2009). A summary of the project follows:

> "The WMA was placed on six test cells on the MnROAD Mainline. The mix was a level 4 Superpave (3-10 million ESALs) with PG 58-34 binder and 20% RAP. Five cells consist of 5" WMA (3" wear, 2" non-wear) over 12" recycled aggregate base, 12" aggregate subbase, 7" select granular, over a clay subgrade. A single asphalt mixture was needed to cover all five cells for a recycled aggregate base pooled fund study, on Cells 16-19 and 23. The sixth cell (Cell 15) consisted of a 3" WMA overlay of an existing HMA pavement, which represents a "typical" rehabilitation strategy in Minnesota. A control cell for WMA on the Low Volume Road (Cell 24) was also included in the study. The control mix has same mix design as the WMA but produced at typical HMA temperatures without the additive. Results of the study will include the

performance of WMA vs. HMA under traffic and environmental loading conditions."

This test project at MnROAD has shown promising results for the WMA that was tested. After construction, samples were collected and taken back to the lab for analysis. The non-wear course average TSR value was 83.4% and the wear course average TSR value was 85.6%, which is above the satisfactory benchmark of 80% and indicates that it is not susceptible to moisture damage. Other testing showed that WMA performed slightly better than HMA in resistance to thermal cracking. However, tests did show that the WMA samples may be more susceptible to short term aging (MnROAD, 2009).

South Dakota

South Dakota has experience using both water-based additives and chemical additives. So far, there have been four documented trials in South Dakota. Two smaller projects happened in 2009. One utilized water-based foaming for a shoulder reconstruction on I-90 near Cactus Flats. The other project in 2009 was in Mission, SD in late November and utilized the chemical additive Evotherm to create an access road for a shopping center. For this late season project, mix was hauled in from 101 miles away in large transport trucks. It was then dumped, remixed, and reloaded into end dump trucks to bring to the paver. By the time the mix reached the job site, mix temperatures were between 165°F-185°F. Cores for density were taken and ranged between 90.5%-92.1% for typical areas and 90.0%-91.8% for suspect areas where mix was reaching the paver at temperatures less than 170°F. Marks in the mix were reported to be rolled out at temperatures down to 130°F (Swedeen, 2010).

In 2010, the South Dakota Department of Transportation (SDDOT) conducted two more projects. Border States Paving placed over 3000 tones of terminal blended Evotherm WMA on South Dakota Highway 73. They reported burner fuel savings of less than 5% due in part to wet aggregate stockpiles, with about 6% moisture content. It was also reported that densities were better than or equal to conventional HMA and that WMA is volumetrically similar to HMA. The WMA was also found to be uniform in temperature than HMA (Swedeen, 2010).

The second study from 2010 was done by Anderson Western in May on South Dakota Highway 20 near the town of Bison. Again, over 3000 tones of terminal blended Evotherm 3G was placed, as well as over 4500 tones of water-based foamed asphalt. Burner fuel savings of 10%-12% were found even though the aggregate stockpiles were moist again, with moisture contents between 5.5%-7.0%. This study also found similar results to the previous study in that densities were better than or equal to conventional HMA and that WMA is volumetrically similar to HMA. Also, the WMA was again found to be more thermally consistent than HMA (Swedeen, 2010).

As of March 30, 2010, South Dakota governs the use of WMA via special provisions. These special provisions can be found in Appendix A. An SDDOT engineer had the following to say about their experience with WMA so far:

> "We can say that so far results are very encouraging..... At this time, I will say that the water foamed technology appears to have the

most potential as far as widespread applications based on economics. On the other hand, we are seeing superior performance with the chemical additives; however, the added expense may limit use of these materials to situations where adverse conditions (unseasonably cold air temps encountered in late or early season operations, long haul distances, etc.) are factors. Even though the primary usage of WMA in SD has been as a compaction aid, I believe other benefits are to be derived and will eventually come to the forefront." (J. Foster, personal communication, May 13, 2011)

Saskatchewan

Saskatchewan has completed two WMA trial projects, which occurred during the summer construction season of 2010. One project involved the chemical additive Evotherm 3G and the other was the organic additive Advera. In addition to these two projects, maintenance crews have used the chemical additive Cecabase on some of their patching jobs. Since these projects are relatively new, no formal performance data has been gathered yet. A summary from a Saskatchewan engineer is listed below (M. Jogi, electronic correspondence, May 18, 2011).

- "Maintenance crews used approximately 1000 tonnes pick up mix from G&C in North Battleford for blade patching with CecaBase RT (Colas)."
- "HJR paved a section of their rubber TLO (thin lift overlay) on Hwy 7 east of Saskatoon with Evotherm 3G-J1 (McAsphalt)."

- "Ministry tried Advera zeolite powder on Hwy 35-14 with Morsky Construction for 2,000 tonnes of mix, and Evotherm 3G-J1 for two days production as well."

Saskatchewan does not have any formal specifications governing WMA yet. They performed these projects on a trial basis and used information they had gathered in literature reviews and supplier's presentations. They also used the standard quality control testing that is normally followed for HMA.

Some general observations that the Saskatchewan engineers saw are as follows (M. Jogi, electronic correspondence, May 18, 2011).

- "Rubber TLO with WMA went very well, the crew were very pleased to work with rubber AC at lower temperatures, and we did not find any difference in the mix (however, on a TLO no densities are possible). Mixing temperature was at 135 deg C."
- "On hwy 35 we lowered mixing temp to 125 deg C for both additives. We found that the mix behaved very "fluid", almost too fluid. I suspect this has to do with the high sand content of our mixes (about 40 percent usually). Most other places limit their natural sands to no more than 20 percent at most, so their mixes are a lot stiffer, and the extra workability from WMA is welcome. Our mixes are not stiff by any means, so the extra workability was really not needed. We did not find any benefits in compaction."

- "We think that in Saskatchewan, the better use for WMA would be to mix it at regular temperatures in late season paving, but we have not yet tried that. The potential project we were looking was completed without WMA. Also, for mixes that have high content of crushed materials, like our rubber asphalt mixes, the WMA workability will be a bonus, since it should make compaction easier."

State DOTs' Approaches to Adopting WMA

The WMA trial projects, described earlier, were made possible either with special provisions or addenda that require the contractor to use WMA, or through permissive specifications that allow the contractor to choose WMA as an alternative to HMA. States that have permissive specifications include California, Florida, Iowa, Minnesota, Texas, Virginia, and Washington. Special provisions for WMA of South Dakota and Minnesota DOTs can be found in Appendix A and B, respectively. It should be noted that both special provisions and permissive specifications can exist in a given state, for example, Minnesota. Although it is not evident how much influence WMA additive suppliers have on determining specifications or special provisions, several state DOTs seek input from the supplier before allowing its use. A recent memo to some of the Mn/DOT engineers (J. Garrity, electronic correspondence, April 4, 2011) indicated that Minnesota sought supplier input for their recommendation on lower lab compaction temperatures. Also, PennDOT seeks supplier input, "especially about the various mixture production, delivery, compaction, and quality control testing temperature ranges recommended by the WMA technology manufacturer" (T. Ramirez, electronic correspondence, May 9, 2011).

To gain perspective on how different states are adopting WMA, DOT engineers from several states were contacted and asked about their state's adoption process. When it comes to evaluating a WMA technology, states tend to have differing viewpoints on how to determine what is "acceptable" and are taking either a hands-on or hands-off approach. "Loose" states that take a hands-off approach leave it up to the contractor to demonstrate that a specific WMA technology the contractor wants to use has a good performance history on prior projects. As such, state DOTs with a "loose" approach perform only minimal testing themselves. States with a "strict" approach are more hands-on and use a meticulous list of procedures as part of their evaluation process. These states often perform their own testing on a trial WMA mix before permitting a contractor to use it in the field. Testing performed includes QC/QA tests and those to determine any potential performance issues with a WMA mix. Once the test results on a given WMA technology is found satisfactory, it is placed on the state's list of acceptable materials that any contractor can use for future projects.

One state that uses a "loose" evaluation process is Texas. When asked about Texas' evaluation process for using WMA, a Texas Department of Transportation (TxDOT) engineer said:

> "...the only thing we require is that the vendor supply us with QCQA [Quality Control/Quality Assurance] data showing the product has been used on 3 or more projects and we prefer that at least one of the projects

> be a Texas project. We have found that Contractors only use the products with good track records so we leave it to them to decide what to use. Our approval process is intentionally very lax... We have not had any problems with this approach so far." (D. Rand, electronic correspondence, January 26, 2011)

This statement from D. Rand indicates that TxDOT relies on the contractor's previous experience with and knowledge of WMA. This "loose" policy puts the burden on the contractors to prove that the type of WMA technology that they would like to use has a proven record of successful projects. The state DOTs using this method are relying on existing research and are assuming the contractor chooses a product that will result in a quality material. These "loose" selection methods may include some testing, but it is mostly quality control and quality assurance (QC/QA) testing. TxDOT approved WMA technologies are listed in Table 8; however, it should be noted that: "We do not try to endorse any product or imply that it is good just because it is on our list. Our list is just an acknowledgment that there is some experience with us of the product." (D. Rand, electronic correspondence, January 26, 2011)

Another state that is "loose" in evaluating new WMA technologies is Minnesota. A Mn/DOT engineer said the following about Minnesota's view of WMA:

> "Mn/DOT does not have any approved products list for WMA technologies. We've either left it completely wide open for the contractor to choose, or we've told the contractor to pick one of about 20 available technologies off the list at www.warmmixasphalt.com. Our

specs are essentially silent on WMA, so we implicitly permit its use everywhere." (T. Clyne, electronic correspondence, May 17, 2011)

Table 8. Approved WMA in Texas (D. Rand, electronic correspondence, Jan. 26, 2011)

WMA Technology	Type	Supplier
Advera	Water-bearing	PQ Corporation
Aspha-Min	Water-bearing	Aspha-Min
Double Barrel Green	Water-based	Astec Industries, Inc.
Evotherm	Chemical	MeadWestvaco Asphalt Innovations
Redi-Set WMX	Chemical	Akzo Nobel Surfactants
Sasobit	Organic	Sasol Wax Americas, Inc.
Terex Warm Mix Asphalt System	Water-based	Terex Roadbuilding
AQUABlack	Water-based	Maxam Equipment
Ultrafoam GX	Water-based	Gencor Industries

Since the Mn/DOT has left the specification "silent" on the issue of WMA, contractors may use this permissive specification to try WMA as an alternative to HMA. If a contractor chooses to use WMA rather than HMA, the Mn/DOT will also allow them to choose which type of technology to utilize in producing WMA.

In contrast, the Pennsylvania Department of Transportation (PennDOT) is taking a "hands-on" approach, creating a procedure to follow when a company would like to use a type of WMA that is not already approved for use in the state. The first step for a new WMA process is for the applicant to fill out a questionnaire which asks a number of questions about the new WMA technology (Appendix D). "This is a set a questions, that I require all new or PennDOT unapproved WMA Technology Companies to provide answers to regarding their production ready WMA Technology" (T. Ramirez, electronic correspondence, January 25, 2011). This questionnaire is used as an information gathering tool and has no right or wrong answers. Once that document is completed and reviewed, PennDOT will either reject the proposal, send the questionnaire back for further detail about areas lacking certain information, or move forward with a pilot construction project which it has detailed in another document (Appendix E).

During a pilot WMA project, PennDOT has samples taken for QC/QA testing, along with other samples which their Materials Testing Division uses for further research. The results of these tests from the pilot projects are then reviewed and analyzed to determine if the WMA technology receives a passing or failing mark. Once a WMA technology is found satisfactory, PennDOT places it on the state's approval list, which can be used by any contractor for future projects. Table 9 shows eight WMA technologies that PennDOT initially approved based on NCHRP Report 09-43 by Bonaquist (2010). Since then, four additional WMA technologies have been added to the approved list. These four additions are all water-based WMA and have been included in the PennDOT list because similarly based technology was already on the approved list. The four technologies that were added are as follows:

- Eastern Industries, Inc.: SMART-FOAM System
- Meeker Equipment Co.: Meeker Warm Mix System
- Maxam Equipment, Inc.: AQUABlack Solutions Warm Mix Asphalt System

- Stansteel Asphalt Equipment Products: Accu-Shear Warm Mix Asphalt System

Table 9. Initially Approved WMA in Pennsylvania (T. Ramirez, electronic correspondence, Jan. 25, 2011)

WMA Technology	Type	Supplier
Advera	Water-bearing	PQ Corporation
Low Emission Asphalt	Water-bearing	McConnaughay Technologies
Double Barrel Green	Water-based	Astec Industries, Inc.
Evotherm	Chemical	MeadWestvaco Asphalt Innovations
Redi-Set WMX	Chemical	Akzo Nobel Surfactants
Sasobit	Organic	Sasol Wax Americas, Inc.
Terex Warm Mix Asphalt System	Water-based	Terex Roadbuilding
Ultrafoam GX	Water-based	Gencor Industries

Virginia is using a similar approach to evaluating WMA technologies. An engineer for the Virginia Department of Transportation (VDOT) stated:

> "…As far as deciding what processes to evaluate for the approved list we left that up to the market. Rather than devoting a lot of resources on evaluating every process we were approached with, without knowing whether a Virginia contractor would be interested, we required potential candidates to find a willing HMA contractor to partner with, and at that time we would begin the evaluation process." (T. Rorrer, electronic correspondence, January 25, 2011)

The engineer from VDOT went on to point out that the following list, although not a standard or special provision, is a summary of the steps that are taken to approve a new WMA technology for use in Virginia.

1. The Contractor will contact the District Materials Engineer and provide documentation regarding the non-approved product or process. This documentation shall include product/process specifications and independent asphalt material testing results.
2. The District Materials Engineer will discuss the product/process with the Asphalt Program Manager (me) and determine whether or not to proceed.
3. If approval to proceed is obtained, the Contractor shall submit a new job mix formula for review and approval by the VDOT District Materials Engineer.
4. At an agreed upon location, the Contractor shall produce no more than 500 tons (i.e. trial section) of warm mix asphalt (WMA) following the special provisions related to the placement of WMA.
5. During production, VDOT and Contractor will obtain samples for testing in compliance with the special provisions related to the testing of WMA. To include TSR testing verifying the .80 ratio.
6. Within one week of production, VDOT will evaluate the laboratory and field density results for the non-approved product/process. VDOT will decide whether or not to reject, conditionally approve, or approve the

> new product/process. For products/processes rejected, the contractor must perform additional testing on non-VDOT projects prior to resubmission to VDOT for consideration. Products/processes resubmitted must return to Step 1 of this procedure. For conditionally approved products/processes, at least one additional trial section will be required for reevaluation. For approved products/processes, the Contractor will be allowed to produce and place the material in accordance to the special provisions for WMA. Approved products/processes will be added to Approved List #66. (T. Rorrer, citing Trenton Clark, electronic correspondence, January 25, 2011).

In summary, different state DOTs are using somewhat different approaches to adopting WMA technologies while all state DOT engineers inquired have expressed satisfaction with their approach. From a limited sample of state DOTs reviewed in this Paper, it appears that either a hands-on or hands-off approach is being used depending on extensiveness of contractors' experience with WMA and any particular performance requirements for a state. State DOTs may be hands-on due to considerations around cold climate that demands particular performance requirements and merits thorough materials testing. However, states with cold climate could be rather "hands-off" if they intend not to preclude any type of WMA from being adopted. "Hands-off" state DOTs may also be such that the contractors in their state have significant work experience with WMA. Finally, it is noted that regardless of adoption approaches, state DOTs may have their list of approved WMA technologies similar to each other. This can be seen from comparing the lists of hands-off and hands-on state DOTs, for example, TxDOT's and PennDOT's shown in Table 8 and Table 9, respectively - eight of the nine technologies on TxDOT's list also show up on PennDOT's list. Typically states with a list of approved WMA technologies have all four types of WMA technologies approved while some states do not have their own list at all, for example, Mn/DOT as they allow the contractors to choose from many available on the market (T. Clyne, electronic correspondence, May 17, 2011).

CHAPTER 5. NORTH DAKOTA'S EFFORTS FOR WMA ADOPTION

North Dakota DOT's Efforts

During the summer of 2010, the NDDOT had their first two WMA projects built using a chemical additive, Evotherm 3G. The NDDOT's research objectives for these projects were as follows (Horner, 2010):

- "Evaluate bumps at cracks in overlays caused by reactivation of crack sealing materials."
- "Determine if WMA meets the current NDDOT standards for HMA specifications, (Density, Ride, etc)."
- "Compare aggregate production, plant operations, and construction practices for differences between WMA and HMA."

During the construction season of 2010, the NDDOT did not use special provisions to allow the use of WMA. Instead, they had "developed specifications for WMA processes including chemical additives and foaming specifications, by working with several other states" (R. Horner, electronic correspondence, June 21, 2010). These specifications have then been incorporated as an addendum to the WMA project plans. An excerpt of the portion of the addendum that pertains to WMA is listed below (NDDOT, 2010).

- "WARM MIX ASPHALT: The warm mix asphalt (WMA) process will be used on this project."
- "The Evotherm 3G product shall be added to the asphalt binder by the supplier or refiner and have no special handling requirements above and beyond those of the binder itself."
- "Production and paving temperatures may need to be increased for long haul distances, decreased ambient temperatures, or other WMA project specific conditions. All requirements in Section 408 for the production and placement of conventional HMA mixtures are to be enforced except as noted in these plans."
- "The contractor shall modify the mix design used to produce the HMA to meet the WMA criteria when produced with Evotherm 3G additive. All current mix design criteria will be required when developing the WMA mix design. The mix design will be contractor developed."
- "The WMA produced shall not exceed temperatures greater than 275°F. Any WMA over that temperature will not be used. During WMA production, the contractor will test the temperature of the mix at the point of discharge from the plant. The temperature test will be done once per hour and the results will be recorded along with the test time and quantity of mix produced. This information will be provided to the Engineer on a daily basis."

- "Place the WMA on dry, unfrozen surfaces and only when weather conditions allow for proper production, placement, handling, and compaction. The minimum delivery, placement and compaction temperatures that will achieve workability and density requirements will be reviewed and approved by the Engineer. The minimum rolling temperature will be established during the start of mix production."
- "All costs for the WMA shall be included in the price bid for 'Hot Bituminous Pavement Cl 29' and 'Warm Mix Modified PG Asphalt'."

The first WMA project in North Dakota was performed in the second half of July, 2010. This project used natural gravel, PG 58-28 binder, and Evotherm 3G to create a 1.5" TLO on ND Highway 11. There was over 8,000 tons of WMA placed over an approximate 5 miles of test section. The remaining 3.7 miles of the project were used as an HMA control section (Swedeen, 2010).

Although the research on this project is scheduled to go into 2013, some preliminary data has been gathered. One piece of information that was collected was the production rate and temperature for the WMA at the plant (Table 10).

Table 10. ND HWY 11 WMA Production Rate and Temperature (Horner, 2010)

Date	Plant Target Temperature (°F)	Average Production Rate (tons per hour)
7/22/2010	250	520
7/22/2010	240	545
7/23/2010	250	517
7/23/2010	235	560

7/23/2010	240	535
Average	243	535.4

Although there was not comparable data available for HMA production rate and temperature for this project, it can be seen how the change in temperature affects the production rate of WMA. There is an inverse relationship between production temperature and production rate.

Another piece of data that was compiled for this project involved comparing the compaction of WMA to HMA. As Table 11 shows, the average compaction rate for WMA was very close to that of HMA, at 93.6% and 94.0% respectively (Horner, 2010).

Table 11. ND HWY 11 Compaction Comparisons (Horner, 2010)

WMA Compaction Control		HMA Compaction Control	
Date	Average Compaction	Date	Average Compaction
7/21/2010	92.9%	7/19/2010	93.8%
7/22/2010	94.3%	7/20/2010	94.2%
Average	93.6%	Average	94.0%

The other project was conducted in late August of 2010 and consisted of a 1.5" TLO on over 8 miles of ND Highway 20. Natural gravels, PG 58-28 binder, and terminal blended Evotherm 3G was used to create of 16,600 tons of WMA. The control HMA section was a 1.5" TLO on approximately 5 miles of US 281, which was paved in mid-September.

Although not all research is complete yet, there have been some observations made on this project as well. Production temperatures and production rates were tracked during this project. The average production temperature for WMA was 240°F and the average production rate was 415 tons per hour (TPH), as seen in Table 12. This data can then be compared to the HMA control section in Table 13. For the control section, the average temperature was at 300°F and the average production rate was 376 TPH. This shows that Evotherm allowed the production temperature to be lowered by around 60°F which increases the production rate by 39 TPH on average.

Table 12. ND HWY 20 WMA Production Rate and Temperature (Horner, 2010)

Date	Average Temperature (°F)	Average Production Rate (tons per hour)
8/20/2010	237	388
8/21/2010	231	408
8/23/2010	239	427
8/24/2010	251	428
8/25/2010	244	423
Average	240	415

Table 13. US 281 HMA Production Rate and Temperature (Horner, 2010)

Date	Average Temperature (°F)	Average Production Rate (tons per hour)
9/13/2010	297	376
9/14/2010	303	374
9/15/2010	293	378
9/16/2010	305	374

Average	300	376

Another piece of information that was monitored was the amount of compaction that was achieved. For this first trial, WMA had a noticeably higher average compaction of 94.3% compared to the HMA control section compaction rate of 92.5% (Table 14).

Table 14. ND HWY 20 WMA and US 281 HMA Compaction Comparison (Horner, 2010)

WMA Compaction Control		HMA Compaction Control	
Date	Average Compaction	Date	Average Compaction
8/20/2010	95.0%	9/13/2010	92.1%
8/21/2010	93.9%	9/14/2010	92.9%
8/22/2010	93.8%	9/15/2010	92.7%
8/23/2010	94.3%	9/16/2010	92.3%
Average	94.3%	Average	92.5%

The NDDOT has plans to continue researching WMA in the future. Of particular interest to the NDDOT is researching water-based foaming technologies. Also, one additional area of potential future research will be using reclaimed asphalt pavement (RAP) in WMA (Horner, 2010). These areas of interest are well represented in the NDDOT's plan for WMA projects to be completed during the construction season of 2011. Summarized in Table 15, these planned WMA projects are to expand on the preceding year's projects by "including new chemical additives, incorporating recycled asphalt pavement, and using the foaming process to develop WMA" (R. Horner, electronic correspondence, June 21, 2011). Each of these planned WMA sections will be about 5 miles in length and will be paved adjacent to the HMA control section. Core samples will be taken once again to measure density. In addition, the NDDOT plans to monitor and record asphalt temperature out of the haul truck, immediately behind the paver, and immediately before and after each compactor (K. Evert, electronic correspondence, April 26, 2011).

Table 15. 2011 NDDOT WMA Projects (K. Evert, electronic correspondence, Apr. 26, 2011)

North Dakota Highway Number	Approximate Project Length (miles)	WMA Type
15	13	Evotherm
15	8	Evotherm and Water-based
3	18	Advera
41	17	Advera
32	17	Evotherm

North Dakota Contractor Survey

A questionnaire survey was developed and sent to nine contractors who were found by looking at bid results from the previous NDDOT asphalt paving projects. Of those nine, six completed the survey. The contractors took the survey on the promise of anonymity, and no information that would identify the respondents was collected - each respondent was assigned a number starting with 1. The rest of this chapter describes the questions asked and provides a discussion of the responses - the individual contractor responses can be found in Appendix F.

The first question asked, "Which type of Warm Mix Asphalt would your company invest in if future projects required the use of one of the following technologies?" They were given the option to choose one or more of the following choices; water-based additives, water-bearing additives, chemical additives, or organic additives. Then, there was a follow-up question asking "What factors drove your choice(s) for the previous question?" In response to this series of questions, five of the six contractors said that they would invest in water-based additives while four of the six said chemical additives. Three contractors indicated that they would be open to using any of the four choices that the NDDOT may require. Three contractors also chose the technologies with which they already had working experience and, therefore, with which they were comfortable. Also worth noting is that two of the six respondents who chose water-based additives cited cost as being a factor.

The response to question 1 suggests that contractors are waiting to invest (more) in WMA technology until the NDDOT provides more guidance for what it wants. Even though some contractors have experience using WMA technologies, most of this experience comes from use in other states since, to date, only two WMA trial projects have taken place in North Dakota.

After the survey results were gathered, it was noticed that contractors likely interpreted question 1 in two different ways. The first way to interpret the question is that the DOT would specify a particular type(s) of WMA technology to use in various paving projects and the contractors should be deciding whether or not to invest in the specified technologies in order to submit competitive bids. The other way to interpret the question is to choose one technology out of the four assuming that the DOT will allow the contractor to choose any type of WMA as an alternative to HMA, for use in a given paving project – this is known as permissive specifications.

The second question asked, "How many years have you (or your company) worked in the asphalt pavement industry?" This question was asked to make sure that the responses were credible. The number of years of experience that the responding contractors had in asphalt paving ranged from 20 to 75 years. This showed that each respondent has significant experience working in the asphalt industry and can, therefore, be a credible source.

The next question asked 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?" Four of the six contractors indicated that they had worked on WMA projects in the past. Of them, three stated that water-based WMA was the most common while two of the four respondents also stated that chemical additives were also commonly used. Organic additives and water-bearing additives were not mentioned by any of the four contractors as being commonly used in their past experiences.

The fourth question was, "As a contractor, what are the main issues you would face when beginning to work with Warm Mix Asphalt?" This question was asked to gain perspective as to what contractors think would be some initial problems when starting to use WMA. Two of the contractors thought that the additional cost would be one of the main issues associated with initial use of WMA. Two other contractors cited the owner's fear of unknown performance and the owner wanting extended warranties – however, an NDDOT personnel clarified that they "do not require external warranties on asphalt paving" (R. Horner, electronic correspondence, June 21, 2011). Other responses included setting up equipment and the addition of additives to the mixing process.

The next question asked in the survey was, "What benefits do you think the use of Warm Mix Asphalt would provide to your company?" This question sought to determine what the contractors think WMA will contribute to their operation. Five of the six responses indicated as potential benefits lower overall cost or specific cost items that can contribute to lowering the overall cost, such as reduced fuel consumption, easier compaction effort, the ability to haul longer distances, and increased recycle usage. Three contractors mentioned the reduced emission of fumes, which would be beneficial for the workers and the environment. The same three contractors also thought that a benefit to them would be an extended paving season.

Question six asked, "What are the drawbacks you see to using WMA?" This was asked to gain insight on the problems contractors perceive to go along with WMA use. Five of the six contractors responded that extra cost or extra equipment would be one downfall. Two contractors also stated the potential for stripping or moisture damage as another potential problem.

The contractors seeing cost as a benefit and a drawback of using WMA could be reflecting that the contractors are aware of potential benefits and cost but also understand that the cost equation could balance out differently depending on the technology and situation. This reflection points to the need for the contractors to obtain experience using WMA in North Dakota, in order to determine where the cost equation that applies to North Dakota will be balanced.

The seventh and final question asked "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 contractors were able to select one or more of the four types of technologies listed earlier for question 1. Two contractors thought water-based additives would be the most suitable while another two were unsure. The other three types of WMA technology, water-bearing additives, organic additives, and chemical additives, each received one response. Although water-based additives received the most responses for the WMA technologies, they were not a choice by the majority. The responses to this final question reaffirmed that North Dakota contractors are not completely backing any one particular type of WMA technology.

To summarize the survey responses, most North Dakota asphalt paving contractors are capable of producing WMA mixes with either foaming processes, or chemical additives, or both. However, some contractors seem hesitant to invest in any particular WMA technology at this point in time while they are willing and eager to try different processes and additives. One possible reason for this hesitancy is that the contractors do not know yet which processes or additives will eventually be required on the NDDOT's future WMA paving projects.

Most Suitable Types of WMA for North Dakota

For a state DOT to adopt WMA for widespread use, "WMA pavements must have equal or better performance when compared to traditional HMA pavements" (Conway, 2011). The general conclusion from NCHRP Interim Report 09-47A (Kvasnak et al., 2009) is that in the field trials conducted to date, WMA has performed as well as HMA. Furthermore, it is believed that most WMA technologies could increase pavement fatigue life in the field. In fact, some of the state DOTs whose adoption process for WMA is described in Chapter 4 have all four types of WMA on their approval list, irrespective of their different adoption approaches. This may be that such state DOTs either do not believe that any one type of WMA is superior to others or consider that different types of WMA can be used to satisfy different performance requirements.

For example, rutting resistance of asphalt pavements can be increased with the use of certain organic and water-bearing additives, such as Sasobit and some zeolites like Aspha-min, that can make asphalt binder slightly more stiff. However, this will also reduce thermal cracking resistance, which is very important for asphalt pavements in North Dakota that typically has extremely cold winters. Low-temperature induced tensile stresses on the asphalt pavement surface layer is believed to cause many transverse cracks and bumps on asphalt pavements in North Dakota, adversely affecting ride quality and requiring repair and rehabilitation (Felker and Parcells, 2009). Thus, considering North Dakota's climate that demands thermal cracking resistance, water-based WMA and chemical additives may be more suitable than organic and water-bearing additives. Although rutting resistance of water-based and chemical additives is known to be slightly lower than that of HMA, typically they still pass rutting-performance benchmarks. Minnesota, which has a few years of WMA experience in a climate similar to North Dakota, has not experienced any rutting problems to date while using chemical and water-based additives (Clyne, 2010)

Besides performance, cost of different types of WMA as well as local contractors' experience and production capability should also be considered when examining the suitability of using WMA in North Dakota. Of all four types of WMA technologies, water-based WMA involves the lowest additional cost per ton if a contractor produces 350,000 tons or more per year (Bennert, 2008). This conclusion by Bennert (2008) also applies to North Dakota in which annual tonnage produced by an asphalt paving contractor ranges from 280,000 tons to over 800,000 tons (G. Mayo of Mayo Construction, personal communication, March 23, 2011). It is also noted that the additional production cost for water-based WMA, which ranges from \$0.12 to \$0.48 per ton (not including the cost of adding anti-strips or lime; see Table 6), may be offset by average cost savings of 18% associated with reduced fuel consumption for WMA (Bennert, 2008).

The North Dakota contractor survey, described earlier, indicated that three contractors out of the six who responded are capable of producing water-based WMA, having already made an upfront investment in necessary equipment purchase and plant modifications. In fact, water-based WMA received the most votes from the responding contractors as best suited for use in North Dakota although they did not represent the majority. These contractors also noted that they have experience using chemical additives as well on asphalt paving projects in neighboring states.

Given North Dakota's climate and known performance characteristics of various types of WMA, water-based and chemical additives appear to be the most suitable for a broad use in North Dakota. These two types are also the most common of any previous WMA projects that the North Dakota contractors have working experience with – however, the contractors' experience was not quantified during this study. If further consideration is to be given to production cost, chemical additives are more advantageous in the short-term or for projects involving small scale production, e.g., field trial or pilot projects. However, water-based WMA may become more cost-effective over time, and how soon this may be the case will depend on the scale of actual production of water-based WMA by the contractors. This in turn is driven by overall production volume for water-based WMA in the state's demand.

Although the research reported here attempted to determine most suitable types of WMA for use in North Dakota, NDDOT may eventually find other types of WMA acceptable for certain applications. For example, water-bearing and organic additives could be beneficial to farm to market roads that carry heavy equipment traffic and require extra rutting resistance. For a moisture prone aggregate source, chemical additives that include anti-stripping agents could be considered. As such, NDDOT should continue to evaluate various types of WMA against performance specified for HMA and determine which WMA processes or additives are an acceptable alternative and under what circumstances. This recommendation coincides with NDDOT's plan for summer 2011 to perform field trial projects with water-based and water-bearing WMA as well as the chemical additive Evotherm, which was tried in the summer of 2010. However, it should be noted that the timing of state-wide adoption decisions being made will depend on, among others, an evaluation approach that NDDOT feels comfortable with. While the contractors are hoping for NDDOT's adoption of certain types of WMA that would suggest potential, broad use in years to come, performance of WMA in North Dakota's climate is unknown, let alone the availability of historic data on its long-term field performance – the first WMA project in the U.S. was in 2006.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The research presented in this paper examined the suitability of WMA for use in North Dakota. The results of review of previous research and North Dakota's and other states' experiences with WMA can be summarized as follows:

- WMA is performing in the field as well as HMA while WMA pavements have been in service for too short a period of time to indicate long term field performance.
- Two potential performance issues with WMA have been found in the laboratory: moisture susceptibility, and rutting. Different than in the laboratory, field trials of WMA have shown results comparable to HMA; it is possible that field conditions were not sufficiently accurately replicated in the laboratory.
- Sasobit and some zeolite additives can decrease performance in regards to thermal cracking, but they may also increase rutting resistance.
- The additional cost of using WMA can be as low as an extra \$0.12-\$0.48 per ton, which does not include the cost of adding anti-strip or lime that is recommended for water-based WMA. Depending on scale of production, chemical additives or water-based processes involve the lowest additional cost.

- State DOTs are adopting similar WMA technologies through varying evaluation approaches. While some state DOTs perform thorough testing on a WMA process or additive under consideration, other state DOTs rely on contractors to identify a quality product for use in pavement construction.
- Some North Dakota asphalt paving contractors have invested in water-based WMA technology while others are open to any types of WMA that NDDOT may require on asphalt paving projects. In either case, the contractors viewed cost as one important factor for their investment decision.

Considering the experiences that a few states with similar weather to North Dakota have had with WMA, as well as North Dakota's limited experience, it can be said that more than one type of WMA may be suitable for use in North Dakota's climate. Different types of WMA present different advantages and disadvantages. As such, one particular type may be better suited for some applications while another WMA technology may be more beneficial for other applications. Noting that North Dakota's neighboring states have been evaluating similar types of WMA to suit their varying needs, North Dakota should first identify the areas of application in which WMA offers the greatest potential for improvement over HMA. In identifying the areas of the state's greatest need, factors other than climate should be considered, including aggregate sources, traffic volume and loads, and overlay versus new construction (R. Horner, electronic correspondence, June 21, 2011). These factors will form the basis for North Dakota and other states in creating a set of test beds and evaluating the suitability of using a specific WMA process or additive in a targeted application area.

The information gathered during the course of this research may be useful to state transportation agencies that are leaving all possible types of WMA open for potential adoption but need to make preliminary comparisons among one another and to HMA. Contractors who are considering WMA as an area of development may also find value in the content of this paper.

Recommendations for Future Research

Currently, the NCHRP Project 09-49 has ongoing research to investigate the moisture susceptibility of WMA. This study is examining if WMA negatively affects the moisture susceptibility of the pavement. It also is looking at setting guidelines for WMA pavements to limit the moisture susceptibility (Kvasnak et al., 2009).

The NCHRP Interim Report 09-49 includes a review of written WMA documents on moisture susceptibility (Epps Martin et al., 2011). Other information gathered included surveying state DOTs, WMA equipment manufacturers, and WMA additive suppliers in an effort to identify existing WMA pavements that may have moisture damage and can be studied. This interim report proposes a work plan for the Phase II of the project, which will examine:

- "laboratory experiments to evaluate the time horizon associated with WMA moisture susceptibility"

- “the effectiveness of standard tests to predict materials and methods to minimize moisture susceptibility”
- “The comparison of LMLC [laboratory-mixed laboratory-compacted] specimens, PMLC [plant-mixed laboratory-compacted] specimens, and PMFC [plant-mixed field-compacted] cores”

As was mentioned earlier, no long-term study on WMA has been completed. Future research should include determining long-term field performance of different WMA technologies. Once long-term performance data exist, a life-cycle cost analysis could be performed and used to compare one WMA technology against another to identify which product will yield the lowest cost over its lifetime. It would also prove beneficial to more accurately measure the energy and fossil-fuel savings that can be attributed to using WMA compared to HMA.

This research also found that results from WMA laboratory testing did not always match results from field trials. Further research could be done to evaluate laboratory testing methods that would better replicate field conditions and, therefore, provide more accurate test results.

To date, there is not much evidence supporting an increased fatigue life in WMA pavements. Although some experts believe that the reduced oxidation of the binder should contribute to a longer fatigue life, some data to the contrary also exist, showing a decreased fatigue life. More research investigating the fatigue properties of WMA would prove to be beneficial.

Warm mix asphalt is one way that the asphalt industry is improving environmental sustainability. Another practice that is good for the environment and can conserve resources is the use of reclaimed asphalt pavement (RAP) as an asphalt pavement. More research on combining RAP and WMA could prove to be beneficial for the environment, conserve resources, and help reduce costs. WMA could prove to be effective in improving workability during field compaction of the rather stiff RAP.

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APPENDIX A. SOUTH DAKOTA SPECIAL PROVISIONS ON WMA

STATE OF SOUTH DAKOTA
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION FOR
WARM MIX ASPHALT CONCRETE
FIELD TRIAL SECTION

PROJECT P 0073(42)25, 248-391, 244-392 PCN 5968, I1B7, & I1B8
BENNETT, JACKSON, JONES, & MELLETTE COUNTY
MARCH 30, 2010

The following specification modifications to the Special Provision for Gyratory Controlled Quality Control/Quality Assurance Specifications for Hot Mixed Asphalt Concrete Pavement shall only apply to all Warm Mix Asphalt (WMA) produced for a field trial section.

Section 320.1 - Add the following to this section:

A field trial section(s) of WMA concrete pavement shall be placed in accordance with these specifications except as otherwise noted and as directed by the Engineer. This trial section will have an established control section of Q2 placed concurrently with the trial section of WMA.

Section 320.2 A. - Add the following to the end of the first paragraph of this section:

WMA additives utilized in the field trial sections shall be combined to the mixture or asphalt binder as recommended by the manufacturer. The dosage rate for the WMA additive shall be based on the mixture type, aggregate, asphalt binder, and job mix formula specific to this project. The dosage rate shall be recommended and verified by the manufacturer. The job mix formula, as noted in this section and specific for this project, shall be the starting point for addition of WMA additives and any changes to the job mix formula as well as the addition of WMA additives shall be verified in writing by the Bituminous Engineer. If the WMA additive is added to the asphalt binder, a separate sample of the asphalt binder with additive shall be submitted to the Bituminous Engineer in addition to the requirements of Section 320.3 D.3.d.

Section 320.3 A. - Add the following note under the table of minimum air temperatures & seasonal limitations:

Seasonal limit of May 1 may be waived for control section and WMA field trial section as directed by the Bituminous Engineer. Minimum temperature requirements shall remain in place unless it is deemed by the Bituminous Engineer that conditions are conducive to completion and analysis of the field trial sections (control and WMA).

Section 320.3 B.1. - Add the following to the end of this section:

The plant shall be capable of monitoring burner fuel usage during the production of the control and the WMA field trial tonnage. A beginning and ending burner fuel quantity for the production of the control and the WMA tonnage will be acceptable.

Section 320.3 D.5.c.1 - Add the following paragraphs after the table of Pay Factor Attributes:

For the WMA field trial section, the Pay Factor Attributes of a. % Air Voids and b. In Place Density (% Compaction) shall be evaluated as follows:

> **Air Voids:** A modified test procedure temperature will be determined based on the production and compaction temperature of the trial placement. Nominal air void assessment will be made and compared to the results from testing the same sample at conventional test temperatures. WMA field trial material will not be subject to the pay factor analysis but may be price adjusted (DOT-18) for deviations due to plant failure and/or production errors.
>
> **In Place Density:** Field test results shall be compared to the applicable lower specification limits for the class of mix produced. WMA field trial material will not be subject to the pay factor analysis but may be price adjusted (DOT-18) for deviations due to low density.
>
> The pay factor analysis (Quality Index) shall still be computed for the WMA field trial lot but payment shall be as noted above.

Section 320.3 J - Delete the first sentence of the 9th paragraph on page 26 and replace with the following:

Irregularities shall be corrected before the temperature of the WMA drops below 140° F (60°C) or as recommended by the manufacturer and approved by the Bituminous Engineer.

Section 320.3 J.1 - Delete the second sentence and replace with the following:

Compaction rolling shall be completed before the temperature of the WMA drops below 140° F (60°C) or as recommended by the manufacturer and approved by the Bituminous Engineer.

Section 320.5.A - Add the following to this section:

The accepted quantities of asphalt binder for the WMA field trial section will be paid for at the negotiated contract unit price for PG 64-28 (WMA modified). This item shall include all modification, shipping, production and mixing costs associated with the asphalt binder for the WMA field trial section.

Section 320.5.B - Add the following to this section:

The accepted quantities of asphalt concrete for the WMA field trial section, only, will be paid for at the negotiated contract unit price for Class Q2 Asphalt Concrete (WMA modified). This item shall include all storage, mixing and placement costs associated with the WMA asphalt concrete.

The price of the Class Q2 Asphalt Concrete (WMA modified) will be adjusted downward based on the documented burner fuel savings. Burner fuel savings will be calculated as follows: burner fuel utilized in production of the control section mixture minus the burner fuel utilized in production of WMA tonnage pro-rated and the savings shared 50%/50% by the Department and Contractor.

APPENDIX B. MINNESOTA SPECIAL PROVISIONS ON WMA

S-1 (2360) PLANT MIXED ASPHALT PAVEMENT – USE OF WARM MIX ASPHALT TECHNOLOGIES

The provisions of the attached 2360 Plant Mixed Asphalt Pavement (Gyratory Design) Specification is hereby modified as follows in order to use Warm Mix Asphalt (WMA)

All provisions for the production and placement of WMA will be the same as the conventional HMA mixtures as stipulated in 2360 Plant Mixed Asphalt Pavement (Gyratory Design) Specification except as noted below.

S-1.1 DESCRIPTION

This mixture designation will be used for the Warm Mix Asphalt.

In the absence of Contract items covering shoulder surfacing and other special construction, the accepted quantities of material used for these purposes will be included for payment with the wearing course materials.

S-2.1 MIXTURE DESIGN

The contractor is responsible to use the same design used to produce the Hot Mix Asphalt, then modifying it to accommodate products or processes to meet the Warm mix criteria. This modification process will be limited to the same as described by the WMA Technical Working Group and found at
http://www.warmmixasphalt.com/WmaTechnologies.aspx

Recycled Asphalt Shingles will not be allowed in any mixes on this project.

S-3.1 MIXTURE QUALITY MANAGEMENT

The Warm Mix Asphalt produced will not be allowed to exceed temperatures greater than 275°F. Any WMA over that temperature will not be allowed to be used.

S-4.1 CONSTRUCTION REQUIREMENTS

The contractor is responsible to submit the following data prior to paving:

1. Which WMA technology and/or WMA additives are to be used

2. WMA technology material safety data sheets (MSDS)

3. Temperature range for mixing

4. Temperature range for compaction

The contractor will test the temperature of the mix at the point of discharge from the plant. The temperature will be taken with a temperature testing device capable of +/- 3°F. All temperature tests are to be documented with the test time, test temperature and quantity of mix produced. The testing rate shall be 1 test per hour. This data will be recorded and turned in daily to project personnel.

The contractor will monitor the aggregate and RAP moisture content prior to introduction to the drying or mixing drum. Testing at a rate of 1 sample per day with the results recorded and turned in to project personnel.

S-5.1 Payment

Payment for WMA will be made on the basis of the following:

Item No.	**Item**	**Unit**
2360.501	Type SP (1) Wearing Course Mixture ((2), (3)) Special WMA	**ton**

(1) Aggregate Size Designation.

(2) Traffic Level as per Table 2360-1-A.

(3) AC binder grade designation.

APPENDIX C. TEXAS WMA POLICY AND APPROVED LIST

Texas Department of Transportation

Warm Mix Asphalt (WMA)

The following Warm Mix Asphalt (WMA) additives and processes are pre-approved for use on department projects. Contact Dale Rand, P.E. of the Flexible Pavements Branch of CST/M&P at (512) 506-5836 for any information and status.

Approval requires the submittal of documentation from a minimum of 3 construction projects using the WMA technology, preferably a minimum of 1 in the State of Texas. Documentation must include a mixture design with mechanical property test results and Quality Control/Quality Assurance (QC/QA) test results measured during production. The following information must be included with the documentation:

- Contact Name & Telephone Number;
- Product Name & Supplier;
- Dates of construction for each project;
- Project Control-Section-Job (CSJ) Number for each project, if available; and
- Location and Highway for each project submitted.

WMA Technology	Process Type	WMA Supplier
Advera (Synthetic Zeolite)	Chemical Additive	PQ Corporation
Aspha-Min (Synthetic Zeolite)	Chemical Additive	Aspha-Min
Double Barrel Green	Foaming Process	Astec Industries, Inc.
Evotherm	Chemical Additive	MeadWestvaco Asphalt Innovations
Redi-Set WMX	Chemical Additive	Akzo Nobel Surfactants
Sasobit	Organic Additive	Sasol Wax Americas, Inc.
Terex	Foaming Process	Terex Roadbuilding
Maxam	Foaming Process	Maxam Equipment
Ultrafoam GX	Foaming Process	Gencor Industries

APPENDIX D. PENNDOT WMA QUESTIONAIRE

The following description of the questionnaire was provided by Timothy Ramirez, the Engineer of Tests for PennDOT Materials and Testing Division. The actual document is on the following page.

1. Provide responses to each of the questions on the attached WMA Technology Questions document.
    a. This is a set a questions, that I require all new or PennDOT unapproved WMA Technology Companies to provide answers to regarding their production ready WMA Technology.

Pennsylvania Department of Transportation (PennDOT)

Bureau of Construction and Materials (BOCM)

Materials and Testing Division (MTD)

WMA Technology:

---

1. Basic information:
    a. Primary technical representative?
        i. Contact Information?:
            1. U.S. Mail Address?
            2. Landline telephone number?
            3. Mobile telephone number?
            4. E-mail Address?
    b. Primary sales representative?
        i. Contact Information:?
            1. U.S. Mail Address?
            2. Telephone number?
            3. E-mail Address?
2. Product Category?
    a. Organic Additive,
    b. Foaming Additive or Process
    c. Chemical Additive
3. Product Form?:

   a. Beads, Pellets, other
4. Any health or safety issues?
5. WMA Technical Representative available during all production and placement?
   a. True technical rep or salesman?
6. Technical Data standardized and able to be disseminated to Engineering Districts and HMA Producers?
   a. WMA Technology Basic Info & Characteristics
   b. Plant production temperatures and any extreme limits
      i. PG Binder storage temperatures at HMA Plant?
      ii. Mixture temperatures during production?
   c. Any known previously experienced issues and solutions
   d. Field compaction temperature ranges and any extreme limits
   e. Plant QC testing procedures or differences from HMA QC testing
      i. Mixture conditioning time and temperatures for:
         1. Ignition furnace or solvent extraction testing (asphalt content & gradation testing)?
         2. Compaction of gyratory specimens for volumetric analysis testing?
         3. Theoretical Maximum Specific Gravity Testing?
7. Terminal Blend?
   a. PG Binder suppliers who are interested or capable of providing?
   b. PG binder grading data?

    c. Additive affect on binder grade?
    d. Dosage rate(s)
        i. Different dosage rate for RAP or different %'s of RAP
8. HMA Plant Blending?
    a. Written process for HMA plant blending?
    b. Equipment required?
    c. PG binder grading data?
    d. PG Binder certification?
    e. Dosage rates?
        i. Different dosage rate for RAP or different %'s of RAP?
9. Approval in other States?
    a. Evaluation reports available?
        i. Can reports be provided?
10. Used in other States as Pilots?
    a. Evaluation or pilot project reports available?
        i. Can reports be provided?
11. Develop mix designs with additive or use existing HMA mix design?
    a. If develop mix designs with additive, is their a written procedure to follow?
    b. Is procedure consistent or provide the appropriate modifications to PennDOT Pub. 27, Bulletin 27?
12. Data on WMA Technology production through plant?

a. Temperature of PG Binder with Additive (Terminal Blend) at plant?

b. Plant production temperatures?

    i. Recommended Range?– Is this standardized for dissemination to Engineering Districts & HMA producers?

c. Particle Coating (AASHTO T 195) data?

d. Recovered PG Binder data?

    i. Is additive able to be recovered?

e. Mixture Composition (AC, Gradation) testing data?

    i. Mixture conditioning time & temps (mid-point) before ignition furnace or solvent extraction testing?

f. Mixture Volumetrics data (Air Voids, VMA, VFA)?

    i. Mixture conditioning time & temp(s) (mid-point?) before gyrating specimens?

    ii. Gyratory specimen compaction temp(s) (mid-point)?

g. Moisture Sensitivity data (AASHTO T 283 – PennDOT modifications)?

    i. Mixture conditioning time & temp(s)?

    ii. Compaction temps for gyratory specimens?

    iii. Lab mixed, lab compacted tensile strength and TSR data?

    iv. Plant mixed, lab compacted tensile strength and TSR data?

13. Project Field Data?

    a. Mixture cooling rate?

        i. Expected loss in temps for standard hauls (<1 hour)

ii. Expected loss in temps for long hauls (>1 hour)?

b. Workability?

i. Hand work/luting?

1. Same as HMA or different?

a. If different, specifically how is it different?

ii. Sticking to equipment, haul trucks, MTV's, etc.?

1. Clean-up?

c. Compaction?

i. Recommended compaction temperature range?

ii. Can WMA mixture be outside range on high side? Low side?

iii. Pavement Core Density data?

iv. Variability of Core Density data?

d. USA project history?

i. Comparisons to HMA control sections?

ii. Longest performance to date?

iii. Successful performance?

iv. Any distresses linked to the WMA technology?

v. Distress differences between WMA and HMA control?

14. Temperature able to open to traffic?

APPENDIX E. PENNDOT WMA TESTING MATRIX

The following description of the testing matrix was provided by Timothy Ramirez, the Engineer of Tests for PennDOT Materials and Testing Division. The actual document is on the following page.

- This document is the current test matrix that I require all new or PennDOT unapproved WMA Technology Companies, Contractors, Material Suppliers, and PennDOT Engineering Districts to agree to for doing an initial pilot project using a new or unapproved WMA Technology. A pilot project is only done after providing response to Item #1.
- Samples and specimens specifically to be submitted to PennDOT's Materials Testing Division (MTD) are highlighted in yellow.
- QC testing information to be submitted to MTD is highlighted in turquoise.
- All other information listed on the test matrix is to be collected jointly by the Prime Contractor, WMA Producer, and the PennDOT Engineering District responsible for the project and submitted to the MTD.

WARM MIX ASPHALT

TEST MATRIX FOR PILOTING NEW WMA TECHNOLOGIES

Construction projects piloting new WMA Technologies in a test section must also include a HMA control section for comparison purposes. The HMA control section Job Mix Formula (JMF) is to be the same JMF that is used in the WMA test section with the only difference being the addition of the WMA Technology. Additional data collection, sampling and testing will be conducted during WMA test section construction and HMA control section construction as summarized below. The requested information, samples or specimens below should be documented and prepared for both the WMA test section and the HMA Control Section. The contractor shall support these activities as directed for each WMA test section. Testing, other than QC testing, shall be conducted by PENNDOT or other selected researchers, with the exceptions noted in 5) Testing.

1) Project Summary
    a) Project location
    b) Contractor

c) Paving date(s)

d) Paving time(s), day, night, etc.

e) Weather conditions – particularly ambient air and surface temperatures during laydown

f) WMA process(es) used

g) Tonnage produced

h) Digital photos or video of the project during construction (production and/or laydown of HMA, photos of key operations, photos after completion, etc.) ***Optional***

i) Any reports about the project produced by the contractor or others. ***Optional***

2) Material Properties

a) Aggregate properties ***(Bulletin 14 values should be reported if used)***

i) Aggregate type(s)

ii) Dry bulk specific gravity

iii) Water absorptions

iv) Stockpile moisture contents

v) Superpave consensus and source properties (generally should be part of mix design, including: coarse aggregate angularity (ASTM D5821), uncompacted voids in fine aggregate (AASHTO T304 Method A), flat and elongated particles (ASTM D4791), sand equivalent (AASHTO T176), LA Abrasion (AASHTO T96), and soundness (AASHTO T104).

b) Binder properties

i) Binder supplier (as listed in Bulletin 15, Section 702

ii) Binder grade (attach copy of Manufacturer's certification or Bill of Lading and copy of Manufacturer's Certificate of Analysis (COA) for the lot/batch of PG binder blended with any modifiers/additives)

iii) Base binder grade, if WMA used to modify binder, e.g., Sasobit

iv) Modifiers (if any)

c) Mix Design (attach copy of mix design volumetric properties)

i) Nominal maximum aggregate size

ii) Target gradation

iii) Optimum asphalt content

iv) Laboratory compaction effort

3) Production information

a) Plant type

b) Plant model

c) Describe method of introducing WMA additive(s)

d) Production rate

e) Aggregate discharge temperature (if applicable)

f) Mix discharge temperatures (history during production)

g) Observations regarding motor amperages, particularly drag chain

h) Collect fuel consumption data for both the HMA and WMA[1]

i) Observations regarding baghouse after WMA run (moisture problem?)

j) Use of silos and typical storage time.

4) Laydown information

   a) Temperature range of WMA at load out

   b) Truck type (tandems, etc.)

   c) Haul distance/Haul time

   d) Release agent used (if any)

   e) Observations regarding dumping material/sticking in truck beds (if any)

   f) Use of transfer vehicles

   g) Paver type and model

      i) Vibratory screed on?

      ii) Screed heated?

   h) Compacted thickness

   i) Temperature immediately behind screed (history)

   j) Roller Train

      i) Type and model

      ii) Weight

      iii) Amplitude and frequency of vibratory rollers (if applicable)

      iv) Tire pressure of pneumatic roller (if applicable)

   k) Roller Pattern – a separate roller pattern should be performed for the WMA and control mixes

   l) Time and mat temperature when opened to traffic

5) Testing

a) Laboratory Mix Tests – to be performed on both the WMA and control sections.

   i) Moisture content of mix at load out (sampled from truck) – PTM 749

   ii) Maximum specific gravity ***Submit QC test results***

   iii) AC content and Gradation Tests – shall be conducted in accordance with quality control frequencies per Standard Specifications. ***Submit QC test results***

   iv) Volumetric analysis testing of gyratory compacted specimens shall be conducted according to standard requirements with modifications, as necessary, from the WMA Technical Representative . ***Submit QC test results***

   v) Gyratory compaction of six specimens for each mix type to specified Ndesign compaction effort without reheating mix other than to desired compaction temperature. Record time needed to reheat mixture samples (if any). After the volumetric properties are measured, the specimens will be labeled, packaged in concrete cylinder molds and delivered to the MTD for testing of rutting potential at the recommended climatic high temperature for the site.

   vi) Prepare 6-8 gyratory specimens to 7 ± 0.5 percent air voids and a height of 95 mm for Tensile Strength Ratio Testing without reheating mix other than to desired compaction temperature. Record time needed to reheat mixture samples (if any). Label, package in concrete cylinder molds and deliver to the MTD for testing.

The following equation has been used to estimate TSR specimen weight in order to obtain 7 percent air voids:

$$M = (0.915)(Gmm)(\pi)(56.25)(9.5) = 1536.1(Gmm)$$

The 150 mm diameter specimens should be compacted to a constant height of 95 mm. Typically NCAT will compact two trial specimens first, allow to cool, determine bulk specific gravity, and adjust the mass as necessary to obtain 7 percent voids for an additional six specimens.

vii) Compact three gyratory specimens to a height of 170 mm at the anticipated in-place (field) density for testing using the Asphalt Mixture Performance Tester (AMPT). The following equation has been used to estimate the target specimen weight for 150 mm diameter specimens compacted to a height of 170 mm. The first factor, 0.895, is the anticipated in-place density (93 percent of Gmm) minus 4.5 percent. The adjustment to the anticipated in-place density is necessary to correct for surface texture and the fact that the center of the specimen is denser than the total specimen (100 mm diameter AMPT test samples, 150 mm tall, will be cored from the oversize SGC specimens).

$$M = (0.895)(Gmm)(\pi)(56.25)(17.0) = 2688.7(Gmm)$$

b) Sampling ***To be obtained for PENNDOT or other researchers as requested.***

   i) Obtain at least one-gallon of the binder, preferably in 4 quart cans.

   ii) Obtain approximately 30 lbs of each aggregate stockpile and RAP, if used.

   iii) Obtain three five-gallon buckets (approximately 180 lbs) of mix.

   iv) Obtain at least a one-gallon sample of any warm mix additive added directly at the plant (zeolite or Sasobit).

Testing Notes

[1]Fuel consumption can be difficult to measure. Natural gas usage is the easiest to quantify. Tank dips can be inaccurate, particularly if recycled oil is used as fuel or another fuel which may not be completely atomized.

APPENDIX F. SURVEY RESULTS

Contractor #	Question#1				
	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?
1	Water Based Additives	Water Bearing Additives	Chemical Additives	Organic Additives	Will invest in all technologies required by the local DOT's as necessary.
2	Water Based Additives				We own one.
3	Water Based Additives	Water Bearing Additives	Chemical Additives	Organic Additives	We have already bought a water based system and have already tried chemical, water bearing, and Wax system additives
4	Water Based Additives		Chemical Additives		Proven technologies with which we have working experience. The water based additives is the most cost effective over time.
5			Chemical Additives		More familiar with the sales rep for customer support. Would be open to any of the products based on cost and what the DOT felt is most beneficial bang for the buck. For a pilot project the Evotherm can be come delivered that way with out the initial investment of pump/foamer. Once the DOT figured out which process / product they were going to go with we then would make the investment, but do not want to spend money without a clear direction.
6	Water Based Additives				one time euipment costs

Contractor #	Question#2	Question#3	
	How many years have you (or your company) worked in the asphalt pavement industry?	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?
1	31	No	
2	20	Yes	Water based & chemical Additves (Evo therm.)
3	50+ years	Yes	Water Injection
4	70 +/-	Yes	Aquablack foaming (Water based foaming)
5	Myself 28 years, company 75 years.	No	
6	30	Yes	evotherm on one of the two jobs in North Dakota in 2010

Contractor #	Question#4	Question#5	Question#6
	As a contractor, what are the main issues you would face when beginning to work with Warm Mix Asphalt?	What benefits do you think the use of Warm Mix Asphalt would provide to your company?	What are the drawbacks you see to using WMA?
1	Addition of additives to the mixing process.	Higher production levels and lower overall costs.	Additional process equipment (injection) and possible stripping if not monitored properly.
2	Cost	We haven't used it enough to tell.	Cost
3	Cost, since WMA is not any cheaper than hot mix contractors have been a little reluctant to go there yet. Chemical and wax are about 2 to 5 dollars to run. Where water systems cost \$45,000 to \$75,000 per system. Although Warm mix saves on fuel or gas it is not enough to compensate the cost of the additive.	Better Work environment, less Fumes(30 to 80 reduction), Less Fuel usage (5 to 8% less), paving later in season (Not Sure about this one), increased recycle usage	Cost, extra testing like T 283 moisture testing, possible binder issues if not checked
4	Overcoming the fears of the inspector/Owner. We have no hesitancy whatsoever using WMA. We prefer it due to its workability and reduced environmental impacts.	Longer construction season Ability to haul greater distances Reduced fumes Increased safety of workforce due to lower mix temperatures Increased workability and density Decreased burner fuel consumption	None that I am aware of.
5	Rolling patterns with different temperature ranges. Making sure the bags in the baghouse do not get blinded with the lower stack temperature. The owner that we are performing the project for is comfortable with the process. Tried to perform a job in the private sector and they wanted extended warranties.	Allow for longer haul distances, later weather paving, reduced burner fuel consumption, less emissions, savings on plant mobilizations in certain circumstances.	Cost, possible baghouse issues, owner wanting to perform.
6	getting the equipment set up	easier compaction, less energy consumption	none just cost to buy the equipment

Contractor #	7	
	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.	Discuss your selection
1	Not sure	Too early in the process to tell.
2	Water Based Additives (Ex. WAM Foam, Double Barrel Green)	
3	Water Bearing Additivies (Ex. Aspha-min, Advera) Organic Additives (Ex. Sasobit)	
4	Water Based Additives (Ex. WAM Foam, Double Barrel Green)	I think all of the techniques would help asphalt performance due to weather conditions.
5	Not sure	Really not sure and also would like to know how adding lime at approximately 1% also plays in to this scenario. Lime is also used as an additive in SD, Wyoming and Montana. By adding both are we doubling up in some of the characteristics that are desired (ex. TSR) or does the products not work as well when we are not adding lime!
6	Chemical Additives (Ex. Evotherm, Rediset WMX)	you can mix at a lesser temperature, but there is a cost to it