UNIVERSITY OF NORTH DAKOTA
Grand Forks

Evaluation of the Rut Resistance Performance of Warm Mix Asphalts in North Dakota

Final Report

UND 2011-01
SPR-R033-004

November 2011

SCHOOL OF ENGINEERING AND MINES

University of North Dakota
Department of Civil Engineering

Evaluation of the Rut Resistance Performance of Warm Mix Asphalts in North Dakota

Final Report

UND 2011-01

SPR-R033-004

Submitted to

North Dakota Department of Transportation

Bismarck, ND

By:

Dr. Nabil Suleiman, Principal Investigator

November 2011

Disclaimer

The contents of this report reflect the views of the author or authors who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views of the North Dakota Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

RCS HHO-30-19

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 — STATE: UND, YEAR: 2011 - NUMBER: 01, SURF:		CONSTRUCTION PROJ NO 8 SPR-R033(004)	LOCATION 28 ND 11 - McIntosh County, ND
	EVALUATION FUNDING 48 — 1 HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 X IMPLEMENTATION		NEEP NO. 49	PROPRIETARY FEATURE? 51 — X Yes; No
SHORT TITLE	TITLE 52 Evaluation of the Rut Resistance Performance of Warm Mix Asphalts in North Dakota			
THIS FORM	DATE 140 MO. November -- YR. 2011		REPORTING 1 INITIAL; 2 ANNUAL; 3 X FINAL	
KEY WORDS	KEY WORD 1: 145 Warm Mix Asphalt		KEY WORD 2: 167 Asphalt Pavement Analyzer	
	KEY WORD 3: 189 Evotherm		KEY WORD 4: 211	
	UNIQUE WORD: 233		PROPRIETARY FEATURE NAME: 255	
CHRONOLOGY	Date Work Plan Approved: 277 June 2011	Date Feature Constructed: 281	Evaluation Scheduled Until: 285 September 2011	Evaluation Extended Until: 289 / Date Evaluation Terminated: 293 December 2011
QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS) 297: 1	UNITS 305: 1 LIN. FT; 2 SY; 3 SY-IN; 4 CY; 5 TON; 6 LBS; 7 EACH; 8 X LUMP SUM		UNIT COST (*Dollars, Cents*) 306: $15,054
AVAILABLE EVALUATION REPORTS	315 CONSTRUCTION	PERFORMANCE		FINAL X
EVALUATION	CONSTRUCTION PROBLEMS 318: 1 X NONE; 2 SLIGHT; 3 MODERATE; 4 SIGNIFICANT; 5 SEVERE		PERFORMANCE 319: 1 EXCELLENT; 2 GOOD; 3 X SATISFACTORY; 4 MARGINAL; 5 UNSATISFACTORY	
APPLICATION	320: 1 ADOPTED AS PRIMARY STD.; 2 PERMITTED ALTERNATIVE; 3 ADOPTED CONDITIONALLY	4 X PENDING; 5 REJECTED; 6 NOT CONSTRUCTED		*(Explain in remarks if 3, 4, 5, or 6 is checked)*
REMARKS	321 The primary objective of this research was to evaluate the rut resistance performance of the NDDOT WMA overlays. The APA results indicate that the WMA mixes generally exhibited higher rut values in comparison with the HMA control specimens. At this juncture, the PI is cautious about the use of WMA in North Dakota on a large scale without further testing. Future tests may include additional APA rut testing, other strength tests, or field monitoring to make a definitive decision on the utility of warm mixes in North Dakota.			

Form FHWA 1461

ACKNOWLEDGMENT

The Principal investigator (PI) appreciates the funding provided by the NDDOT that made this research study possible. The PI also wishes to thank the Materials and Research Division staff for their insights and for obtaining and delivering the study specimens. Finally, the author hopes that NDDOT will continue its research partnership with the Civil Engineering Department at UND and offer more funding for future research projects.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

BACKGROUND

New emerging technologies in asphalt production and placement with the premise of saving fuel and lowering emissions as well as providing other benefits to contractors and transportation agencies have been gaining popularity in recent years (1, 2). These technologies have been grouped together under the name “warm mix asphalt” (WMA). Conventional hot-mix asphalt (HMA) is typically produced and compacted at temperatures between 285ºF and 340ºF; cold-mix asphalt is compacted at ambient temperatures (70ºF to 120ºF) (1, 3, 4, 5). WMA falls between the two and is generally defined as asphalt mixtures produced at temperatures between 212ºF and 275ºF.

Several WMA technologies are available (2, 5, 6). When asphalt is produced at lower temperatures, there are many potential benefits such as reduced emissions and energy consumption and increased worker safety (1, 7). WMA technologies also allow asphalt to be placed at cooler ambient temperatures and to be hauled farther without compromising workability. The lower production temperatures result in less binder oxidation during production and laydown, which may lead to greater fatigue resistance (6, 7). Potential drawbacks of the technology include an increased susceptibility to moisture damage since the lower production temperatures may lead to the aggregate not being sufficiently dried before mixing (6, 7, 8). Additional concerns include an increased potential for rutting, possibly because of less aging (stiffening) of the binder, and the potential for increased curing times which could mean delays in opening roads to traffic.

Evotherm is a product developed especially for WMA by MeadWestvaco Asphalt Innovations in the United States (6). It is based on a chemistry package that includes additives to improve coating and workability, adhesion promoters, and emulsification agents. The chemistry is delivered in an emulsion with a relatively high asphalt residue (approximately 70 percent). Evotherm is stored at about 175°F (80°C). The water in the

Evotherm emulsion is liberated in the form of steam when it is mixed with hot aggregate. The resulting WMA appears like HMA in appearance. “Evotherm warm mix asphalt requires no equipment changes at the plant or job site. Evotherm is metered into existing materials and drops into existing HMA job mix formulas (9).” The mix can be stored in silos. (6)

To date, over a dozen field trials have been constructed in four countries using Evotherm. The National Center for Asphalt Technology (NCAT) representatives attended and tested material from a field trial of Evotherm conducted near Indianapolis in July 2005. The WMA using Evotherm was produced in a hybrid batch/drum plant in drum plant mode (1, 6). Discharge temperatures from the mixing drum stabilized at approximately 200°F (93°C). Even at such low temperatures, the WMA mixture appeared black like HMA with none of the brown or gray coloration generally associated with emulsions. After the WMA production, the bag house was examined. The bags and fines appeared dry. The following conclusions were drawn from the laboratory evaluation of Evotherm by NCAT (6):

- Evotherm improved the compactibility of the mixtures in the vibratory compactor. Statistics indicated an average reduction in air voids up to 1.5 percent.
- Addition of Evotherm does not affect the resilient modulus of an asphalt mix compared to mixtures having the same PG binder.
- Addition of Evotherm generally decreased the rutting potential of the asphalt mixes evaluated.
- Lower compaction temperature used in producing WMA may increase the potential for moisture damage.
- More research is needed to evaluate field performance, asphalt content selection, and the selection of binder grades for lower production temperatures.

Virginia Department of Transportation (VDOT) evaluated HMA and WMA mixtures used during two trial sections paved in Virginia in 2006. The WMA was produced with the Sasobit technology. The Virginia study discusses the effects of lower temperature production on the compactibility, volumetrics, moisture susceptibility, rutting potential, and fatigue resistance of the two mixtures used during VDOT’s field trials. The study found that HMA and WMA should have equivalent performance when properly constructed. The study recommends that acceptance property requirements for WMA should not differ from those for HMA, with the exception of temperature and TSR values. The use of recycled asphalt pavement content was recommended in future studies.

Warm-mix asphalt (WMA) mixtures produced using two different WMA technologies were evaluated in a field project located in Milwaukee, Wisconsin (10). The technologies evaluated were Sasobit and Evotherm (6, 7, 8, 10). A control section was also produced so comparisons could be made between WMA and conventional hot-mix asphalt (HMA). Mixture volumetric properties, rutting susceptibility, moisture resistance, and dynamic modulus measurements were conducted to evaluate material performance. In-place field performance data were also collected. Laboratory tests in the Wisconsin study indicated approximately equal performance between the Sasobit and control mixtures. Evotherm emulsion mixture exhibited higher rut depths, lower tensile strengths, and lower moduli than the HMA, which may be a result of fuel contamination as reported by the NCAT research team (10). However, field performances of all three mixtures were comparable after four months of traffic.

A laboratory evaluation and design of WMA was conducted at the Michigan technological University, Michigan (11). In the Michigan study, the Aspha-min additive was mixed with a PG 64-22 binder at a rate of 0.3 and 0.5 percent of the total weight of the mix and was compacted at two temperatures: 212^{o}F and 248^{o}F. The dynamic modulus (E*) test was conducted on the specimens and inputted into the MEPDG program for evaluation. The results of the study indicate that the E* values for the warm mixes have not differed from the HMA mixes. Also, the predicted depth of rutting based on the level 1 analysis of the MEPDG was decreased relative to the control HMA mixes.

According to what have been reported by many studies regarding WMA mixes, some of the findings regarding issues like rutting potential, moisture sensitivity, compactability, and curing time are not conclusive, and often contradictory. Thus a lot of research relating to WMA is still needed.

PURPOSE AND NEED

Warm Mix Asphalt (WMA) technology was developed in Europe a dozen years ago in an effort to reduce greenhouse emissions. Higher energy costs and increased environmental awareness have brought attention to the potential benefits of warm mix asphalt in the United States. Potential benefits such as reduced plant emissions, workability at lower temperatures, extension of the paving season into colder weather, decreased binder aging, and reduced energy consumption at the plant may be realized with different WMA technology applications.

Warm Mix Asphalts are produced by incorporating additives into asphalt mixtures to allow production and placement of the mix when heated to temperatures well below of those of the conventional hot-mix asphalt (HMA). The additive reduces the viscosity of the asphalt binder providing total aggregate coating at 35-100^{o}F lower than the typical 300^{o}F+ HMA temperatures.

The North Dakota Department of Transportation (NDDOT) has placed WMA overlays on sections near Valley City using Evotherm 3G chemical additive (12). The primary purpose of this proposed research is to evaluate the rut resistance performance of the NDDOT WMA overlays. Field core samples representing the WMA and the control HMA sections near Valley City will be tested for rut resistance under dry and wet conditions using the asphalt pavement analyzer. The field specimens’ rut resistance evaluations will give insights into the usefulness of the using warm mixes in North Dakota.

OBJECTIVES AND SCOPE

<u>The main objectives of this proposed study are</u>:

- To evaluate the rut resistance of North Dakota’s WMA field samples as well as HMA control samples from a trial section near Valley City, North Dakota using the Asphalt Pavement Analyzer for dry and wet conditions.

- To assess the performance of the WMA specimens by comparing their rut resistance results to the control HMA specimens' rut resistance results for both dry and wet (moisture resistance) conditions.

SPECIMEN COLLECTION AND PREPERATION

SPECIMEN COLLECTION

For this research project, six inch diameter field specimens (cores) from a warm mix asphalt project “H-MDF-2-011(025)035” near Valley City, North Dakota were collected by NDDOT and delivered to UND. NDDOT also collected and delivered HMA field core samples from the control section of the same WMA project for testing and comparison with the WMA rut results. Sixteen WMA and 16 HMA cores were provided by the NDDOT. The 32 cores were identified according to location, direction of traffic (EB or WB), and mix type (WMA or HMA). The core specimen identification information is summarized in Table 1.

Table 1: Field Core Specimen Identification

Core Locations	Core Number	Quantity - EB	Quantity - WB	Type
54.500	1-4	2	2	HMA
55.000	5-8	2	2	HMA
55.500	9-12	2	2	HMA
56.000	13-16	2	2	HMA
57.329	17-20	2	2	WMA
58.939	21-24	2	2	WMA
59.548	25-28	2	2	WMA
60.170	29-32	2	2	WMA

SPECIMEN PREPERATION

According to the contract documents, 12 WMA core specimens were prepared for APA rut testing, six of which to be tested under dry conditions and another 6 cores to be tested under wet conditions. Twelve HMA core specimens were also prepared in a similar fashion to the WMA cases. The remaining 8 specimens were kept as replacements for damaged or spoiled specimens. The core specimens were cut from the bottom (using a concrete saw) to a height of three inches (75 mm) from the top, which is the height needed for APA rut resistance testing. The top surfaces of the specimens were preserved to their original condition (no cutting).

Figure 1: The Saw Used in Sizing the Specimens to APA Height Requirements.

The bulk specific gravities and percent air voids of the core specimens were determined prior to APA testing based on density worksheets provided by the NDDOT. Table 2 below, displays the bulk specific gravity and in-place air voids for all the specimens. Most of the field air voids were determined to be within the range of 3 to 5 percent.

Prior to APA dry condition testing, the specimens were heated to 58^{o}C (matching the high temperature of the PG grade of the binder used in the project) for 6 hours. The 58^{o}C will also be maintained during the actual APA dry condition testing. The wet condition involves placing the specimens in a 58^{o}C water bath for 24 hours prior to the rut resistance testing. Also for the wet test, the specimens were tested while immersed in 58^{o}C water tank of the APA. The test preparation procedure was maintained for WMA and HMA cases.

Table 2: Bulk Specific Gravity and Air Voids Determination

Plug No.	Weight in Air	Weight in Water	SSD	Volume	Gmb	Air Voids
	(A)	(B)	(C)	D = C - B	E = A/D	%
1	2932.7	1662.0	2938.0	1276.0	2.298	3.91
2	3024.2	1717.5	3029.1	1311.6	2.306	3.61
3	3153.9	1788.7	3159.0	1370.3	2.302	3.78
4	3118.0	1765.0	3123.5	1358.5	2.295	4.05
5	2871.7	1611.8	2876.3	1264.5	2.271	5.06
6	3112.5	1748.6	3118.6	1370.0	2.272	5.02
7	3185.3	1788.4	3192.1	1403.7	2.269	5.13
8	3144.2	1767.2	3151.6	1384.4	2.271	5.05
9	3114.9	1737.8	3123.2	1385.4	2.248	6.00
10	3020.6	1681.2	3027.0	1345.8	2.244	6.17
11	3192.8	1800.5	3198.0	1397.5	2.285	4.49
12	3181.3	1797.2	3186.0	1388.8	2.291	4.24
13	3263.6	1862.0	3268.1	1406.1	2.321	2.97
14	3180.3	1808.2	3185.6	1377.4	2.309	3.47
15	3118.9	1745.5	3125.4	1379.9	2.260	5.51
16	3099.0	1735.3	3105.5	1370.2	2.262	5.45
17	3217.2	1822.0	3223.1	1401.1	2.296	4.01
18	3208.9	1815.1	3215.6	1400.5	2.291	4.21
19	3160.8	1789.2	3166.0	1376.8	2.296	4.02
20	3247.9	1840.3	3253.8	1413.5	2.298	3.94
21	3151.1	1774.0	3158.4	1384.4	2.276	4.84
22	3050.4	1704.7	3058.1	1353.4	2.254	5.77
23	3159.6	1789.6	3165.3	1375.7	2.297	3.98
24	3208.4	1816.4	3214.7	1398.3	2.295	4.08
25	3160.0	1779.0	3167.1	1388.1	2.276	4.83
26	3172.9	1790.8	3181.1	1390.3	2.282	4.59
27	3195.3	1804.9	3201.2	1396.3	2.288	4.33
28	3187.0	1800.8	3193.2	1392.4	2.289	4.31
29	3084.6	1725.9	3091.4	1365.5	2.259	5.56
30	3174.8	1776.7	3181.1	1404.4	2.261	5.49
31	3141.5	1785.4	3148.5	1363.1	2.305	3.65
32	3254.7	1861.6	3260.2	1398.6	2.327	2.71

RUT RESISTANCE PERFORMANCE TESTING AND ANALYSIS

BACKGROUND

The utilization of the Asphalt Pavement Analyzer to evaluate rutting resistance of asphalt mixtures has been to be fast, cost-effective, and practical to use. In this study, testing with the APA was conducted according to TP 63-03 “Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures,” a provisional AASHTO designation with modifications to accommodate NDDOT project requirements.

The 24 field core specimens that were collected and prepared for APA testing are set to endure 8,000 loading cycles (for both dry and wet conditions) at 100 psi pressure (13). Each APA run is consisted of 4 specimens (2 HMA and 2 WMA). Table 2 below shows 4 specimens placed in the molds and ready for temperature or water conditioning before testing. Two WMA specimens and 2 HMA specimens HMA were tested as one run in the APA. There were a total of 6 runs performed in the study.

Figure 2: Placing Specimens in the Molds for an APA Run

A 9.0 mm (3/4 inch) deformation is considered the criterion of rutting failure for class 29 or lower classification pavements. The relative performance of the mixes will be examined based on comparing their APA rut values. Figure 3 displays the outcome of one APA specimens that includes 2 WMA (right) and 2 HMA (left).

Figure 3: Rut Depths of One APA Run: HMA (left) and WMA (right).

APA RESULTS AND ANALYSIS

The APA rut values for the dry and wet cases are shown in Table 3 and Figures 4 and 5.

Table 3 APA Rut Values for the Dry and Wet WMA and HMA Cases

	Dry Testing Case				**Wet Testing Case**			
	WMA		**HMA**		**WMA**		**HMA**	
Plug No.	*21*	*23*	*1*	*3*	*18*	*20*	*2*	*4*
Rut Values	**8.08**	**8.83**	**6.55**	**8.73**	**9.95**	**9.05**	**6.45**	**7.63**
Plug No.	*25*	*27*	*9*	*11*	*22*	*24*	*6*	*8*
Rut Values	**9.12**	**9.36**	**7.37**	**8.11**	**8.1**	**8.45**	**6.19**	**5.49**
Plug No.	*29*	*31*	*13*	*15*	*30*	*32*	*14*	*16*
Rut Values	**9.25**	**8.76**	**8.34**	**8.07**	**7.72**	**8.16**	**5.63**	**8.34**

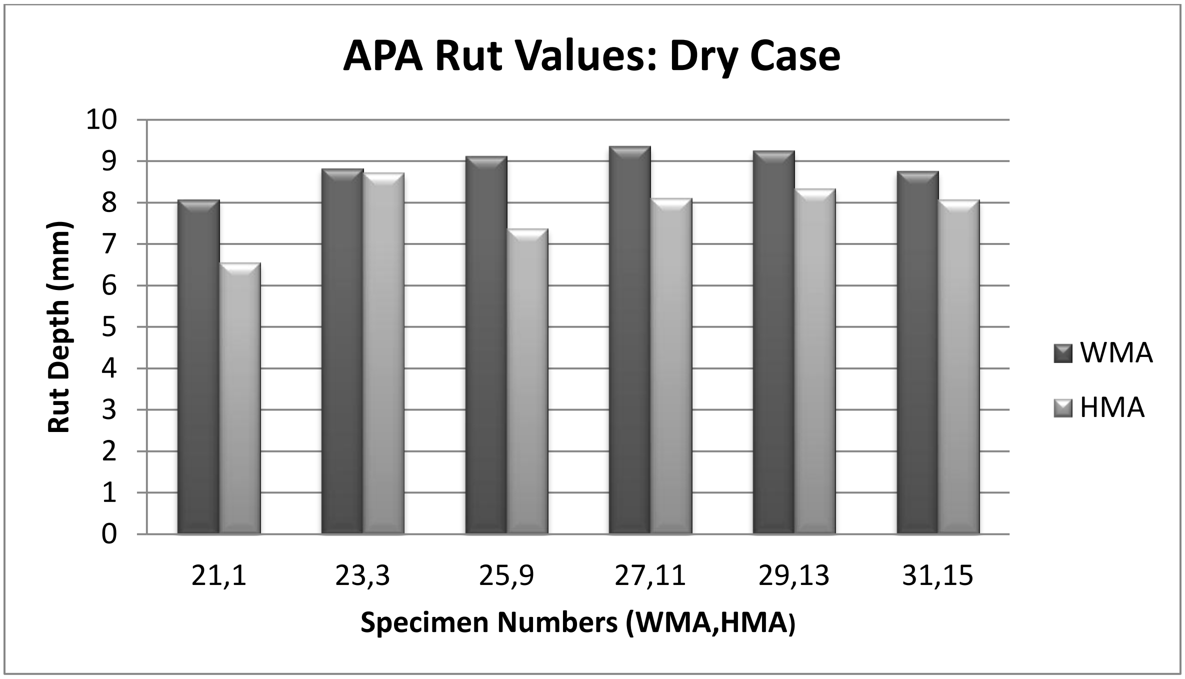

Figure 4: APA Rut Values for WMA and HMA (Dry Case)

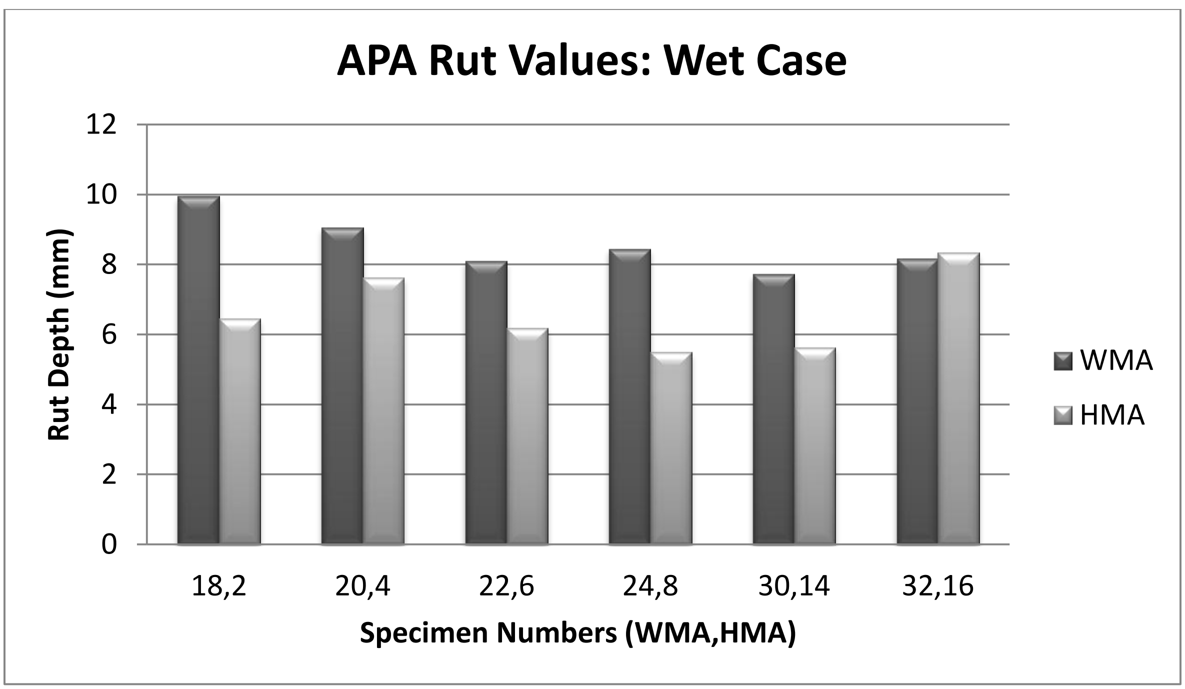

Figure 5: APA Rut Values for WMA and HMA (Wet Case)

The numbers between 1 and 32 in Table 3 and Figures 4 and 5 represent the specimen numbers cored from the field. In Table 3, the rut values (in mm) are written directly under the corresponding specimen number. The dry and wet rut results are displayed side by side in the table. Also the results of WMA and HMA are listed side by side within each testing Case (dry or wet). For Figures 4 and 5, the numbers (such as 21,1) represent the specimen numbers for the WMA and HMA, respectively.

The APA results indicate that the WMA mixes generally exhibited higher rut values in comparison with the HMA control specimens. For the dry condition, the average WMA rut value was 13 percent higher than the average rut value of the HMA mixes. And for the wet condition, the average rut value for the WMA specimens was 29 percent higher than that of the HMA average value. The variations between rut values were lower for the warm mixes with standard deviations of 0.46 and 0.81 for the dry and wet cases, respectively. For the Hot mixes, the standard deviations were 0.78 and 1.14 for the dry and wet cases, respectively.

Nineteen out of the total 24 specimens passed the 9.0 mm criterion. All of the 5 failed specimens were from WMA mixes. Three failed specimens were under the dry condition and 2 more specimens failed under the wet condition. Therefore, the failure rates for WMA specimens stand at 50 percent under the dry condition and 33 percent under the wet condition. Six out of the 7 specimens that did not fail exhibited rut values above 8 mm or close to the 9.0 mm failure criterion.

The PI did not notice any specific trend between air voids and their rut values of the specimens. The air voids ranged between 2.71 percent and 6 percent, with majority of the air voids values (21 out of 32) were below 5 percent. A plot between air voids (in percent) and rut values (in mm) for all the data points is shown in Figure 6 below. The R^2 value is 0.023 which indicates no significant trend between the data points exists.

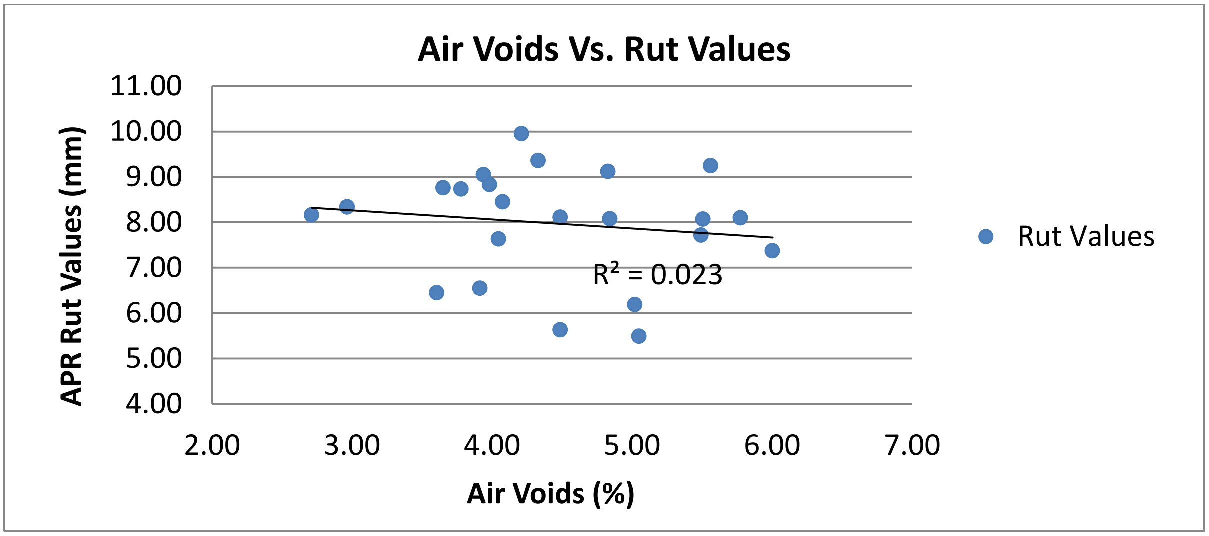

Figure 6: Correlation between Air Voids and Rut Values

SUMMARY AND CONCLUSIONS

New emerging technologies in asphalt production and placement with the premise of saving fuel, reducing plant emissions, increasing workability at lower temperatures, extending the paving season into colder weather, and decreasing binder aging have been gaining popularity in recent years. These technologies have been clustered together under the name “warm mix asphalt.” Warm Mix Asphalts are produced by incorporating additives into asphalt mixtures that reduces the viscosity of the asphalt binder and allow total aggregate coating at temperatures well below of those of the conventional hot-mix asphalt.

The reported findings of previous WMA studies, as shown in the literature, were not conclusive on issues such as rutting potential and moisture sensitivity. A lot of research relating to WMA mixtures is still needed.

Evotherm is a product developed especially for WMA. It is based on a chemistry package that includes additives to improve coating and workability, adhesion promoters, and emulsification agents. The North Dakota Department of Transportation (NDDOT) has placed WMA overlays on sections near Valley City, North Dakota using Evotherm 3G chemical additive.

The primary objective of this research was to evaluate the rut resistance performance of the NDDOT WMA overlays. Field core samples representing the WMA and the control HMA sections near Valley City were tested for rut resistance under dry and wet conditions using the asphalt pavement analyzer.

The APA results indicate that the WMA mixes generally exhibited higher rut values in comparison with the HMA control specimens. As reported, the average WMA rut values were 13 percent and 29 percent higher than the average rut values of the HMA mixes under dry and wet conditions, respectively. Since the premise of wet testing using the APA is done to somewhat represent durability performance, this research results confirm the earlier fears of reduced durability when using the warm mixes.

The APA rut results show that 5 specimens out of the 32 have failed the 9.0 mm rut criterion. Six out of the 7 WMA specimens that did not fail exhibited rut values close to the 9.0 mm criterion. Granting that the WMA failure rates are high, one should be cautioned that those results are based on a small sample size. To be able to come up with definitive conclusions, more WMA samples should be tested. Although no HMA specimens failed the rut test, nearly half of them had rut values between 8 and 9 mm. While there was no specific trend between the calculated air voids and the rut values, the air voids percentages were mainly on the low side.

According to the NDDOT documents (12), both warm and hot mixes were placed as 1.5 inch overlays. The measured thickness of the overlay based on the 32 specimens was 2 inches. Since the overall thickness of the specimens is 3 inches, the lower 1 inch of the study specimens consisted of unspecified old pavement. The results of this study should be valid assuming that the older pavement is consistent throughout the section where the cores were taken. A problem could arise, if some of the cores were taken directly over a crack, a pothole, or other form of old pavement distress. For this research study, the PI does not suspect inconsistency problems since the specimens' results variability measured in standard deviations are not high.

At this juncture, the PI is cautious about the use of WMA in North Dakota on a large scale without further testing. Future tests may include additional APA rut testing, other strength tests, or field monitoring to make a definitive decision on the utility of warm mixes in North Dakota. The potential to extend the paving season into cold weather, see savings in fuel cost, and realize reductions in harmful emissions are very strong incentives to continue researching warm mixes in North Dakota.

REFERENCES

1. Kandhal, Prithvi. NCAT evaluates warm mix. Asphalt. Technology News. Vol. 17, No. 2. National Center for Asphalt Technology. Auburn, Alabama, 2005.
2. Newcomb, D. An Introduction to Warm-Mix Asphalt. National Asphalt Pavement Association, Lanham, MD. http://fs1.hotmix.org/mbc/Introduction_to_Warm-Mix_Asphalt.pdf. (Accessed November 10, 2010).
3. Federal Highway Administration. Warm Mix Asphalt Technologies and Research. http://www.fhwa.dot.gov/pavement/asphalt/wma.cfm. (Accessed November 14, 2010)
4. National Asphalt Pavement Association. WMA Technologies. http://www.warmmixasphalt.com/WmaTechnologies.aspx. (Accessed October 25, 2010)
5. Goh, Shu, Zhanping You, and Thomas, Van Dam. Laboratory Evaluation and Pavement Design for Warm Mix Asphalt. Proceedings of the 2007 Mid-Continent Transportation Research Symposium, Ames, Iowa, August, 2007.
6. Hurley, G. and B. Prowell. "Evaluation of Evotherm™ for Use in Warm Asphalt Mixes," NCAT 06-02, Auburn University, Auburn, AL, 2006.
7. Hurley, G. and B. Prowell. "Evaluation of Aspha-min® Zeolite for Use in Warm Asphalt Mixes," NCAT Report No. 05-04, Auburn University, Auburn, AL, 2005.
8. Hurley, G. and B. Prowell. "Evaluation of Sasobit® for Use in Warm Asphalt Mixes," NCAT Report No. 05-06, Auburn University, Auburn, AL, 2005.
9. Meadwestvaco (MWV). Evotherm Warm Mix Asphalt. Website Address: http://www.meadwestvaco.com/SpecialtyChemicals/AsphaltAdditives/MWV002106. Website accessed on October 28, 2011.
10. Graham C. Hurley, G., B. Prowell, and A. Kvasnak. Wisconsin Field Trial of Warm Mix Asphalt Technologies: Construction Summary. Sponsored by the Federal Highway Administration. NCAT Report No. 10-04, Auburn University, Auburn, AL, 2010.
11. Graham C. Hurley, G., B. Prowell, and A. Kvasnak. Michigan Field Trial of Warm Mix Asphalt Technologies: Construction Summary. Sponsored by the Federal Highway Administration. NCAT Report No. 09-10X, Auburn University, Auburn, AL, 2009.
12. NDDOT. Warm Mix Asphalt Work Plan. H-MDF-2-011(025)035. Materials and Research Division. North Dakota Department of Transportation, Bismarck, ND, 2010.
13. Eugene Skok, E., E. Johnson, and A Turk. Asphalt Pavement Analyzer Evaluation. Final Report. Report No. MN/RC 2003-02, Department of Civil Engineering, University of Minnesota. Minnesota Department of Transportation, St. Paul, Minnesota, 2002.