Laboratory Evaluation and Pavement Design for Warm Mix Asphalt

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ABSTRACT

For many years, the asphalt industry has been aware of the energy savings and environmental benefits inherent in cold mix or warm mix asphalt technologies. Environmental awareness and the need for improved energy efficiency has increased rapidly over the past few years and extensive measures such as the air pollution reduction targets set by the European Union under the Kyoto Protocol have encouraged efforts to reduce greenhouse gas emissions. Warm mix asphalt (WMA) is one technology that is gaining popularity in the industry in response to these effort. The objective of this study is to evaluate the performance of WMA made Aspha-min using the Mechanistic-Empirical Pavement Design Guide (MEPDG). An asphalt mixture with a nominal maximum size of 12.5mm (1/2”) and PG64-28 binder was used. A control mixture, WMA with 0.3% of Aspha-min, and WMA with 0.5% of Aspha-min were tested and the test results were used in the MEPDG. The results from the MEPDG are also discussed.

Key words: Warm Mix Asphalt—Laboratory Evaluation— Aspha-min—Traditional Hot-Mix Asphalt—Mechanistic-Empirical Design Guide (M-EPDG)

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INTRODUCTION

The asphalt industry has been concerned about energy savings and environmental benefits in cold or warm asphalt process for decades. In recent years, environmental awareness has been increasing rapidly and extensive measures like air pollution reduction targets set by the European Union under the Kyoto Protocol have encouraged efforts to reduce greenhouse gas emissions. Traditional hot mix asphalt (HMA) is produced in either batch or drum plants at a discharge temperature between 280°F (138°C) and 320°F (160°C). The amount of fuel consumed is relatively large due to the continuous heating of aggregate, thus increasing the energy costs and production of greenhouse gasses. Warm mix asphalt (WMA), a new paving technology that originated in Europe, appears to allow a reduction in the temperature at which asphalt mixed are produced and placed. To be practical, WMA production must use existing HMA plants, specifications, and standards. The current focus is on dense graded mixes for wearing courses. WMA allows the asphalt mixture to be compacted at a temperature range of 250°F (121°C) to 275°F (135°C). Figure 1 shows the compaction temperature for HMA, WMA, and cold mix asphalt. As shown in Figure 1, the WMA temperature is between HMA and cold asphalt mix. There are several proprietary technologies used to produce WMA (FHWA. 2001) which are:

1. Aspha-min®, a product from Eurovia Service GmbH, Bottrop, Germany. It is a synthetic zeolite and creates foaming effect in the binder.
2. WAM-Foam®, a product of a joint venture between Shell International Petroleum Company Ltd., London, UK and Kolo-Veidekke, Oslo, Norway. It is a two-component binder system that introduces a soft and hard foamed binder at different stages during plant production.
3. Sasobit®, a product of Saso Wax (formerly Schümann Sasol) from South Africa.
4. Asphaltan B®, a product of Romonta GmbH, Amsdorf, Germany. It is a low molecular weight esterified wax.
5. Evotherm®, a product developed by MeadWestvaco Asphalt Innovations, Charleston, South Carolina. It is a technology based on a chemistry package that includes additives to improve coating and workability, adhesion promoters, and emulsification agents.

All those technologies reduce the viscosity of the asphalt binder at a given temperature and allow the aggregate to be fully coated at lower mixing temperatures. The application of WMA can have a significant impact on pavement projects in and around non-attainment areas. It was reported that the manufacturers and materials suppliers achieved energy savings on the order of 30%, with a corresponding reduction in CO_2 emissions of 30%. The mixture production and placement temperature could bring several cost, environmental, and performance benefits (Jones 2004). The advantages of the WMA are briefly summarize as reduced fuel cost, reduced mixing and compaction temperature, early site opening, lower plant wear, lesser aging of binder, reduced fumes and emissions, improve workability, and extended paving window.

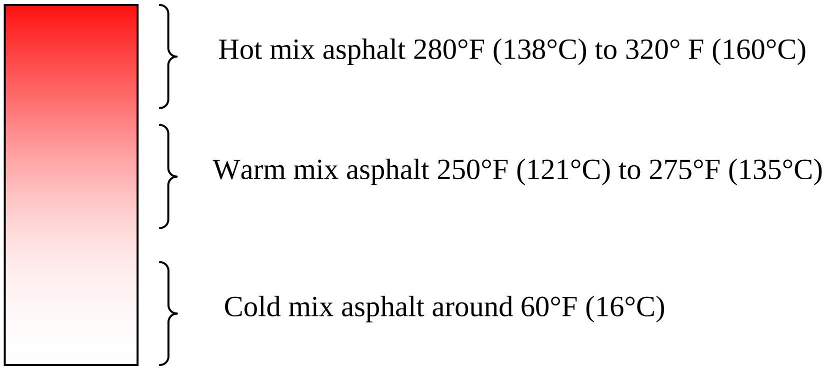

Figure 1. Typical mixing temperature range for asphalt mixtures.

LITERATURE REVIEW

Aspha-min is a product of Eurovia Services GmBH Bottrop, Germany (Von Devivere et al. 2003), often referred to as Eurovia. It is available as a very fine white powder in 25 or 50 kg bags or in bulk for storage in silos. It is a manufactured synthetic zeolite (Sodium Aluminum Silicate), which has been hydro thermally crystallized. Water is held internally by the Aspha-min at 21 percent by mass and is released in the temperature range of 185°F to 360°F (85°C to 182°C). The framework silicates (zeolites) in Aspha-min have large vacant spaces in their structure that allow space for large cations such as sodium, potassium, barium and calcium, and even relatively large molecules and cation groups such as water. In their most useful form, the spaces are interconnected and form several long, wide channels of varying sizes depending on the mineral. These channels allow the easy movement of the resident ions and molecules into and out of the zeolite structure. The most well-known use for zeolite is in water softeners. Zeolite is characterized by its ability to lose and absorb water without damage to its crystal structures. It can have the water in their structures driven out by heat and other solutions pushed through the structure. It can then act as delivery system for the new fluid (FHWA 2007; Kristjansdottir 2006).

By adding Aspha-min to the mix at the same time as the binder, a very fine water vapor is created. This release of water creates a volume expansion of the binder that results in the formation of asphalt foam, allowing increased workability and aggregate coating at lower temperatures (Harrison and Christodulaki 2000; McKeon 2006). Eurovia recommends adding Aspha-min at the rate of 0.3% of the mass of the total mix, which can result in a potential 54°F (30°C) reduction in typical HMA production temperatures. This reduction in temperature was reported to lead to a 30% reduction in fuel energy consumption. Eurovia stated that all commonly known asphalt and polymer-modified binders can be used with Aspha-min. Also, the addition of recycled asphalt is compatible with Aspha-min (Harrison and Christodulaki 2000; McKeon 2006).

A combination field and laboratory study was conducted using Sasobit and Aspha-min to evaluate the performance of WMA (Daniel 2006). The field section with and without Aspha-min additive were placed on the entrance road to Hookset Crushed Stone in November 2005. The samples and cores were tested using the third-scale Model Mobile Load Simulator (MMLS3) to evaluate performance with and without moisture. The laboratory tests using the TSR (Tensile Strength Ratio) showed WMA had higher moisture sensitivity than typical HMA. This project is currently ongoing and further study will be conducted to evaluate the performance of WMA.

A laboratory study was conducted by the National Center for Asphalt Technology (NCAT) to determine the applicability of Aspha-min to typical paving operations and environmental conditions (Hurley et al. 2006). Two aggregates, granite and limestone, were used. The Superpave gyratory compactor and a vibratory compactor were used to determine the mixture compactability over a range of temperatures. Mixes were compacted at 300°F (149°C), 264°F (129°C), 230°F (110°C), and 190°F (88°C), with the mixing temperature about 19°C (34°F) above the compaction temperature. The results obtained indicated that the addition of Aspha-min lowered the air void level in the gyratory compactor, increased the potential for moisture damage, and lowered the TSR (Tensile Strength Ratio) as compared to the control mixture. It was also found that the addition of Aspha-min did not affect the resilient modulus and rutting potential. However, it was indicated that the resilient modulus decreased as the compaction temperature decreased and air void level increased, and the rut depth increased as the temperature decreased for all the factors in combination.

A study on field performance of WMA was conducted at the NCAT test track (Prowell et al. 2007). The results indicated that both HMA and WMA field sections showed excellent rutting performance after the application of 515,333 ESALs over a 43 day period. One of the WMA sections was also evaluated for early opening to traffic and showed good performance.

Researchers have studied the rutting potential and the rheological properties of binders with the addition of Aspha-min and Sasobit (Wasiuddin et al. 2007). The results show that Aspha-min did not give any beneficial effect in temperature reduction in PG 64-22 based on the rotational viscometer results. The rutting potential decreases with a decrease in mixing and compaction temperature for both Sasobit and Aspha-min mixture and no significant direct decrease in production temperature with realized with Aspha-min. In addition, a field demonstration project in Florida indicated that the addition of Aspha-min in the mix has improved the workability compare to the control mix and was also equally resistant to moisture damage as the control mix (Hurley et al. 2006).

There are several Aspha-min comparison tests done by Eurovia. Results of the field test indicated that no significant changes were observed in surface characteristics after three years. The Aspha-min section was comparable to the traditional HMA comparison section (Von Devivere et al. 2003). A field demonstration test was conducted by Hubbard Group in Orlando, Florida in February 2004 (McKeon 2006). The objective for the field demonstration was to compare the conventional HMA with a mix containing the Aspha-min additive at the reduced temperature in a typical paving setting and to compare the workability, compactability, elevator drag strain, and mix volumetric properties. The compaction temperatures used during the test were 310°F (154°C) for the control section and 270°F (132°C) for the Aspha-min section. Aspha-min was added at the rate of 0.3% of the total weight of mixture during this test. The main results obtained from Hubbard Group were:

1. There were no changes in maximum specific gravity or bulk specific gravity for the Marshall and Superpave gyratory compacted specimens when Aspha-min was added.
2. There was a significant increase in air voids before and after the aging process when Aspha-min was added.
3. There was a slight decrease in stability when running the Marshall Stability test whenAspha-min was added.

The conclusions and recommendations drawn from Hubbard Group for the use of Aspha-min are:

1. Comparison of all laboratory tests is favorable with almost no change in volumetric properties and Marshall Stability.
2. The amperage meter dropped from 34 amps to 32 amps on the mix elevator, possibly indicating better workability in the warm mix asphalt.
3. The nuclear density was 2.8 pcf (44.85 kg/m^3) higher after initial compaction in the warm mix.
4. The lower temperature did not change the workability and the material texture was the same.

The combined results of past studies on WMA indicate significant promise in cost saving and reduction of emissions. Although a number of studies have been conducted on WMA, an evaluation of how the use of WMA impacts pavement design using the new MEPDG has not been done. Therefore, the objective of this paper is to use the test results obtained from laboratory tests to perform an evaluation of WMA using the MEPDG software 1.0.

MATERIALS TESTED AND EXPERIMENT DESIGN

In this study, a PG 64-22 asphalt binder was used. The control mixture (HMA) was sampled from the job site and the aggregates were sampled to produce the WMA. The Aspha-min was added to the control mix at the rate of 0.3% and 0.5% based on the total weight of the mixture. The control mixture was compacted at 142°C (288°F) and both mixes with 0.3% and 0.5% Aspha-min were compacted at 100°C (212°F) and 120°C (248°F). The dynamic modulus (E*) test was conducted and the results from the E* test were input in MEPDG. Figure 2 shows the general flow for the experiment design in this study.

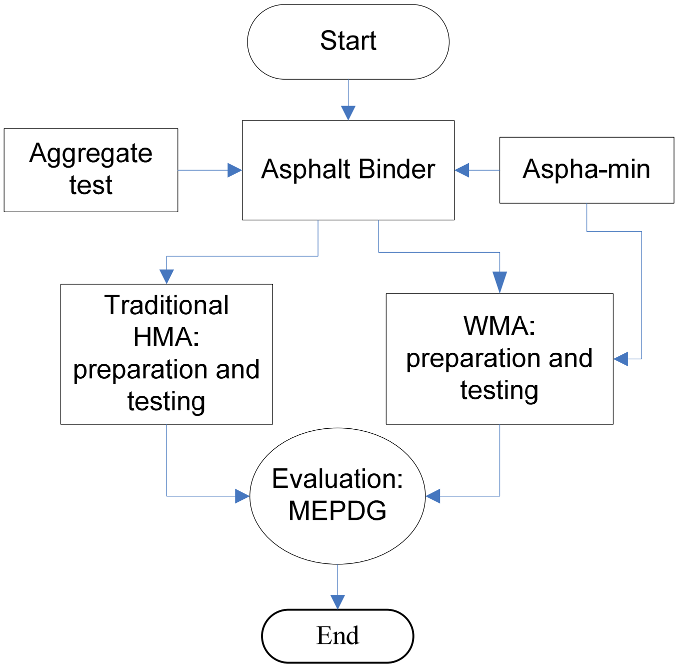

Figure 2. Flow chart illustrating testing and analysis sequence for asphalt mixtures.

DYNAMIC MODULUS

The dynamic modulus (E*) is the ratio of stress to strain under haversine (or sinusoidal) loading conditions and is used as one of the material characterization inputs in the MEPDG to model pavement performance. In the study described in this paper, E* testing was performed according to AASHTO TP62-03. The temperatures used for the measured E* were -5°C, 4°C, and 21.1°C. The frequencies used in this test were 0.1Hz, 0.5Hz, 1Hz, 5Hz, 10Hz, and 25Hz. Five types of mixture were used: a control mixture, 0.3% Aspha-min mixture compacted at 100°C and 120°C, and 0.5% Aspha-min mixture compacted at 100°C and 120°C. The descriptors used to identify these mixtures in this paper are shown in Table 1.

The E* test results are presented in Figure 3. Observations from the graph indicated that most of the mixtures to with Aspha-min added did not significantly affect the E*. In addition, mixture with additional 0.5% Aspha-min and compacted at 120°C have a higher E* based on statistical analysis, pair t-test. This raises question of how much this will impact the development of distress in the pavement. To answer this question, the results E* results were used in the MEPDG to evaluate the predicted pavement performance.

Table 1. Descriptors for each mixture used in the graph and tables.

Descriptor	Description
Control	Control mixture, compacted at 142°C
0.3% AM_100C	Asphalt mixture with 0.3% Aspha-min and compacted at 100°C
0.3%AM_120C	Asphalt mixture with 0.3% Aspha-min compacted at 120°C
0.5% AM_100C	Asphalt mixture with 0.5% Aspha-min compacted at 100°C
0.5% AM_120C	Asphalt mixture with 0.5% Aspha-min compacted at 120°C

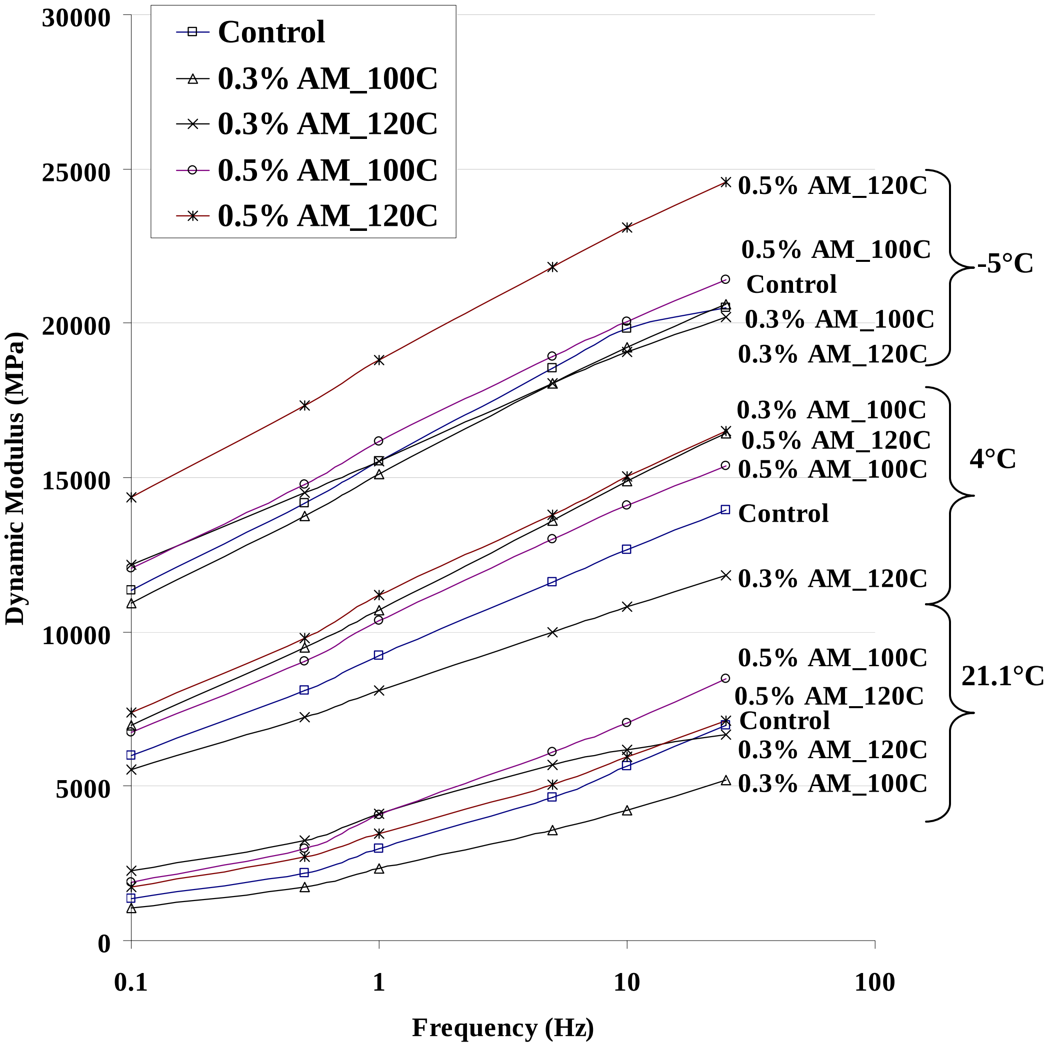

Figure 3. Dynamic modulus test result for the WMA and control mixtures.

MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE (MEPDG)

The Mechanistic-Empirical Design Guide (MEPDG) is being developed under the National Cooperative Highway Research Program (NCHRP) Project 1-37A and is designed to be adopted by the American Association of State Highway and Transportation Officials (AASHTO) for use as the future pavement design guide for the public and private sectors. The development of the MEPDG is based on the collective experience of pavement experts, data from road tests, calculation of pavement response, and mechanistic and empirical pavement performance models (Mulandi et al. 2006; Priest et al. 2005). The MEPDG software is able to predict the development and propagation of various kinds of pavement distress, including rutting and fatigue cracking, using input data on asphalt mixture characteristics obtained from laboratory testing. There are three hierarchical levels in the MEPDG, Level 1, Level 2, and Level 3, with the accuracy of prediction increasing from Level 3 to Level 1. Level 3 is used for the design where there are minimal consequences of early failure and the inputs would be typical average value for the region; Level 2 design is used when resources or testing equipment are not available for the tests required for level 1 and its inputs normally would be user selected possibly from an agency database, could be derive from a limited testing program or could be estimated through correlations, and; Level 1 design is typically used for obtaining inputs for designing heavily trafficked pavements or wherever there are dire safety or economic consequences of early failure. In addition, level 1 input require laboratory or field testing, such as dynamic modulus testing of HMA (Mulandi et al. 2006). In this study, a Level 1 design was used with the measured dynamic modulus as shown in the previous discussions. The assumed values for creep compliance were used for all the WMA and control mix. The creep compliance will most dramatically impact the prediction of thermal cracking. This study focuses exclusively on the development and propagation of rutting. The design pavement life was set at 10 years.

One of the features in the MEPDG is that it allows the user to input very specific climatic data and traffic information. In this study, the climate data for Lansing, Michigan was used. Table 2 presents the temperature data for the surface layer and Table 3 for the base layer. For traffic information, Table 4 presents the traffic parameters assumed for use in this study and Table 5 the vehicle distribution for different classes used in this study. It is noted that Level 3 accuracy for traffic inputs was assumed in the MEPDG software for this evaluation.

The rutting predicted using the MEPDG was used as the pavement distress for comparison in this study. Figure 4 and Table 6 show the results of the predicted rutting depth over 10 years using MEPDG software version 1.0 for each of the mixtures studied. Table 7 shows the percent difference in predicted rutting for each mixture compared to the control mixture.

Table 2. Average monthly quintile temperatures for surface layer in Lansing, Michigan.

Month	1st Quintile (ºF)	2nd Quintile (ºF)	3rd Quintile (ºF)	4th Quintile (ºF)	5th Quintile (ºF)	Mean Temp. (ºF)	Std. Dev. (ºF)
January	13	21	25.7	30.7	38.9	25.9	9.3
February	18.1	26.8	31.9	36.6	44.2	31.5	9.4
March	22.9	31.6	37.4	44.4	57	38.7	12.3
April	35	44.3	51.9	61.2	76.5	53.8	14.9
May	46.3	55.5	62.7	70.8	83.6	63.8	13.4
June	57.6	67.8	75.3	84.9	98.5	76.8	14.6
July	61.7	71.1	79	88.7	100.3	80.2	13.9
August	59	67.9	74.7	84.7	96.9	76.7	13.6
September	49.4	59.3	66.6	75.4	91.1	68.4	14.9
October	37.7	46.5	52.9	60.2	73.3	54.1	12.8
November	28.8	36.1	41.1	46.5	55.2	41.5	9.4
December	20.3	26.8	31.2	35.6	42.9	31.4	8.2

Table 3. Average monthly quintile temperatures for base layer in Lansing, Michigan.

Month	1st Quintile (ºF)	2nd Quintile (ºF)	3rd Quintile (ºF)	4th Quintile (ºF)	5th Quintile (ºF)	Mean Temp. (ºF)	Std. Dev. (ºF)
January	13.4	21.2	25.7	30.6	38.5	25.9	9
February	18.5	27	31.9	36.3	43.6	31.5	9
March	23.3	31.7	37.4	44.1	56.1	38.5	11.8
April	35.7	44.7	52	60.9	75.6	53.8	14.3
May	46.9	55.9	62.8	70.5	82.7	63.8	12.8
June	58.2	68.2	75.3	84.5	97.5	76.8	14
July	62.5	71.6	79	88.3	99.3	80.2	13.2
August	59.8	68.5	74.9	84.2	95.9	76.7	13
September	50.1	59.8	66.8	75.1	90.1	68.4	14.3
October	38.3	46.8	53	60.1	72.6	54.2	12.3
November	29.3	36.3	41.2	46.4	54.7	41.6	9.1
December	20.7	27	31.2	35.6	42.6	31.4	7.9

Table 4. General traffic inputs for MEPDG.

Description	Value
Initial two-way AADTT:	1000
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	95
Operational speed (mph):	60
Mean wheel location (inches from the lane marking)	189
Traffic wander standard deviation (in):	10
Design lane width (ft):	12
Growth Rate	4%
Growth Function	Compound

Table 5. Assumed AADTT distribution by vehicle class.

Classification	Percent Distribution (100% Total)
Class 4	1.8%
Class 5	24.6%
Class 6	7.6%
Class 7	0.5%
Class 8	5.0%
Class 9	31.3%
Class 10	9.8%
Class 11	0.8%
Class 12	3.3%
Class 13	15.3%

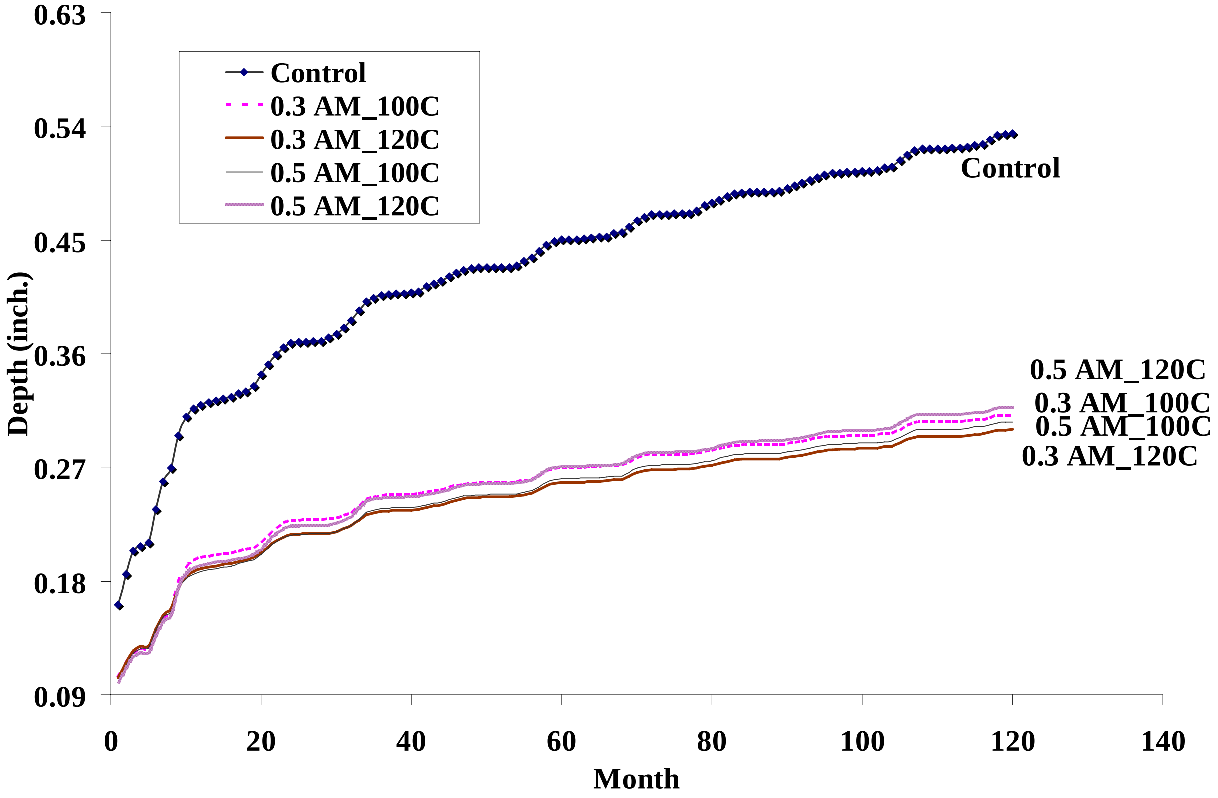

Figure 4. Prediction of rutting depth over 10 years using MEPDG Software Version 1.0.

Table 6. Prediction of rutting depth using MEPDG Software Version 1.0.

	Mixture				
Year	**Control**	**0.3AM_100C**	**0.3AM_120C**	**0.5AM_100C**	**0.5AM_120C**
1	0.3197	0.1984	0.1899	0.188	0.1932
2	0.3684	0.2268	0.2165	0.2159	0.2233
5	0.4502	0.2694	0.2579	0.2603	0.2701
10	0.5345	0.3112	0.3	0.3059	0.3179

Table 7. Percent difference in rut depth for each mixture compared to the control mixture.

	Mixture			
Year	**0.3AM_100C**	**0.3AM_120C**	**0.5AM_100C**	**0.5AM_120C**
1	38%	41%	41%	40%
2	38%	41%	41%	39%
5	40%	43%	42%	40%
10	42%	44%	43%	41%

From Figure 4, it is observed that the depth of rutting increases rapidly during the first 20 months with a decreasing rutting rate thereafter. It is also observed that the predicted rutting depths for all WMA mixtures are higher than for the control mixture. Table 6 shows the result of predicted rut depth at 1 year, 2 years, 5 years, and 10 years for asphalt pavement using the MEPDG. It was found that the additional Aspha-min improves the rutting resistance significantly. Table 7 reveals that in the percent difference for WMA compared to the control mixture. The greatest different for WMA and control is approximately

44% (compare with WMA made with 0.3% Aspha-min compacted at 120°C).These results are based on many assumptions and should be considered as preliminary results. Further study is ongoing to verify the mixture properties, mixture design, and pavement field performance.

CONCLUSIONS

WMA had shown significant promise in lowering the required mixing and compaction temperatures while decreasing emissions for asphalt pavement construction. The literature review indicated that WMA with Aspha-min has improved workability, decrease cooling time after construction, and in general allowed for a reduction in mixing and compaction temperature (although some studies indicated no reduction). In this study, it was found that the addition of Aspha-min does not affect the value of E* for all mixtures examined. In addition, WMA decrease the predicted depth of rutting based on the Level 1 analysis using the MEPDG and the greatest different for WMA and control was found to be 44%. This might give a potential in improving the rutting resistance for the future pavement design. Future research to gain greater understanding of both the short-term and long-term aging of WMA as well as how well this is modeled in the MEPDG needs to be conducted. To accomplish this, a thorough analysis of distress data collected from field projects needs to be undertaken

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