This paper presents the details on the first state WMA pavement project in Connecticut. The three-day construction took place between July 20th and 22nd, 2010 and it involved preparing three experimental sections, i.e. one section with a conventional HMA (control section) and two WMA sections with different technologies, wax and foamed asphalt. All three sections are located on Route 70 in central Connecticut which is a two-lane, low-traffic collector road. Each section is approximately 0.5-mile long and includes lanes in both directions. The construction was done as 2-in overlay with 12.5mm SuperPave mix over sections with selected milling and leveling. All sections were paved by a single paving crew with the same equipment and all mixes were prepared in the same drum plant located approximately 12 miles north of the project site. A significant amount of each mix was sampled over three day construction period for further evaluation in the laboratory. Specimens were compacted in the gyratory compactor at the plant within 60 minutes after production without additional reheating (plant fabricated specimens) for each warm mix. The rest of the materials were collected in loose form and reheated and compacted in laboratory conditions (laboratory fabricated specimens). This paper discusses the effect of specimen preparation procedure on the results from several tests conducted in the laboratory, such as Tensile Strength Ratio, Advanced Pavement Analyzer, Indirect Tensile Ratio and Disk Compat Tension. The results from the WMA specimens are also compared against conventional HMA specimens to statistically evaluate any potential differences that could imply discrepancy in the field performance. Finally, the paper presents the performance data from all sections after the first winter season and correlates these observations with the laboratory results.

BACKGROUND

Project Background

From July 20th to the 22nd of 2010, 3 test sections were placed on Rt. 70 in Meriden, CT. The selected section of Rt. 70 is a two-lane collector road with low truck traffic. A conventional hot-mix asphalt pavement, Sasobit ® wax-modified warm mix and a foamed asphalt mix were placed by the same paving crew and the same equipment. Each test section is approximately 1 km long and spanned both directions of travel (2 lanes total) as seen in Figure 1. Selected milling and leveling were performed prior to placement- a common practice for the Connecticut DOT.
The mix used for all 3 trials was a 12.5mm nominal maximum aggregate size SuperPave mix designed by Tilcon Connecticut, Inc. One section contained Sasobit wax pellets that were added to PG64-22 binder at 1.5% by weight one day before mixing. Another section was placed with foamed asphalt pavement in which water is sprayed into the drum mixers causing the asphalt binder to foam and reduce the required mixing temperature. The final section was constructed with a conventional hot-mix section used as a control. Cores were taken during construction and used in conjunction with the nuclear gauge to ensure the proper density was being achieved. The paving was a 50 mm overlay on milled pavement with leveling placed one day prior to paving.

Warm mix asphalt has benefits ranging from reduced emissions of noxious gases to longer haul times and lower manufacturing costs (1). Sasobit wax, as a warm mix additive, functions by reducing the viscosity of the asphalt at temperatures above the melting point of the wax, 120°C (1,2). Water can be introduced to the asphalt pavement mixing process in two ways. Firstly, a contractor may decide to use moist aggregate. This solution can be difficult to yield homogeneous mix as all the aggregate must have the same moisture level. Size and mineral composition of the aggregate can play a part in how effectively each retains water. The second method is spraying water into the mixer using a nozzle- a much easier way to control the moisture level but more costly to implement. In either case, the water vaporizes which causes the expansion of the binder ultimately lowering its viscosity (1). Previous studies have compared the compactibility, air voids and densification of warm-mix asphalt to conventional hot mix showing minimal or no differences between the two in the lab (3).

OBJECTIVES:
The purpose of this study was to evaluate the effects of Sasobit wax modifier and foamed asphalt mixes on the field performance, laboratory rutting resistance and fracture energy of asphalt mixes. The experimental effort included in this paper was performed as follows:
- Evaluate the rutting susceptibility of plant-sampled, laboratory-compacted specimens in the Hamburg Wheel-Tracking device.
- Evaluate the indirect tensile (IDT) creep compliance of plant-sampled, laboratory compacted specimens.
- Evaluate the fracture energy of plant-sampled laboratory-compacted specimens.
- Compare road survey data for 3 test sections after 1-year of in-situ conditions.

Sampling Plan/ Preparation
During construction, trucks were sampled as they left the plant. Mix was then stored for laboratory compaction at a later date. Mixes were reheated to 130°C for the two warm-mix pavements, and 160°C for conventional mix.
Low Temperature Laboratory Performance

An Instron load frame 1331 was used in conjunction with a fast track 8800 system for monitoring sensors on the specimens. Laboratory specimens were prepared by reheating loose mix sampled from haul trucks at the plant and compacted to a height of 150mm in a Pine Gyratory Compactor. The target air voids for each specimen was approximately 6% but varied slightly by treatment. After a curing period, the gyratory compacted specimens (GCS) were cut with a wet saw according to Table 1. The experimental design was intended to compensate for variability in density with specimen depth as percent voids changes with depth of the specimen (4).

<table>
<thead>
<tr>
<th>Cutting Procedure</th>
<th>Location in Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix</td>
<td>Top</td>
</tr>
<tr>
<td>Conventional</td>
<td>2 IDT</td>
</tr>
<tr>
<td></td>
<td>2 DCT</td>
</tr>
<tr>
<td>Foamed</td>
<td>1 IDT</td>
</tr>
<tr>
<td></td>
<td>4 DCT</td>
</tr>
<tr>
<td>Sasobit</td>
<td>1 IDT</td>
</tr>
<tr>
<td></td>
<td>2 DCT</td>
</tr>
</tbody>
</table>

In-Place Performance at 1 Year

Eastbound and Westbound surveys were conducted on all test sections using two Automatic Road ANalyzer (ARAN) vans (Figure 2) operated by Connecticut DOT. The sections were then compared for pavement distress normalized to pre-construction conditions. Both lane-rutting data and high-resolution imagery were collected with respect to location along the test sections.

![Figure 2 Connecticut DOT Automatic Road Analyzer Vans used for performance analysis of the three test sections.](image)

TESTING PROCEDURES

Hamburg Wheel Tracking

An advanced pavement analyzer built by Pavement Technologies, Inc. was used to perform the Hamburg wheel tracking test. Specimens with a height of 75mm and diameter of 150mm are submerged in a water bath and undergo repeated loadings by steel wheels at a temperature of 45° C and 50° C. The rutting susceptibility was measured by the inflection point on the rut depth curve recorded by the machine (rut depth vs. number of passes of the wheels). It is generally accepted that an inflection point below 10,000 cycles occurs for mixes prone to moisture-induced damage (5).

Creep Compliance

The IDT creep compliance measurements were conducted in accordance with AASHTO T 322 (6). This method requires a 38mm specimen tested in split cylinder configuration as seen in the test setup in Figure 3. Tests were conducted at three temperatures (0° C, -12° C, and -24° C) after a conditioning period of 2 hours at temperature.
FIGURE 3 IDT Test configuration

A seating load of 0.35 kN was applied to raise the sensors above their noise threshold. The specimen was then immediately loaded to 100 µs in the horizontal direction in the center of a specimen. The load required to achieve the load was then held constant for 1000 seconds and the creep compliance function was then calculated for each specimen. Compliance \( J(t) \) was calculated using the simple average approach, i.e. treating each specimen separately:

\[
J(t) = \frac{1}{n} \sum_{i=1}^{n} J_i(t)
\]

Where:

, , , and, 

\[
J_i(t) = \frac{\Delta \sigma}{\Delta \varepsilon}
\]

Where:

After testing for creep compliance was finalized, the specimens were tested for tensile strength at their corresponding temperatures. This was conducted by applying a constant rate of displacement on the specimen while recording the induced load. Tensile strength \( S_t \) was then calculated using the equation (3):

\[
S_t = \frac{F}{A}
\]

Where:


Disk Compact (Tension) Test

The fracture energy and toughness of the pavements was compared using the disk compact (tension) test (DC(T)). DC(T) tests were performed on 50mm thick specimens cut to disk-like geometry as seen in Figure 4.
A strain gauge was placed on the crack opening after which the specimens were conditioned for 1 hour. The test began with the application of a seating load of 0.35 kN on the specimen. Once this load was achieved, the testing procedure varied the load applied to the specimen to maintain a constant rate of crack mouth opening displacement (CMOD). This CMOD rate was maintained until the applied load fell below a minimal threshold value. Fracture energy and toughness were then calculated.

The fracture energy is determined using equation (4) from ASTM D 7313-07a (7):

$$E_f = \int_a^b \sigma(x) \, dx$$

(4)

where:

$$\sigma(x)$$

and,

$$a, b$$

To calculate the total fracture energy, an exponential function was used to extrapolate the softening region of the load-displacement curve. The total area under the load-displacement curve was extrapolated until zero force and this value was used in the energy calculations. The extrapolation process an accepted practice in fracture mechanics (8) and it is rather necessary due to limited range of the CMOD gauges and the noise level of the load cell. Specimen and ligament lengths were recorded using calipers in 3 locations on the specimen, then averaged. Fracture toughness is calculated as follows:

$$K_{IC} = \frac{E_f}{b}$$

(5)

where:

$$E_f$$

and,

$$b$$

$$K_{IC}$$

(6)

Performance Data

The data collected by the ARAN vans was analyzed for pavement distresses. In particular, linear transverse and longitudinal cracking as well as rut depth were compared across the three
sections. Transverse and longitudinal cracks were summed in linear feet. This value was collected by visual examination of high-resolution pavement photos taken by the ARAN vans. Each photo covered 5m (16 feet) length and 1 lane’s width (~10 feet). The rutting data was collected using a laser distance measuring bar across the front of the van. The results of the rut depths for each section are presented in the results section of this paper.

RESULTS AND ANALYSIS

Hamburg Wheel Tracking

The Sasobit, foamed asphalt and conventional mixes were run at 45° C and 50° C. The results are shown below in Figure 5. Several of the trials were considered to be outliers and omitted due to testing error. In the Figure below, many of the trials just reached their stripping inflection near the conclusion of the test, or demonstrated very mild transitions between the rutting and stripping portions of the deflection curve. Quadratic functions were fit to each curve and their inflection points were determined using the fitted equations to increase the accuracy. The results in Table 2 show the inflection point and corresponding rut depth for each of the tests reported.

![Figure 5: Rut depth vs. cumulative number of passes for each trial.](image)

**TABLE 2 Stripping inflection point and corresponding rut depth for tested mixes.**

<table>
<thead>
<tr>
<th>Mix</th>
<th>45° C</th>
<th>50° C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rut Depth (mm)</td>
<td>Inflection (Passes)</td>
</tr>
<tr>
<td>Conventional</td>
<td>-6.04</td>
<td>16666</td>
</tr>
<tr>
<td>Foamed</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sasobit Wax</td>
<td>-7.922</td>
<td>20000</td>
</tr>
</tbody>
</table>

Based on the results from the Hamburg WT test, the foamed asphalt actually reduced the rutting severity at 50° C, and had no adverse effects on the inflection point. The Sasobit wax additive appears to have increased rutting severity, but extended the inflection point. From these results it could be expected that the Sasobit wax additive can add protection against moisture damage, but decreases the creep resistance of the mix. All of the tests exceed the general 10,000 pass requirement for strong-performing pavement (9)

**IDT Creep Compliance and Strength**

The master curves for all three mixes are displayed in Figure 6. These functions were obtained by manually shifting using time-temperature superposition. The reference temperature used for shifting the creep compliance curves is -12° C.
It can be seen in the mastercurves that the foamed asphalt and conventional pavements have nearly identical curves, whereas the Sasobit wax additive increased produced stiffer material. The curves were fit using specimens with the same mix but random locations from different gyratory compacted specimen so as to eliminate confounding variables (such as air voids content).

The IDT strength test results are displayed in Figure 7. From this data, it is clear that foamed asphalt pavement and Sasobit wax have little effect on the tensile strength of a mix. The strength has an inverse relationship to temperature as expected. A nested ANOVA was run to determine the contribution of temperature and mix on the variation in the results. It was concluded that temperature is highly significant, but mix type was insignificant for tensile strength results.

Disk Compact Tension

The disk compact tension data were used to calculate the fracture energy and toughness for each of the specimens tested. The results are shown in Figure 8, no strong difference can be inferred between the three mixes from the results of this test. Overall the Sasobit-wax additive had consistently high variability compared to the foamed asphalt and conventional pavements. An analysis of variance shows, similar to tensile strength that temperature has a highly significant effect, but mix type has insignificant effect on the fracture toughness.
Field Performance

Transverse and longitudinal cracking were summarized in both the Eastbound and Westbound directions along each section. Results are presented for each mix type. Figure 9 shows the linear meters of cracking per section.

It can be seen from Figure 9 that the Sasobit test section had the greatest amount of cracking after 1 year. The majority of the cracks identified were transverse which indicates the low temperature as the primary cause. While the sections are only one year old, this cracking was very low severity. The potential relative differences between sections will develop over time which will lead to more firm conclusions about the performance of these sections. Just for comparison, cracking observed after the first winter was less than 2% of the cracking measured in 2010 before the construction of test sections.

Rut depth was average per section per wheel path. The results of rutting data collected and processed automatically by the ARAN van are displayed in Figure 10. The data was also processed using analysis of variance for the means of each mix for α=0.05. The resulting ANOVA showed significant differences between all 3 mixes, with foamed asphalt having the lowest average rutting and Sasobit wax having the highest amount of rutting.
Without being able to normalize this data to post-construction rutting there is no way to confirm that the change in rut depth over one year has resulted in this degree of rutting, but the sites will be monitored and compared on a yearly basis.

SUMMARY AND CONCLUSION

This study compared field and laboratory performance for two (2) warm mix asphalts and a conventional hot mix asphalt. The test sections were placed consecutively on State Route 70 in Meriden, CT. Hamburg WT, IDT and DC(T) tests were performed on each mix as well as a survey in the field 1 year after placement using an Automatic Road Analyzer Van. While the overall performance of the mixes appears to be quite similar there are several distinct points that this work in this paper identifies:
- Sasobit wax had the longest time until the stripping inflection point, but had the greatest amount of rutting.
- Conventional HMA and Foamed Asphalt mixes had nearly identical creep compliance master curves whereas Sasobit had a visually greater resistance to creep.
- Tensile strength did not vary significantly between any of the specimens when temperature was fixed.
- DC(T) fracture toughness had no significant difference by mix when temperature was fixed.
- Sasobit wax showed higher cracking in the field. This performance could be related to variance in subsurface conditions.

Previous performance studies have shown equal or better performance for many warm mix additives (1,10). Pavement research across the world has shown the influence of local materials, technologies and users can greatly vary the performance of a pavement mix across different regions. The majority of findings in this paper align with those of previous research, and further monitoring of the test sections should be conducted in attempt to verify the differences noted in this report.

Acknowledgements

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REFERENCES


