National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

Shell Thiopave® Test Sections at Pavement Test Track — One Year Report

RESEARCH SYNOPSIS–NCAT REPORT 11-03

Background

High asphalt binder prices have renewed interest in sulfur as a binder replacement option. Sulfur also has the potential to reduce pavement strain and improve performance by increasing the modulus of the asphalt concrete. Several decades ago, sulfur-modified asphalt mixes were used in numerous experimental pavements. Although these pavements generally performed well, there were issues with hydrogen sulfide (H2S) emissions during production and pavement construction, which caused safety concerns for plant and paving crews. At that time, sulfur was used in a molten-liquid form added directly to the asphalt binder.

To overcome the hydrogen sulfide environmental hazard, Shell Sulfur Solutions developed a new pelletized sulfur formulation called Thiopave©. The Thiopave© system uses sulfur pellets combined with a warm-mix additive (WMA), which allows production temperatures around 275˚F (135˚C). Thus, hydrogen sulfide emissions are reduced to an acceptable level.

The National Center for Asphalt Technology (NCAT) previously conducted extensive laboratory testing on a variety of Thiopave© mix designs in preparation for constructing two full-scale experimental test sections at the NCAT Pavement Test Track. The goal of the laboratory testing, fully documented in NCAT Report 09-05, was to give insight on the mechanistic and performance characteristics to guide decisions regarding the construction of pavement sections.

Figure 1 Shell Thiopave© pellets and compaction aid.

The laboratory investigation evaluated five mixtures: a control (no Thiopave©) and four Thiopave© options. The control mix was designed to the standard 4 percent air void content, while the Thiopave© mixtures involved replacing 30 and 40 percent of the virgin binder with Thiopave© at 2 and 3.5 percent design air void content, respectively. An array of laboratory tests was conducted on each mixture. Some important observations and findings from the lab analysis include the following:

- An increase in dynamic modulus (E*) measured at 21˚C and 10 Hz occurred over a two-week period. The modulus of the Thiopave© mixtures increased modulus by about 300 to 400 ksi, while there was almost no discernible increase in the modulus of the control mixture.
- E* mastercurves showed significant increases in the modulus of the Thiopave© materials relative to the control mix, especially at higher temperatures/lower frequencies; the stiffest was the 40 percent Thiopave© mix at 3.5 percent design air voids.
- Beam fatigue testing conducted at 600, 400 and 200 microstrain indicated a decrease in fatigue life relative to the control mixture as the amount of Thiopave was increased; however, the higher modulus of the Thiopave mix would lead to lower strain levels in the pavement.

As laboratory testing was conducted, eight potential Thiopave© sections and a control section were evaluated using the Mechanistic Empirical Pavement Design Guide (MEPDG) and PerRoad. In general, the MEPDG simulations predicted better performance as the amount of Thiopave© increased because of the relatively higher modulus and/or when the design air voids decreased. PerRoad also showed a general reduction in strain response with an increase in Thiopave©.

Based on the lab data and simulations, it was decided to construct two sections at the Test Track. One section was 7 inches thick (section N6) to compare against several other sections having the same thickness in the 2009 test track cycle. The other section was 9 inches (section N5) thick to examine perpetual pavement design concepts and compare against sections of similar thickness. As of September 2010, when this report was written, about one year of traffic (nearly 5 million ESALs) had been applied to the sections.

Objective

The objective of this report was to document the findings from the Shell Thiopave© and control sections at the NCAT test track after one year of testing. The findings include data obtained during construction, laboratory-determined mechanistic properties, deflection testing, dynamic strain and pressure measurements, and preliminary performance results.

Description of Study

Test Sections and Instrumentation

There are five mixtures that can be subdivided into Thiopave©-modified and control mixtures. The Thiopave© intermediate and base mixtures were placed in the intermediate and base courses of sections N5 and N6 on the test track, and the control intermediate and base mixtures was placed in S9. The control surface mix was placed in the surface layer of all three sections (N5, N6 and S9). It is important to note that the plant-produced mixes used in construction unintentionally contained less Thiopave© than those evaluated in the earlier laboratory study. The preliminary analyses were based on 30 to 40 percent Thiopave©, while during construction of the test sections, the mixtures were produced with 22 to 39 percent Thiopave©.

In each section, 12 asphalt strain gauges were used to capture strain at the bottom of the asphalt concrete (AC). Two earth pressure cells were installed to measure vertical stress at the asphalt concrete/aggregate base interface, and finally, temperature probes were installed just outside the edge stripe to measure temperature at the top, middle and bottom of the asphalt concrete, in addition to three inches deep within the aggregate base.

Laboratory Testing on Binders and Plant-Produced Mixtures

During production of the mixtures in this study, samples of binder and mix were obtained for laboratory testing and characterization. All the binders used in the three sections (two Thiopave sections and one control) were tested in the NCAT binder lab to determine the performance grade (PG) and high temperature creep recovery properties.

Dynamic modulus testing was performed in an IPC Global Asphalt Mixture Performance Tester (AMPT) to quantify the stiffness behavior of each mixture over a wide range of testing temperatures and loading rates. This testing was performed in accordance with AASHTO TP 79-09. Bending beam fatigue testing was performed in accordance with AASHTO T 321-07 to determine the fatigue limits of the 19.0 nominal maximum aggregate size (NMAS) base mixtures of the Thiopave© and control sections. Six beam specimens were tested for each mix, and within each set of six, two beams each were tested at 200, 400, and 800 microstrain.

The final part of the laboratory testing was to evaluate the rutting susceptibility of the Thiopave© mixtures and control base and surface mixtures using the Asphalt Pavement Analyzer (APA). Testing was performed in accordance with AASHTO TP 63-09, and test specimens were prepared to 75 mm in height and to an air void level of 7±0.5 percent. Six replicates were tested for each mix and the specimens were tested at 64˚C.

Falling Weight Deflectometer (FWD) Testing and Backcalculation

Two phases of FWD testing were conducted on the three sections. The first phase (short-term testing) involved daily testing on each section from the time paving was completed until it was opened to traffic. This was intended to track modulus changes due to short-term aging and curing. The second phase (ongoing) involved testing each section several times per month to track modulus changes due to environmental and seasonal changes as well as potential changes due to pavement damage. For both phases, backcalculation of the deflection basins was conducted using EVERCALC 5.0 and based on a three-layer system consisting of the entire depth of asphalt concrete, over the aggregate base on top of the subgrade.

Pavement Response and Performance Measurements

From August 2009 to August 2010, weekly pavement response measurements were taken on the test sections using the embedded strain gauges and earth pressure cells. Weekly data collection consisted of collecting pavement responses from about 15 truck passes (three passes of five trucks) in each section, a frequency consistent with previous data collection efforts at the track. After collecting, processing and archiving the data, analyses were conducted to examine seasonal trends in pavement response, temperature effects on pavement response, responses normalized to particular reference temperatures, responses over time at a normalized temperature and distributions of pavement response.

Rut depth and roughness of the test sections were also measured on a weekly basis using the International Roughness Index (IRI). As of Aug. 28, 2010, 4.7 million ESALs had been applied to the test sections.

Key Findings and Recommendations

Based on the data collected in this study, the following conclusions and recommendations can be made:

1) Dynamic modulus testing of plant-produced laboratory-compacted specimens showed that the Thiopave©- intermediate was the stiffest mixture; followed by the control-intermediate; then the Thiopave© base; control base; and the least stiff, the control surface.
2) Beam fatigue testing of the base layers demonstrated significantly higher cycles to failure for the Thiopave© base mix relative to the control base mix.
3) Fatigue transfer functions developed from beam fatigue testing were combined with measured AC strain data from each test section to compare estimated fatigue performance between sections. An estimated 3.9 times improvement in performance was found when comparing N6 (Thiopave© 7 inch) against S9 (control 7 inch).
4) The predicted endurance limit for the Thiopave© base mixture was 76 percent higher than that of the control base mixture.
5) APA testing showed less than 5.5 mm of rutting on all mixtures tested – the control surface, control base, Thiopave© intermediate and Thiopave© base – after 8,000 cycles.
6) FWD testing conducted before traffic was opened did not indicate significant increases from curing (sulfur crystallization) in backcalcuated AC modulus in the Thiopave© sections. The slight increases over time were comparable to the control section, but were not strongly correlated to the days of aging.
7) Strong correlations between backcalculated composite AC moduli and mid-depth pavement temperature were shown for each test section. The Thiopave© sections were more influenced by temperature than the control section. At colder temperatures (50˚F), the thicker Thiopave© section (N5) had the statistically highest AC modulus, followed by the thinner Thiopave© section (N6) and the control section (S9).
8) The backcalculated composite AC modulus data versus test date through August 2010 did not indicate any bottom-up fatigue cracking in any of the test sections.
9) Strong correlations between mid-depth pavement temperature and pavement response (AC strain, base pressure and subgrade pressure) were found for each test section under each axle type (steer, tandem and singles). Despite statistically different AC moduli, there were no statistical differences in the AC strain at the three reference temperatures (50, 68 and 110˚F) found between N6 (7-inch Thiopave©) and S9 (7-inch control). Section N5 (9-inch Thiopave©) was statistically lower in all cases because of the increased thickness.
10) As of August 2010, all test sections exhibited similar performance. No cracking was evident in any section, and all sections had similar rutting performance and almost no change in pavement roughness. Monitoring will continue through the end of traffic in 2011.

Acknowledgements and Disclaimer

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