The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

Performance Assessment of Warm Mix Asphalt (WMA) Pavements

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Problem

Warm Mix Asphalt (WMA) is a new technology which was introduced in 1995 in Europe. WMA is gaining attention all over the world because it offers several advantages over conventional asphalt concrete mixes. The benefits include: (1) Reduced energy consumption in asphalt mixture production process; (2) Reduced emissions, fumes, and undesirable odors; (3) More uniform coating of aggregate with binder, which should reduce surface aging; and (4) Extended construction season in temperate climates. WMA requires the use of additives to reduce the temperature of production and compaction of asphalt mixtures. WMA technologies include:

- Aspha-min, the addition of sodium aluminum silicate or zeolite to the asphalt mix.
- Sasobit, the addition of a paraffin-wax compound extracted from coal gasification.
- Evotherm, the addition of an emulsion to improve the coating and workability of WMA mixes.

Objectives

The following are the primary objectives of this research:

- To conduct a detailed laboratory study to evaluate the engineering and physical properties of WMA mixtures prepared according to the three techniques mentioned above and a conventional HMA mixture.
- To build and test pavement sections containing each of the selected mixtures (3 WMA types and one conventional) as a wearing (sacrificial) course compacted on conventional HMA layers designed following perpetual pavement guidelines. All sections will be subjected to repeated loads in the (APLF) at Ohio University under high, medium and low temperatures. It is planned to support each of the 4 types of wearing courses on two different thicknesses of the planned perpetual pavements, for a total of 8 test sections. It will be necessary to develop a comprehensive instrumentation plan to monitor environmental conditions and response of the pavement structures when subjected to dynamic loading with properly installed instrumentation.
- To examine the influence of pavement thickness on the tensile strain developed at the bottom of the perpetual pavement layer.

- To monitor and test pavement sections containing the three techniques mentioned above to be built on GUE-541. This section was selected by engineers from the Ohio Department of Transportation, as a demonstration and evaluation project.
- To compare the performance of WMA mixtures and pavements with that of conventional HMA in the controlled setting of the APLF and in the field section.
- To document the performance of perpetual pavements containing 3 types of WMA and one conventional wearing course and to monitor pavement response in the form of deflections, strains and pressures in and under perpetual pavements. These data will be of extreme importance in future validations of perpetual pavements' analysis and design procedures
- To assess the advantages of WMA over conventional HMA in regards to reduced energy utilization and fume emanation during processing and placement.

This research includes an assessment of the performance of WMA mixes and conventional HMA test sections at APLF and in the real built road. This research will be used as a reference for the departments of transportation and the pavement community in general. The research will also evaluate the engineering properties of WMA mixes and conventional mixes. All the results obtained from these perpetual pavement sections can be used as a basis for recommendations for future installations of WMA or HMA in the production process of asphalt mixtures and the compaction of roadways. The new pavement technology is expected to reduce the energy consumption in mixing and laying asphalt. It is also expected to be environmentally friendlier and longer lasting.

Pavement Description

SR541, Guernsey County: ODOT selected an overlay of a portion of State Route 541 between Kimbolton and Plainfield, primarily in Guernsey County, the GUE-541 project, as an opportunity for studying WMA pavements. The test road was divided into four sections, one with each of the WMA mixes or conventional HMA used as a 1.25 in (31.8 mm) surface layer. The overlay also included a 0.75 in (19 mm) HMA layer underneath the surface layer.

APLF: Perpetual pavement sections with WMA surface layers were also constructed and studied in the Accelerated Pavement Load Facility (APLF) in Lancaster. The same three WMA mixes and HMA control mix were used on the 1.25 (31.8 mm) surface courses. The different surfaces were applied to 8 ft (2.4 m) wide lanes, which were subdivided into a northern half with a 16 in thick (406 mm) pavement and a southern half with a thickness that ranged from 16 in (406 mm) to 13 in (330 mm) in 1 in (25 mm) decrements. The full-depth pavement was built up as follows: 12 in (30 cm) coarse aggregate topped by ~5 ft (~1.5 m) of type A6-A7 subgrade soil, a dense graded aggregate base (DGAB, ODOT Item 304) of depth 6 in (15 cm), a 4 in (10 cm) Fatigue Resistant Layer, a 7.75 in (19.7 cm) intermediate AC (ODOT Item 448) layer, a 3 in (7.6 cm) AC leveling layer of ODOT Item 446 Type II, and a 1.75 in (3.2 cm) surface layer of ODOT Item 446 Type I HMA or one of the WMA mixes. For the southern half of each WMA lane, the intermediate layer (ODOT Item 448) was reduced by 1 in (2.54 cm), 2 in (5.08 cm), or 3 in (7.62 cm) and the DGAB increased a corresponding amount to keep the surface of each pavement structure at the same elevation.

The southern sections of each lane were fully instrumented with four Dynatest PAST II AC strain gauges oriented to measure longitudinal and transverse strain 1 inch (25 mm) above the bottom of the fatigue resistant AC layer, two Micro Sensors GHSD 750 LVDTs (one referenced to the bottom of the pavement, the other to a point 5 ft (1.5 m) below the surface), and one Geokon Earth Pressure Cell, all spaced 18 in (45.7 cm) apart longitudinally along the lane centerlines to measure the dynamic response.

Experiment Description

SR541, Guernsey County: Before the overlay commenced, a DCP was used to measure the modulus of the subgrade. During placement of the surface layer, instrumentation was set up to collect emissions samples. Emissions were also monitored at the plant site. To measure the temperature, an infrared camera was used. Core samples were collected at 3, 12, and 20 months after construction and subjected to laboratory testing. Cores were also available from the APLF pavements at the time of construction. Tests conducted at Ohio University included indirect tensile strength, air void ratio, creep compliance. Additionally, cores were sent to the National Center for Asphalt Technology (NCAT) for detailed analysis.

APLF: The APLF study involved heating or cooling the pavement to three temperatures: 40°F (4.4°C), 70°F (21.1°C), and 104°F (40°C), then collecting a set of response data during application of 6000 lb (26.7 kN), 9000 lb (40 kN), and 12,000 lb (53.4 kN) by rolling wheel load and FWD, then applying 10,000 passes at 5 mph (8 km/h) of the 9000 lb (40 kN) rolling wheel load, followed by another set of response measurements. To monitor surface rutting, profiles were measured using a profilometer after 0, 100, 300, 1000, 3000, and 10,000 passes of the rolling wheel load.

Conclusions and Recommendations

Warm Mix Asphalt Conclusions:
The four different sections of the outdoor GUE-541 overlay showed no obvious differences in visual inspection after 20 months of service.

The laboratory measurements of indirect tensile strength indicated no significant difference between the WMA mixes and the HMA control mix. The variations in observed strength appear to be due to differences in conditions under which cores were retrieved and normal measurement fluctuations.

The working temperatures of the warm asphalt mixes were 38.0°F (21.1C°) to 65.8°F (36.5C°) lower than the HMA.

Emissions at the paving site of total particulate matter for all three warm mixes were 67%-77% less than those for the HMA control mix. Emissions of benzene soluble matter were decreased by 72%-81% relative to the HMA.

Emissions at the plant for Aspha-min and Sasobit were reduced by at least 50% for volatile organic compounds, 60% for carbon monoxide, 20% for nitrogen oxides, and 83% for sulfur dioxide. Evotherm measurements showed significant increases in sulfur dioxide and particularly for volatile organic compounds, a slight reduction in nitrogen oxides and a 20% reduction in carbon monoxide. The NCAT report on this project also noted reductions in carbon dioxide emissions from Aspha-min and Sasobit, and attributed the increases in Evotherm emissions to increased fuel use.

Although reported differently in the recent NCAT report for one section, the GUE-541 pavement has not exhibited unusual raveling during the first 14 months of service. A follow-up field review in 2009 showed no unusual raveling or other distress in any section.

In the APLF, all three of the warm mix asphalt surfaces appeared to experience more consolidation than the HMA control surface during the initial stages of application of the wheel load. After the initial consolidation, further consolidation of each pavement was about equal. The difference was about twice as great for Evotherm than for the other two WMA mixes. In the long term, this constant difference in consolidation represents a relatively small portion of total consolidation experienced by the pavement. The NCAT report also noted significantly greater rutting for the Evotherm mix in their test.

The AC consolidation measured with a straightedge includes components under the tires and shoving/heaving between and outside the tire edges. These components progress according to a power equation of the form $y = ax^b$ as loading cycles accumulate. If no tests had been performed at 40°F (4.4°C) and 70°F (21.1°C), more initial consolidation would have been observed in all four lanes, and constants *a* and *b* would have been somewhat different, although relative deformations would likely have remained the same.

APLF Perpetual Pavement Conclusions:
The strains measured in the Fatigue Resistant Layer (FRL) did not show significant differences between the different sections in the APLF. It thus appears that the reduction of a perpetual pavement thickness from 16 in (40 cm) to 13 in (33 cm) accompanied by a corresponding increase in the thickness of the base structure will respond about equally well to loads.

At the highest APLF temperature of 104°F (40°C), the highest longitudinal strains exceeded the FRL design strain. However, the uniformly distributed high temperature in the APLF pavement structure led to the high strains and represented an extremely harsh condition. Under real world conditions, a temperature gradient would exist between the hot surface and the cooler subgrade, which would be expected to reduce the strain at the bottom.

The transverse and longitudinal strains under FWD loading were about equal, as expected. At 104°F (40°C) and under a 9,000 lb. (40 kN) load, transverse strain one inch (2.54 cm) from the bottom of the AC, surface deflection and pressure on the subgrade were much larger under tires traveling at 5 mph (8 km/h) than under the FWD load plate.

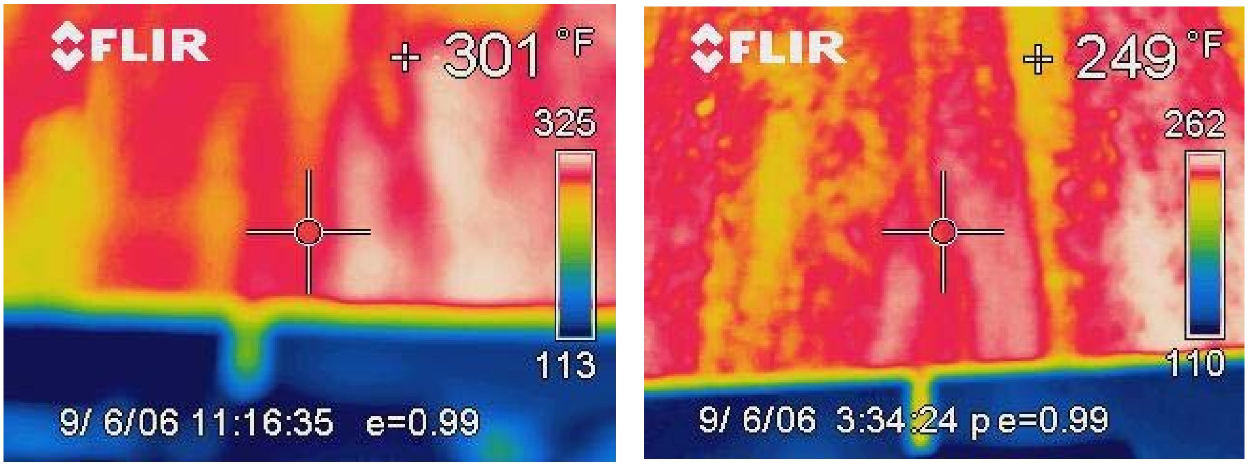
Implementation Potential

Based on the observed response and performance measurements, WMA performs at least as well as the HMA control mix. In addition, all three WMA mixes can be placed at significantly lower temperatures and produce reduced emissions at the paving site, leading to reduced costs. Warm Mix Asphalt has shown its ability for reducing energy consumption and emissions with no loss of pavement quality and no significant negative issues have turned up in performance to date.

It is thus recommended that WMA be more broadly deployed. ODOT has already taken steps to implement this recommendation by recently modifying its Construction and Materials Specifications to allow the use of WMA created using foaming technology on light and medium traffic roads. ODOT has installed foamed WMA technology on selected paving projects starting in 2008. Four of these projects, each with a different contractor, include stack tests. The performance of these sections should be monitored since they use a WMA technology different than those tested in this project.

Performance of WMA pavements under the severe conditions in the APLF suggest that WMA surfaces may also bear heavier traffic loads.

WMA should also be tested on a section of road that experiences heavy truck traffic to determine how well the material performs under such conditions. If the WMA performs well under heavy load conditions as well, then the material should be used widely so that the state can reap the benefits of reduced cost and environmental impact.



Infrared camera pictures comparing temperatures of HMA (left) and Sasobit WMA (right) mixes at time of construction in the Accelerated pavement Load facility. The number in the upper right corner of each image is the temperature registered at the location of the large cross-hairs in the image, and the scale at the right edge shows the colors associated with temperatures over the entire image. All temperatures are in Fahrenheit. Note that the scales are different. The blue areas at the bottom are the off the pavement.

Photograph of the paving operation on SR541 showing monitoring equipment attached to paver, indicated with arrows.