Field Monitoring of the Long Term Pavement Performance (LTPP) Warm-Mix Asphalt (WMA) Site in Oklahoma

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ABSTRACT: As Warm-Mix Asphalt (WMA) moves into mainstream use, the lower WMA production temperature and injection of water in some WMA technologies have raised concerns on how it may affect short- and long-term field performance over the design life. Under the Long Term Pavement Performance (LTPP) Specific Pavement Study 10 (SPS-10) experiment initiative, the Oklahoma Department of Transportation (ODOT) constructed six testing sections with five different WMA methodologies and one HMA control section. This paper presents the application of several art-of-the-state high speed instruments to collect comprehensive array of pavement performance data for long term performance monitoring of this site. The newly developed 3D laser imaging technology is used to collect 1mm 3D surface data for the evaluation of pavement surface distress and transverse profiling for rutting. Longitudinal profiling for roughness and macro-texture for safety are acquired via a high speed inertial profiler, while pavement friction is continuously collected using a Grip Tester. Four data collection events have been performed since the construction of the site. Data collected on the WMA sections and the control HMA section are compared and evaluated for surface performance deterioration. It is demonstrated that the WMA sites using various technologies exhibit better or comparable performance relative to the conventional HMA, in terms of pavement cracking, rutting, and roughness. Aggregate properties and mixture design significantly impact the pavement macro-texture and skid resistance properties.

INTRODUCTION

Background

The warm mix asphalt (WMA) technology is defined as an asphalt concrete paving material produced and placed at temperatures approximately 50 °F cooler than those used for conventional hot mix asphalt (HMA). WMA technologies incorporate foaming processes that use water, chemical additives or surfactants, organic additives, and those using non-foaming additives (Prowell et al., 2012). The plant foaming and additives technologies account about 84% and 16% of the WMA market in the United States (U.S.) (Hansen and Copeland, 2014). WMA offers significant benefits, notably, lower energy demand during production and construction, extended paving season, reduced emissions at the plant and the paver, improved working conditions, early traffic opening, the potential of using higher percentage of reclaimed asphalt pavement (RAP) or reclaimed asphalt shingles (RAS), and increased allowable haul distances (Prowell et al., 2012). As a result, WMA for asphalt pavement construction has dramatically increased over the past decade: by 2014, WMA in the U.S. reached about one-third of the total asphalt mixture market, and its usage increased about 577 percent since 2009 (Hansen and Copeland, 2014).
However, as WMA moves into mainstream use, one primary obstacle of WMA implementation is the uncertainty of how WMA may affect short- and long-term field performance. Lower WMA production temperatures and the water injection used with some WMA technologies have raised concerns on possible rutting and moisture susceptibility of WMA pavements. Various field projects were constructed with the purpose of comparing WMA performance to conventional HMA in terms of mix design practices, engineering properties (fatigue cracking, thermal cracking, rutting, or moisture susceptibility), and constructability (Copeland et al. 2010; Choubane et al., 2013; Buss et al., 2014; Rahman et al., 2016; Raghavendra et al., 2016, and Wen et al., 2016). Due to the fact that WMA projects in U.S. are in the early stages of their design lives and the existing pavement data collection technologies have limitations in (1) data accuracy and (2) data collection speed which poses interruption of traffic flow, long-term pavement performance monitoring for field WMA mixture is limited thus far.

Recognizing that the knowledge gap exists in the comparison of WMA and HMA field performance over the performance life, the Long Term Pavement Performance (LTPP) Program of Federal Highway Administration (FHWA) initiated the Specific Pavement Study 10 (SPS-10) program (“Warm Mix Asphalt Overlay of Asphalt Pavement Study”), to evaluate the short and long term performance of WMA relative to HMA (Puccinelli, 2014). Additionally, the use of RAP or RAS with WMA was also considered in the SPS-10 studies. Accordingly, the experimental matrix of LTPP SPS-10 includes, at a minimum, one HMA control section and two WMA test sections using foaming process and chemical additive with 10-25% RAP and RAS content (Puccinelli, 2014). Other factors, including climate zones (Wet-Freeze, Dry-Freeze, Wet-No Freeze, and Dry-No Freeze), traffic levels (high or low), WMA types, and RAP or RAS levels, can be incorporated for supplemental sections (Puccinelli, 2014). Through this initiative, Oklahoma Department of Transportation (ODOT) constructed a field site including one HMA section and five WMA sections in November 2015, which is the testing bed of this project.

**Objective**

In this paper, the state-of-the-art 1mm 3D laser imaging technology along with several high speed data collection instruments are used to collect a comprehensive array of pavement performance data on the ODOT SPS-10 WMA pavement site. Pavement surface characteristic data, including cracking, rutting, roughness, texture, and friction, are collected using high speed data collection devices without traffic control. Thus far four data collection events have been performed since the construction at a three-month interval. Pavement performance data are analyzed and compared to investigate the field performance of the WMA technologies relative to the conventional HMA.

**LTPP SPS-10 SITES IN OKLAHOMA**

The Oklahoma Department of Transportation (ODOT) constructed six LTPP SPS-10 field sections with different mixture design methodologies on the west bound of State Highway SH-66 in Yukon of Oklahoma in November 2015. The annual average daily traffic (AADT) on this road is 5,900. Table 1 lists the experiment design for the SPS-10 sites, including binder Performance Grade (PG), aggregate combination for each section and mainline (transition between each section), and insoluble residue value for the corresponding aggregate.
As shown in Table 1, Sections 1 to 3 are the required SPS-10 experimental designs, while Sections 4 to 6 are the supplemental sections with mixes chosen by the ODOT Division Office. Sections 1 to 3 are constructed as the conventional HMA control section, WMA using Astec double barrel green (foaming process) and Evotherm M1A (chemical additive) with the same aggregate combination. Sections 4 and 5 are WMA using Evotherm M1A constructed with the same aggregate combination as the first three sites but different binder grades. Section 6 is constructed with stone matrix asphalt (SMA) without fibers (typically used to combat drain down issues) using the same binder grade as those in the first three Sections. The insoluble residue values of the aggregates used in Section 6 and mainline are different from the other sites. The gradation curves of the aggregate combinations are shown in Figure 1. The gradation of aggregate combination 1 and 3 is close to each other, whereas the aggregate combination 2 for the SMA MWA is distinctively different. All the gradations of the mixes meet the corresponding specification requirements for ODOT.

<table>
<thead>
<tr>
<th>Section ID</th>
<th>Binder (PG)</th>
<th>Comment</th>
<th>Aggregate Combination</th>
<th>Insoluble Residue (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70-28</td>
<td>HMA with RAP + RAS</td>
<td>1</td>
<td>56.3</td>
</tr>
<tr>
<td>2</td>
<td>70-28</td>
<td>WMA Foaming with RAP + RAS</td>
<td>1</td>
<td>56.3</td>
</tr>
<tr>
<td>3</td>
<td>70-28</td>
<td>WMA Chemical with RAP + RAS</td>
<td>1</td>
<td>56.3</td>
</tr>
<tr>
<td>4</td>
<td>64-22</td>
<td>WMA Chemical with RAP + RAS</td>
<td>1</td>
<td>56.3</td>
</tr>
<tr>
<td>5</td>
<td>58-28</td>
<td>WMA Chemical with RAP + RAS</td>
<td>1</td>
<td>56.3</td>
</tr>
<tr>
<td>6</td>
<td>70-28</td>
<td>WMA Chemical Stone Matrix Asphalt (SMA) with mineral filler</td>
<td>2</td>
<td>43.6</td>
</tr>
<tr>
<td>Mainline</td>
<td>70-28</td>
<td>HMA with RAP</td>
<td>3</td>
<td>60.8</td>
</tr>
</tbody>
</table>
FIELD DATA COLLECTION INSTRUMENTS

The data collection efforts in this paper include the four testing events on the SPS-10 sites in November 2015 (immediately after the construction), March, June and September 2016 at approximate three-month interval. Several high speed data collection instruments, including the OSU 1mm 3D laser imaging technology, AMES 8300 Survey Pro High Speed Profiler, and Grip Tester, are used to collect pavement cracking, rutting, roughness, macro-texture and friction data without interrupting the traffic.

The latest iteration of 1mm 3D laser imaging technology named PaveVision3D Ultra (3D Ultra) in Figure 2(a) is used for comprehensive pavement surface data collection. This technology is able to conduct real-time automated pavement condition survey at 1mm resolution up to 60 mph (Wang, 2011), including automatic and interactive cracking detection and classification based on various cracking protocols, transverse profiles for rutting, longitudinal profiles for pavement roughness, macro-texture measurements, hydroplaning prediction, and grooving evaluation for safety analysis, and roadway geometry in terms of horizontal curve, longitudinal grade and cross slope.

The AMES Model 8300 Survey Pro High Speed Profiler as shown in Figure 2(b) is designed to collect surface macro-texture data along with standard profile data at highway speeds. Multiple texture indices such as Mean Profile Depth (MPD) can be calculated based on ASTM E1845-09 (ASTM, 2009). Grip Tester (Figure 2(c)) is designed following the ASTM E274/E274M-15 (ASTM, 2015) to continuously measure the longitudinal friction operating around the critical slip of an anti-lock braking system (ABS). Comparing to the traditional locked wheel testing method, grip tester can provide greater details of skid resistance with spatial variability for project and network level friction management. The device has the capability to test at highway speeds (50 mph/80 kph) as well as low speeds (20 mph/32 kph) using a constant water film thickness.
PAVEMENT PERFORMANCE DATA ANALYSIS

Pavement Cracking

Figure 3. Minor Cracking Example on Section 4.

No cracking was found in the 1mm 3D data sets collected immediately after the SPS-10 construction and in March 2016. However, several minor cracks are observed on Section 4 with various lengths during the June and September 2016 data collections. Figure 3 shows an example minor cracking with approximate 450mm in length. By September 2016, no crack is observed on other SPS-10 Sections based on the collected 1mm 3D data. Thus far, the WMA Sections exhibit comparable performance to the traditional control HMA based on the limited data sets in terms of pavement surface cracking.

Pavement Rutting and Roughness

Rutting is defined as the permanent traffic-associated deformation within pavement layers. Rutting in the left and right wheel-paths are calculated at 25 ft interval for each data collection, whose average results with standard error bars are summarized in Figure 4(a). Section 6 exhibits slightly higher rutting value than other experiment Sections. From November 2015 to September 2016, the average rutting values for all the Sections have increased, especially during the most recent three data collection activities. It is observed that the rutting measurements in November 2015 is moderately higher than those in March 2016. This is primarily due to the remaining construction debris on the pavement surface immediately after installation during the November 2015 data collection, which has negatively impacted the accuracy of rutting measurements. Pavement longitudinal profile data is automatically collected by the AMES Profiler at posted speed limit, and the International Roughness Index (IRI) is calculated and summarized at 25 ft interval. The comparisons of average IRI values of the four data collection events along with standard error bars are plotted in Figure 4(b). The IRI numbers have slightly increased, while all the sites are in good conditions with the absolute IRI less than 70 in/mi. Therefore, no distinct difference is perceived in pavement roughness performance between WMA and HMA technologies.
Pavement Macro-Texture

It is widely accepted that surface macrotexture is a predominant contributor to wet-pavement safety. The high-speed pavement macrotexture measurement was performed using the AMES high-speed profiler and the OSU 1mm Ultra 3D technology. The comparisons of average MPD with standard error bars for the four data collection events are plotted in Figure 5(a). Moderate to significant differences are observed between the first two data collection events for most Sections, while the trends of MPD values are more consistent in the later three data collection. Remaining debris on the pavement surfaces, presence of traffic control safety cones, and the fresh bitumen film in the asphalt mix are the possible reasons that contribute to the variations of MPD measurements in the November 2015 data collection. Section 6 with SMA mixture design exhibits the highest texture depth, while Sections 1 to 5 have similar macro-texture properties since they are constructed with the same aggregate combination.

Pavement Friction

Skid resistance is the ability of pavement surface to prevent the loss of tire traction. Pavement friction data were collected continuously using the Grip Tester at the testing speed of 40 mph. The friction number of Grip Tester is summarized and reported every three feet along the entire testing track. Figure 5(b) illustrates the development tendency of friction numbers over time from November 2015 to September 2016 with standard error bars.

Sections 2 and 3 show better or comparable performance in pavement skid resistance relative to the conventional HMA (Section 1), while Sections 4 and 5 demonstrate worse skid resistance performance. The difference between Sections 2 and 3 and Sections 4 and 5 is the binder grade: Sections 2 to 3 use PG 70-28, while Section 4 uses PG 64-22 and Section 5 employs PG 58-28. It maybe concluded that binder grade could have a significant impact on pavement
skid resistance. However, future monitoring of the site is needed to validate the observation.

In addition, it is consistent for all the sections that the friction numbers slightly increased from November 2015 to March 2016, while clear decreasing trend is followed for the subsequent three data collections. Due to the application of traffic polish, the bitumen film formed during construction is gradually removed from the aggregate surfaces. Aggregates are more exposed to the traffic with larger contact areas between the pavement surface and the vehicle tire. As a result, the evolution of skid resistance with an initial increase in friction coefficient occurs in the following months after the construction of pavement surface, as shown in Figure 5(b). This period could range from six months to two years depending on the traffic level, mixture design, and climate condition (Do et al., 2007).

Two factors could result in the decreasing tendency of skid resistance for the succeeding three data collection activities. Due to traffic wear, the surface aggregates have lost macro-texture and been smoothed and polished over time. Second, higher ambient temperatures during the June and September 2016 data collections may soften the pavement mixture and generate lower skid resistance between pavements and testing tire.

Section 6 with SMA mixture exhibits lower friction numbers as compared to Section 3 for all the four data collection events, as shown in Figure 5(b). Both Section 3 and Section 6 use the same binder grade and WMA technology, but different aggregate combination and mix design. During the November 2015 data collection, thick fresh bitumen film was observed on Section 6 immediately after construction, which could cause the lowest friction values of all the sections. In addition, the relatively lower insoluble residue value of the aggregate as compared to other sections is another possible reason for the lower skid resistance of Section 6. The film were gradually disappeared under traffic polishing in later data collection. It is also observed that Section 6 with SMA mixture displays a better capability in maintaining pavement skid resistance than that of other Sections.

CONCLUSION AND FUTURE RESEARCH

Extensive data collection has been performed aiming to monitor and evaluate the field performance of the LTPP SPS-10 MWA sections in Oklahoma as compared to the conventional HMA. The surface characteristics data collected include pavement cracking, rutting, IRI, friction and texture. Four data collection activities have been completed after the construction, respectively in November 2015, March, June and September 2016. The newly developed 1mm PaveVision3D technology, the AMES Profiler and Grip Tester are employed for the data collection at highway posted speed without interfering traffic flow. Below are the observations of the performance comparisons of the LTPP WMA sites within their first year of service:

- WMA Sections 2 and 3, with the same binder grade as that of HMA (Section 1), achieve better or comparable performance in pavement cracking, rutting, roughness, macro-texture, and skid resistance relative to the conventional HMA.
- WMA Sections 4 and 5, with lower binder grade as that of HMA (Section 1), display better or comparable performance in pavement rutting, roughness, and macro-texture whereas worse skid resistance
performance relative to the conventional HMA. Minor cracks are observed on Section 4 while no crack is observed on other SPS-10 Sections based on the 1mm 3D surface data sets.

- WMA Section 6 exhibits better or comparable performance in pavement cracking, rutting, and roughness comparing with the traditional HMA (Section 1). In particular, Section 6 with SMA mix exhibits lower friction numbers as compared to Section 3, who use the same binder grade and WMA technology but different aggregate gradation. However, Section 6 seems to maintain better pavement skid resistance than other sections.

The results and data presented in this paper are from the first year of a five-year long term performance monitoring of the LTPP SPS-10 site in Oklahoma. The field data collection will continue for five years, and the data will be compared and analyzed. In addition, several other instruments such as static localized high-resolution 3D device and dynamic friction tester are used for field evaluation. Field material sampling, coring and testing are also performed to evaluate WMA long term performance relative to HMA in laboratory. However, due to length limitation, these results are excluded in this paper.

ACKNOWLEDGEMENTS

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REFERENCES


