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Laboratory Evaluation and Field Implementation of Polyethylene Wax-Based Warm Mix Asphalt Additive in USA

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Abstract: The use of Warm Mix Asphalt (WMA) for the construction of roads around the world is growing rapidly. This paper presents a new organic WMA product that has been recently introduced to the US market, which is Polyethylene (PE) Wax-based WMA additive with crystal controller to increase the low temperature cracking resistance and anti-stripping agent to enhance moisture susceptibility. To determine the optimum dosage rate, the viscosities of the binder with varying amounts of additive were measured. Based on the Asphalt Binder Cracking Device (ABCD) test, it was found that the low-temperature cracking temperature of asphalt binder would not be affected by the amounts of the additive up to 3.0%. The new Polyethylene (PE) Wax-based WMA mixtures with Reclaimed Asphalt Pavement (RAP) materials were also tested using the Hamburg wheel tracking device and the wheel passes were significantly higher with WMA mixtures PG 64-28 binder, Minnesota aggregates and 25% RAP than the ones with 64-22 binder, Iowa aggregates and 10% RAP. The Hamburg test results seemed to be influenced by more on the characteristics of aggregates and RAP materials than the WMA additive. Two in-service roads in Iowa and Minnesota were successfully rehabilitated using the PE Wax-based WMA mixtures. The average void of 3.8-cm (1.5-inch) WMA overlay (9.0%) was higher than that of HMA overlay (7.0%) placed on an urban street in Iowa City. It was partly due to asphalt temperature that was lowered to match the lower aggregate temperature. However, it is interesting to note that the average air void of the cores obtained from the rehabilitation section of the same street using the same WMA was significantly lower (6.0%). In Minnesota's state highway, the average air voids of four WMA and HMA cores for quality control were 5.85% and 5.29%, respectively and those of four other WMA and HMA cores for quality assurance were 6.05% and 6.01%, respectively. The WMA pavements were easier to reach 94% density with fewer passes of a compactor than the HMA.

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***Key words**: Asphalt binder cracking device; Hamburg wheel tracking device; Low temperature cracking; Moisture sensitivity; Pavement overlay; Polyethylene wax; Warm mix asphalt.*

Introduction

Warm Mix Asphalt (WMA) has become a mainstream of the asphalt pavement construction in the United States and the world due to the reduced fuel consumption, less carbon dioxide emission, reduced oxidation of asphalt, early opening to traffic and a better working environment for workers. The main purpose of the project is to evaluate a new Polyethylene (PE) Wax-based WMA additive (Fig. 1) through laboratory test and field implementation. The PE Wax-based WMA additive works by reducing the viscosity of the asphalt. Its melting point is 100℃ and crystallization point is 90℃. The new PE Wax-based WMA additive named "LEADCAP" controls the crystallization so that it does not become brittle at low temperature. The LEADCAP is positively charged to enhance the bonding of asphalt binder to negatively charged aggregate surface.

This paper focuses on the evaluation of the WMA mixtures with the LEADCAP additive and Reclaimed Asphalt Pavement (RAP) materials using a Hamburg wheel tracking device. Texas DOT recommended 10,000 passes for PG 64-xx, 15,000 passes for PG 70-xx and 20,000 passes for PG 76-xx until reaching a rut depth of 12.5 mm [1]. Based on 3,700 Hamburg test results, almost 50% of all HMA mixes with PG 64-xx in Texas did not meet 10,000 pass requirement. It was recommended that, when justified, districts of Texas DOT should consider lowering the Hamburg specification to a value of not less than 5,000 passes for mixtures with PG 64-xx.

Hamburg wheel tracking tests have been performed on multiple

Fig. 1. PE Wax-Based Warm Mix Asphalt Additive.

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HMA and WMA samples and the results show that HMA specimens have a higher rutting resistance than WMA specimens using a variety of additives [2]. The moisture susceptibility of WMA specimens was measured using multiple WMA additives at multiple temperatures and aging times and it was discovered that the rutting resistance increased as aging time increased [3]. Dry Hamburg wheel tracking tests have been performed on multiple WMA and HMA samples that were produced at varying temperatures and it was found that the resistance to rutting decreased as mixing and compaction temperature decreased [4].

WMA mixtures, which were cured for two hours at the compaction temperature, exhibited Hamburg test results as low as a half of the HMA [5]. When the curing time was increased from two to four hours and increasing the curing temperature to 135℃ (275℉), however, the Hamburg test results of WMA were equivalent to HMA. Because the field WMA mixtures discussed in this paper included the RAP materials, the influence of RAP materials on the Hamburg test results would be of interest. The overall effect of RAP content on Hamburg test was inconclusive with results showing the wheel passes were similar among mixtures with 15% to 50% RAP contents except ones with 30% RAP content [6].

This paper presents a comprehensive evaluation of the LEADCAP additive. First, the viscosities and low-temperature cracking temperatures were measured with varying amounts of the LEADCAP additive. Second, the Hamburg tests were performed on both laboratory and field specimens that include RAP materials. Third, the field densities were measured from the cores from both WMA and HMA thin overlays for comparison.

Viscosity and Low Temperature Cracking Test

For each temperature from 135, 130, 125 to 120℃, as shown in Fig. 2, the viscosities of the PG 64-28 binder (y-axis) with varying amounts of the LEADCAP additive from 0% to 3.0% (x-axis) were measured using a rotational viscometer and plotted against the dosage rate. The test result shows a steady decline in viscosity with increased dosage of the additive; however, the rate of decrease in viscosity is not proportional to the dosage rate. Fig. 2 shows a drastic reduction in viscosity up to 1.0% of the additive but remained relatively steady as the dosage rate is increased up to 3.0%. This viscosity test result confirms that at least 1.0% should be added to asphalt lowered to 120 ℃.

Fig. 3 shows plots of the strains developed in PG 64-34 asphalt binder with varying amounts of the LEADCAP additive as a test temperature was gradually lowered using the Asphalt Binder Cracking Device (ABCD). The test ended when the sample was cracked, producing a sudden jump in strain. The virgin asphalt binder PG 64-34 cracked at -51.0℃. As the WMA additives were increased from 0.5% to 3.0%, the cracking temperatures increased slightly from -49.9℃ to -48.6℃. This result confirms that the cracking temperature of asphalt binder would not be significantly affected by the additive. However, it is interesting to note that when the amount of additive increased, the failure strain increased. This result indicates that the additive may increase the toughness of asphalt binder at low temperature.

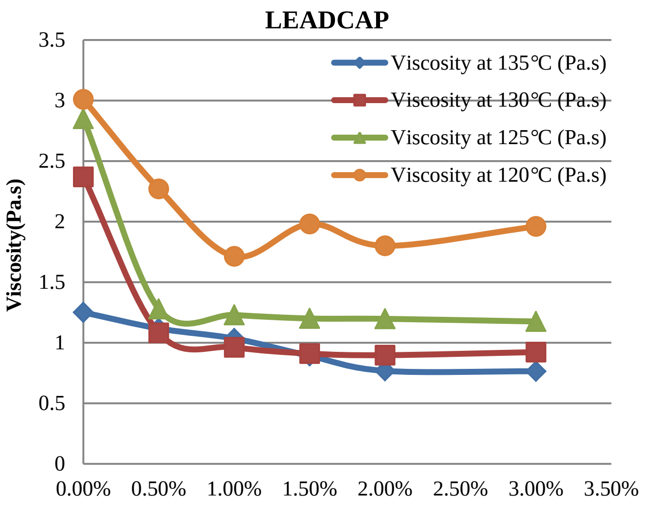


Fig. 2. Viscosities of Asphalt Binder with Varying Amounts of LEADCAP Additive.

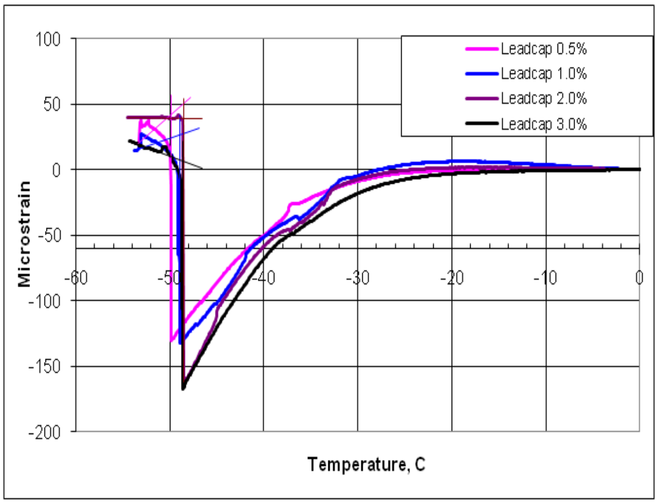


Fig. 3. Cracking Temperatures of PG 64-34 with Varying Amounts of the Additive.

Hamburg Wheel Tracking Test of Laboratory Mixtures

Fig. 4 shows the Hamburg Wheel Tracking device that applies a constant load of 685 N through a steel wheel. The tests are run in a water bath that is heated to 50℃ after the test specimens are conditioned for 30 minutes [7]. A test is completed when the wheel has passed over the specimens 20,000 times for 6.5 hours or when the rut depth exceeds 20 mm. Short-term aging for volumetrics is set to be two hours at the compaction temperature for both WMA and HMA mixtures. The HMA mixture is short-term aged for 4 hours at 135℃ (275℉) then followed by 2 hours at the compaction temperature. WMA mixture is short-term aged for two hours at compaction temperature then aged for 16 hours at 60℃ (140℉).

Mix Design and Aggregate Gradation

The laboratory mixture was designed for a 1 million Equivalent Single Axle Load (ESAL) road. The mixture used limestone

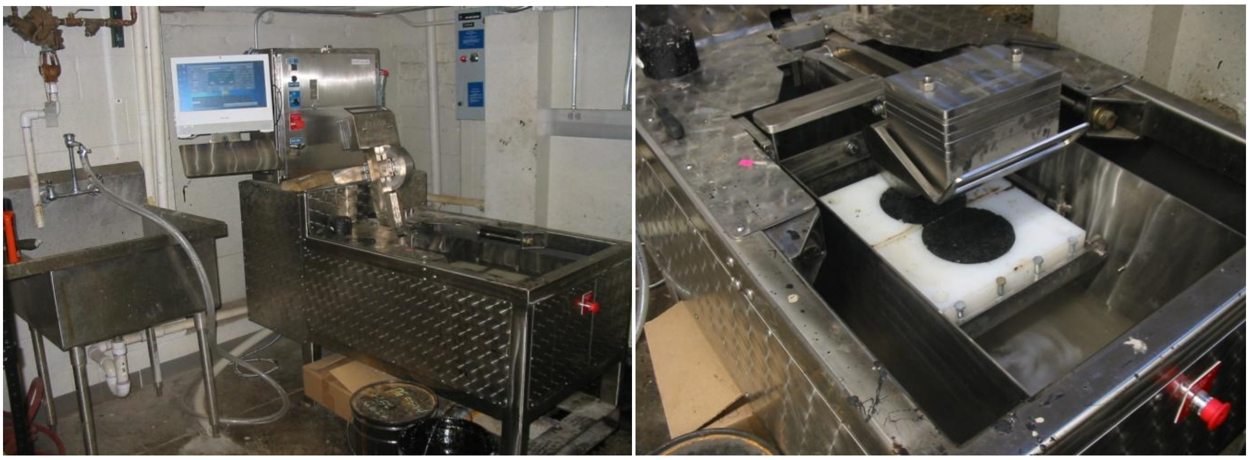


Fig. 4. Hamburg Wheel Tracking Device and Specimens Ready for Testing.

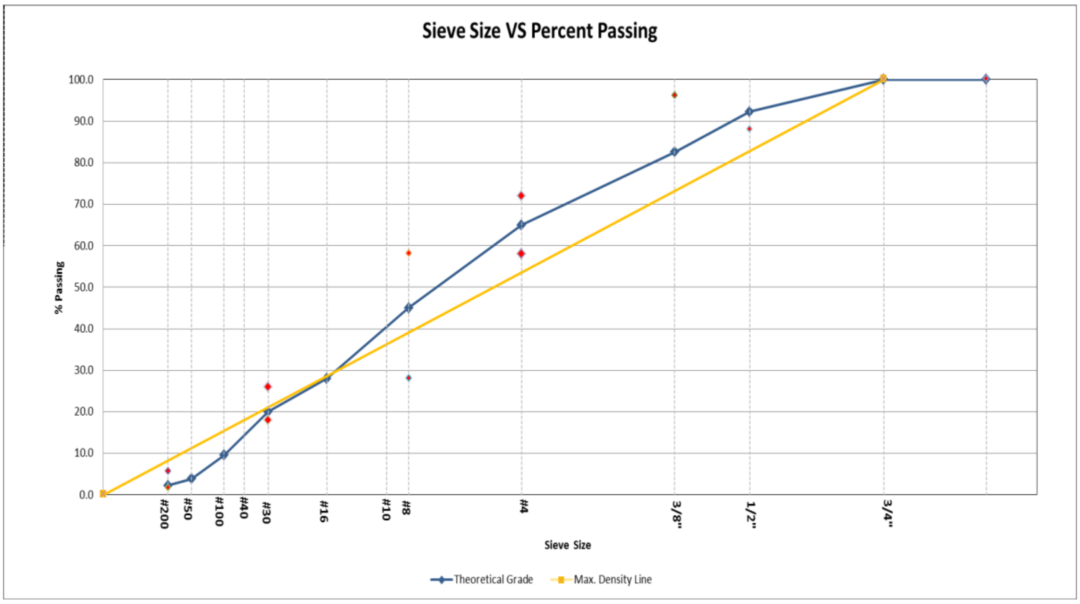


Fig. 5. 0.45 Gradation Chart of Aggregates

aggregate with a 12.5-mm nominal maximum size as shown in Fig. 5. The Superpave mix design was performed to determine the optimum binder content using PG 64-34 binder. The optimum binder content was found at 5.0% for HMA mixtures and 4.8% for WMA mixtures. For the Hamburg Wheel Tracking test, however, 5.0% binder content was adopted for both HMA and WMA mixtures.

Sample Preparation

To produce WMA test specimens, the aggregate was heated at temperature of 125℃ for 6 hours and the PG 58-28 asphalt was heated at 145℃ for 1.5 hours in the oven. The WMA additive was then added to the heated aggregate in the bucket mixer and then asphalt was added. Aggregate, asphalt and WMA additive were mixed for 60 seconds and the WMA mixtures were then heated at 125℃ for 30 minutes in the oven. The heated WMA mixtures at 125℃ were added in a preheated gyratory mold at 125℃ and compacted for 86 gyrations. To prepare a control HMA mixture, the aggregate was heated at temperature of 165℃ for 6 hours and PG 58-28 asphalt was heated at 145℃ for 1.5 hours in the oven. Next, the heated asphalt was added into the heated aggregates. Aggregate and asphalt were mixed for 60 seconds and the HMA mixtures were then heated at 135℃ for 60 minutes in the oven. The heated HMA mixtures at 135℃ were added in a preheated gyratory mold at 135℃ and compacted for 86 gyrations.

Test Results

As shown in Fig. 6, the wheel passes applied on the WMA with air voids of 6.61%, 6.57% and 6.67% and the HMA with air voids of 6.58%, 6.6% and 6.68% until a 20-mm rut depth were averaged at 7,140 and 10,273, respectively. Pictures of WMA and HMA specimens after the experiment are shown in Fig. 6. The test results are very consistent among three trials for WMA and HMA.

Field Implementation of PE Wax-based WMA Additive in Iowa

As shown in Fig. 8, on August 15, 2011, the first project of the PE

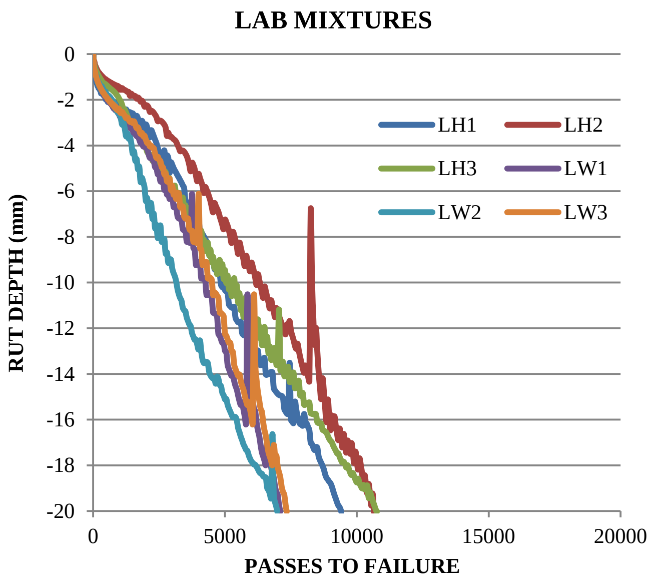
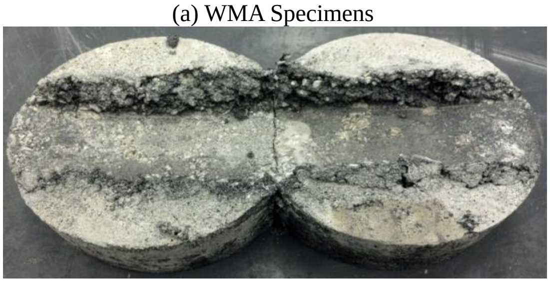


Fig. 6. Rut Depth of Laboratory WMA (LW) and HMA (LH) Mixtures versus Wheel Passes

(a) WMA Specimens



(b) HMA Specimens

Fig. 7. Pictures of (a) WMA and (b) HMA Specimens after 20,000 Passes.

Street in Iowa City.

Fig. 8. WMA Pavement with the New PE Wax-based Additive on Capitol Street in Iowa City.

Wax-based WMA Additive in the USA was applied for rehabilitating Capitol Street between Prentiss Street and Court Street in Iowa City. The existing pavement was milled and replaced with a 3.8-cm (1.5-inch) HMA binder course and 3.8-cm (1.5-inch) WMA surface course. A total of 327 tons of a 1 million ESAL 12.5-mm WMA surface mix with 10% RAP was used. The PG 64-22 asphalt binder used in this project was heated to 135°C (275°F) before mixing with the aggregate at 135°C (275°F). The asphalt mixture was stored in a holding container until it was ready to be loaded onto dump trucks at 130°C (266°F). It was then driven to the jobsite and placed on top of the binder course at 115°C (239°F). The WMA mixture was compacted at a temperature of 110°C (230°F). On September 27, 2012, due to the underground utility rehabilitation, a part of the Capitol Street constructed on August 16, 2011, was re-constructed using the 100 tons of the same LEADCAP WMA mixtures.

Densities of Field Mixtures and Cores

The field asphalt mixtures were sampled to determine the volumetric properties. As shown in Table 1, an average bulk-specificity gravity of HMA mixtures was 2.366 and average maximum specificity gravity was 2.476, resulting in air voids in laboratory-compacted field mixtures of 4.40%. The average field density of seven cores was 2.302 resulting in average field voids of 7.0%. Average bulk-specific gravities of WMA mixtures placed in 2011 and 2012 were 2.369 and 2.402, and average maximum specific gravities were 2.467 and 2.480, resulting in average air

Table 1. Volumetric Properties of WMA and HMA Mixtures from the Field.

Job Site	Miami (HMA)	Capitol 1 (WMA)	Capitol 2 (WMA)
% RAP	10%	10%	10%
Actual Virgin Binder Content (%)	4.60	4.60	5.40
Actual Total Binder Content (%)	5.17	5.17	5.85
Dust (-No. 200) (%)	4.1	4.1	5.7
Dust-Binder Ratio	0.84	0.84	1.12
Lab Compacted Gmb	2.366	2.369	2.402
Gmm	2.476	2.467	2.480
VTM (%) of Lab compacted Specimens	4.4	3.97	3.10
Gmb of Field Cores	2.302	2.240	2.331
VTM (%) of Field Cores	7.0	9.0	6.0

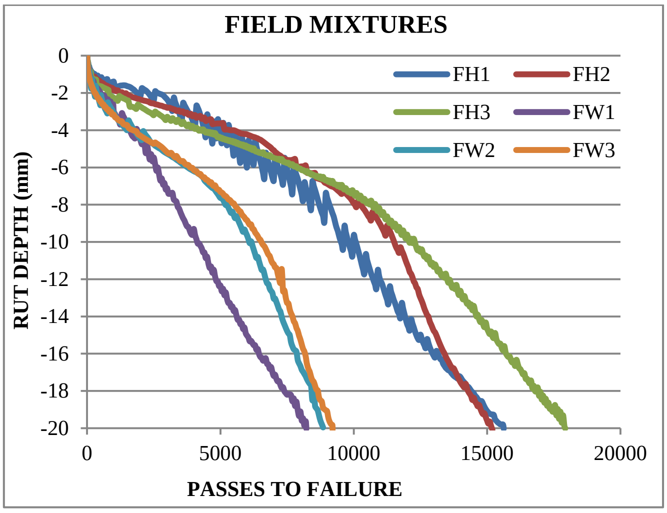


Fig. 9. Rut Depth of Field WMA (FW) and HMA (FH) Mixtures Versus Wheel Passes.

voids of laboratory-compacted field mixtures of 3.97% and 3.10%, respectively. The average field densities of WMA mixtures placed in 2011 and 2012 were 2.240 and 2.331, resulting in air voids of 9.0% and 6.0%, respectively. It should be noted that the binder content of WMA mixtures in 2012 was higher than the WMA mixtures in 2011.

Hamburg Test of Field WMA and HMA Mixtures

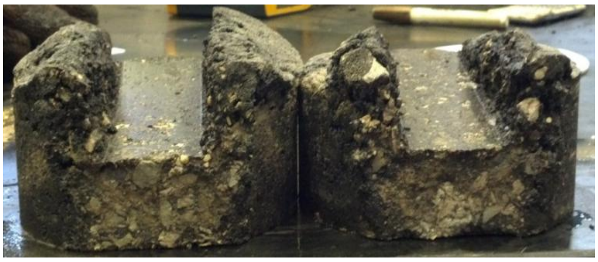
As shown in Fig. 9, the wheel passes applied on the WMA with air voids of 6.62%, 7.09% and 6.87% and the HMA with air voids of 7.07%, 7.17% and 7.35% until a 20-mm rut depth were averaged at 8,760 and 16,252, respectively. The field mixtures included 10% RAP materials and used PG 64-22. It is interesting to note that the field mixtures of both WMA and HMA performed better than laboratory mixtures. Fig. 10 shows pictures of Hamburg test specimens of Field WMA and HMA mixtures after reaching 20-mm rut depth.

Field Implementation of PE Wax-based WMA Additive in Minnesota

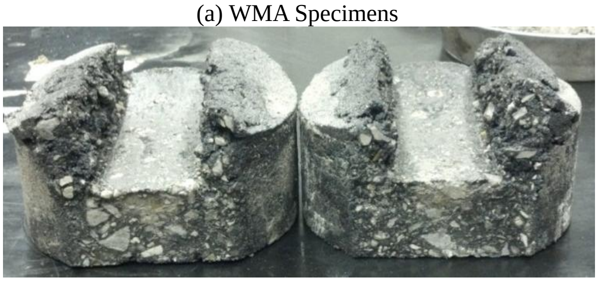
On July 10, 2012, as shown in Fig. 11, 5.1-cm (2-inch) mill and overlay was applied on southbound outside lane of TH 169 State Highway in Champlin between the Mississippi River and Hayden Lake Road using WMA mixtures with LEADCAP. The LEADCAP section is on the outside lane from the river to the sharp corner (Past the sharp corner to Hayden Lake Road is HMA). The Superpave wear course with 12.5-mm mix with PG 64-28 for a traffic level 4 (3-10 million ESALs) was used along with 25% RAP. The HMA was produced at 160°C (320°F) whereas the WMA was produced at 135°C (275°F). A total of 1,400 tons of asphalt mixtures were used (a half HMA and a half WMA).

Densities of Field Mixtures and Cores

Based on the MOBA Bar PAVE-IR device, the mix temperature of the WMA mat was more consistent with than the HMA. The WMA



(a) WMA Specimens



(b) HMA Specimens

Fig. 10. Specimens of (a) PE Wax-based WMA and (b) HMA Specimens After the Experiment

Fig. 11. WMA Rehabilitation Project on TH 169 State Highway in Champlin, Minnesota.

was easier to reach a 94% density with fewer passes and the lower temperature did not affect the compaction requirements. In fact, the contractor applied only 4 passes of breakdown roller (vibratory steel double drum), then pneumatic and finish rollers whereas they applied 6 passes of breakdown roller, then pneumatic rubber tire and finish rollers. The field density during construction was

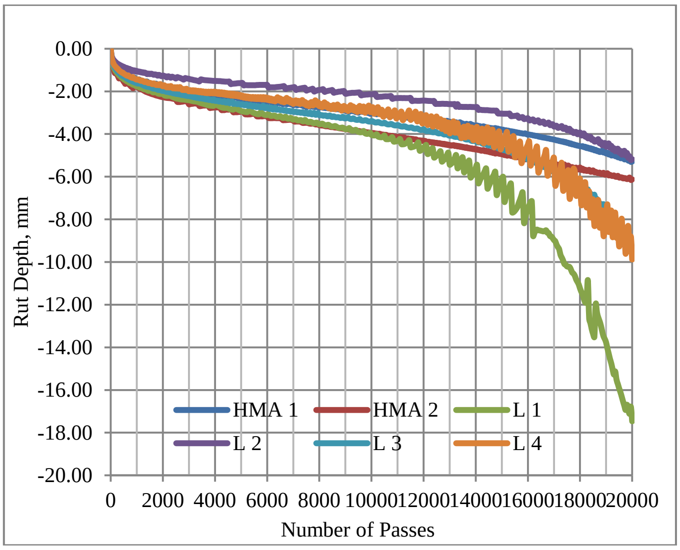


Fig. 12. Rut Depth of Field WMA and HMA Mixtures from Minnesota over 20,000 Passes

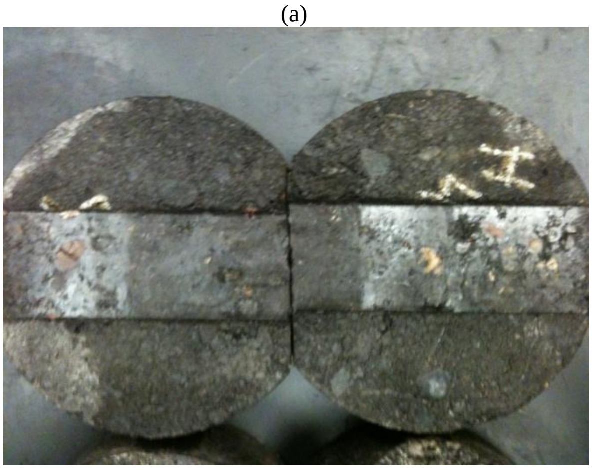
continuously monitored using the PQI non-nuclear device, which confirmed that the target density of WMA mat was achieved with less passes of a roller than HMA.

An average bulk specific gravity of laboratory-compacted field WMA mixtures was 2.406 and an average maximum specific gravity was 2.499, resulting in an average air void of 3.72%. An average bulk specificity gravity of laboratory-compacted field HMA mixtures was 2.426 and average maximum specificity gravity was 2.521 resulting in air voids of 3.77%. A total of eight cores were made (two cores from each of four different spots) and a Valley Paving company measured densities of four cores and Minnesota DOT measured the other four cores. The average field densities of four WMA and HMA cores measured by the contractor were 2.353 (2.361, 2.305, 2.373 and 2.372) and 2.388 (2.408, 2.427, 2.392 and 2.324), resulting in average field voids of 5.85% and 5.29%, respectively. The average field densities of four WMA and HMA cores measured by the agency were 2.348 and 2.370, resulting in average air voids of 6.05% and 6.01%, respectively. One of the WMA cores (with a density of 2.305) was from the existing roadway in a terrible condition with a serious subgrade issues. Therefore, when the contractor compacted the WMA overlay in this segment, they chose to do the only static roll to eliminate the potential for the roadway to sink.

Hamburg Test of Field WMA and HMA Mixtures

As shown in Fig. 12, all four WMA specimens with air voids of 6.60%, 6.46%, 7.05% and 6.38% and two HMA specimens with air voids of 7.21% and 7.88% endured 20,000 passes before reaching a 20 mm rut depth. It should be noted that the air voids did not correlate well with the performance where WMA specimen with air voids of 6.6% performed worse that the WMA specimen with air voids of 7.05%. The field mixtures of both WMA and HMA from Minnesota project performed significantly better than field mixtures from Iowa City project. It should be noted that the field mixtures of Minnesota project were designed for a higher traffic load and they included 25% RAP materials. Fig. 13 shows pictures of Hamburg

(a)



(b)

Fig. 13. Specimens of (a) the WMA and (b) the HMA after 20,000 Load Repetitions.

test specimens of field WMA and HMA mixtures after 20,000 passes.

Summary and Conclusions

This paper presents the new Polyethylene (PE) Wax-based Warm Mix Asphalt (WMA) additive which has been successfully applied to rehabilitate pavements in Iowa and Minnesota. The viscosity of the asphalt binder decreased significantly when up to 1.0% additive was added but it remained relatively steady as the dosage rate increased up to 3.0% at all test temperatures of 120, 125, 130 and 135°C. Based on the ABCD test device, the virgin asphalt binder PG 64-34 cracked at around -51.0°C. As the WMA additive was increased from 0.5 to 3.0%, a low-temperature cracking temperature remained steady near the cracking temperature of the virgin asphalt binder.

Based on the limited Hamburg test results of laboratory HMA and WMA mixtures with the PE Wax-based additive, the HMA specimens performed slightly better than WMA specimens although both specimens reached 20 mm rut depth at around 10,000 passes. When the Hamburg tests were performed on the field HMA and WMA mixtures with 10% RAP from Iowa, both endured more wheel passes with HMA mixtures reaching 15,000. Field HMA and WMA mixtures with 25% RAP from Minnesota all performed well to exceed 20,000 passes before reaching 20 mm rut depth.

The average air void of 3.8-cm (1.5-inch) WMA overlay (9.0%) was higher than that of HMA overlay (7.0%) placed on an urban street in Iowa City. It was partly due to asphalt temperature that was lowered to match the lower aggregate temperature. As a result, aggregate temperature for WMA was also significantly lower than HMA. However, the average air void of the cores obtained from the rehabilitation section of the same street using the same WMA additive was 6.0 %. In Minnesota's state highway, the average field densities of four WMA and HMA cores measured for quality control were 2.353 and 2.388, resulting in average air voids of 5.85% and 5.29%, respectively. The average field densities of four WMA and HMA cores for quality assurance were 2.348 and 2.370, resulting in average air voids of 6.05% and 6.01%, respectively.

WMA pavements using the new PE wax-based WMA additive were successfully constructed in Iowa City, Iowa and Champlin, Minnesota. Based on the PAVE-IR device, temperature was more consistent with the WMA than the HMA while achieving a 94% density with fewer roller passes. Based on the PQI readings during the construction, the contractor reduced number of roller passes from 6 to 4 while achieving the similar density as HMA and received an incentive from Minnesota DOT for exceeding the minimum density requirement.

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