NCAT Report 11-02

Three-Year Evaluation of the Colorado Department of Transportation’s Warm-Mix Asphalt Experimental Feature on I-70 in Silverthorne, Colorado

Final Report

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Sponsored by: Colorado Department of Transportation

May 2011

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ACKNOWLEDGEMENTS

This project was sponsored by the Colorado Department of Transportation (CDOT). The project team received much assistance during field data collection, rut measuring, crack mapping, coring, and laboratory testing. The team appreciates and thanks Kevin Brown, Roberto deDios, Dan Falls, Mike Gallegos, Shamshad Hussain, Brock Johnson, Aziz Khan, Denny Maurer, Janet Minter, Neal Retzer, Bryan Tchouban, and Ed Trujillo. Also, special thanks to Todd Anderson and the CDOT's Region One Maintenance personnel for traffic-control operations. The team also appreciates and thanks the Colorado Department of Transportation for its sponsorship of this project.

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ABSTRACT

The Colorado Department of Transportation (CDOT) constructed an experimental feature with warm-mix asphalt (WMA). Three WMA additives were used: Advera, Sasobit, and Evotherm DAT. The production, constructability, laboratory performance testing and field performance of the WMA experimental feature were demonstrated by comparing it to CDOT's standard hot-mix asphalt (HMA) as the control. Overall, the production and construction of all the WMA test sections were comparable to the HMA control sections. The WMA test sections were compacted about 30˚F to 50˚F (17˚C to 28˚C) cooler than the HMA control. The laboratory performance testing of all the WMA test mixes was comparable to the HMA control mix. However, the laboratory performance testing indicated the WMA test mixes were slightly more susceptible to rutting and slightly more susceptible to moisture damage than the HMA control mix. After three years of field evaluations, the performance of the WMA test sections was comparable to the HMA control sections in regards to rutting, cracking, and raveling. The field performance was excellent. It should be noted that this location has a very harsh winter climate.

1. CHAPTER 1 OVERVIEW

1.1 Introduction

Warm-mix asphalt (WMA) is the generic term for a variety of technologies that allow the producers of hot-mix asphalt (HMA) pavement material to lower the temperatures at which the material is mixed and placed on the road. Reductions of 50˚F to 100˚F (28˚C to 56C˚) have been documented. Such drastic reductions have the obvious benefits of cutting fuel consumption and decreasing the production of greenhouse gases. In addition, engineering benefits include better compaction on the road, the ability to haul paving mix for longer distances, and extending the paving season by being able to pave at lower temperatures.

The Colorado Department of Transportation (CDOT) constructed a project with an experimental feature of WMA in July and August 2007. Three WMA technologies were included in the demonstration: Advera, Sasobit, and Evotherm DAT. A control HMA was produced to compare the production, constructability, laboratory performance testing, and field performance of the WMA test sections. This report summarizes the production, construction, laboratory performance testing, and three-year field performance of the sections.

1.2 Background

WMA is a new technology that allows asphalt mixes to be produced at lower temperatures than traditionally required for HMA. The production of an asphalt mix at temperatures less than 275˚F (135˚C) can result in lower emissions, decreased fuel usage, and reduced oxidation of the asphalt compared to mixes produced at 300˚F (149˚C) and above. The reduced emissions and fuel usage can be environmentally beneficial, and reduced fuel usage can be economically beneficial.

The motivational factor for CDOT's use of WMA as an experimental feature on this project was to extend the paving season. Traffic continues to increase in Colorado, and the mountain corridors are no exception. In the past, overlays could be placed on the mountain roadways during the day. The increased traffic has required overlays to be placed at night. This has been especially problematic at higher elevations because the low nighttime temperatures reduced the length of the paving season substantially. It was hoped that WMA could be compacted at lower temperatures, lengthening the nighttime paving season in the mountains.

The question that arises is: Is the performance of the asphalt mix affected by using a WMA technology? If it is adversely affected, then the environmental, production, and economic benefits could be negated. If the performance of WMA pavement is as good as or better than HMA pavement, then the change in production practices would likely be very worthwhile.

The asphalt mix properties typically of interest when evaluating a new WMA technology are moisture susceptibility, rutting susceptibility, strength, and stiffness. Moisture susceptibility is a concern since the reduced temperature may result in incomplete drying of aggregate. Any moisture remaining in or on the aggregate could affect the bond between the asphalt and aggregate, thus leading to premature pavement failure. The reduced mixing temperature of the WMA may result in softer asphalt than the same mix produced at HMA temperatures since there is less oxidation of the asphalt. The softer asphalt has raised concern that WMA may be more prone to rutting and poor tensile strength. However, there may also be benefits to softer asphalt. One of the benefits of a softer binder is a less stiff mix, which may improve the asphalt's resistance to fatigue and thermal cracking.

1.3 Purpose and Scope

The purpose of this study was to compare the production, constructability, laboratory performance testing, and three-year field performance of three WMA technologies with a control HMA. This report summarizes the comparison of the WMA experimental feature and the HMA control.

1.4 Project Description

1.4.1 Project and Location

The project was located on I-70 about 70 miles (110 km) west of Denver. It was CDOT Project Number IM 0702-262 built by Region 1. It began at the Town of Silverthorne at Mile Post (MP) 204.6 and extended 9.0 miles (14.5 km) east up the mountain to the West Portal of the Eisenhower-Johnson Memorial Tunnel at MP 213.6. It included only the three uphill, eastbound lanes. The three downhill, westbound lanes were constructed as part of a different project the following year.

The entire project was advertised with just over 36,000 tons (33,000 tonnes) of HMA. In addition, there were 3,000 tons (2,700 tonnes) of WMA advertised as an experimental feature. The low-bid project was awarded to Asphalt Paving Company. The unit prices for the HMA were $48 per ton (hauled, in-place) and $66 per ton for the WMA (hauled, in-place). The bid price for the WMA was approximately 38% higher than the standard HMA. It is important to keep in mind that the WMA was an experimental feature that had significantly lower quantities, additional equipment at the plant, and additional material.

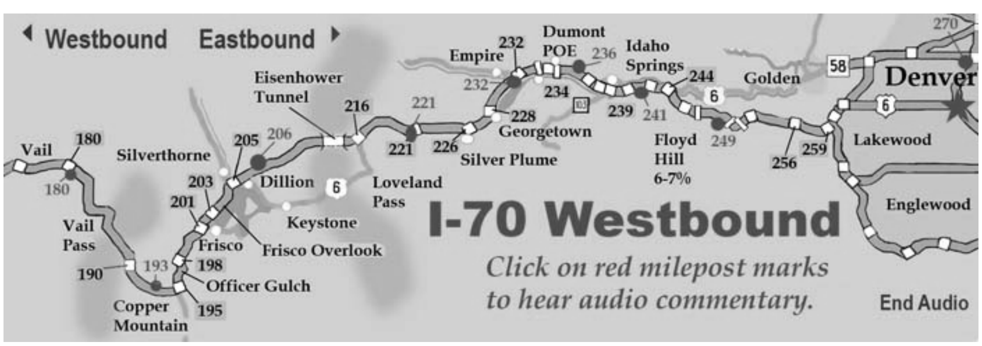


Figure 1 Project Location from MP 204.6 to 213.6

1.4.2 Pavement Design and Rehabilitation Strategy

The existing pavement had 10 to 13 inches (25.4 to 33 cm) of asphalt over fill with an *R*-value of 75. Existing pavement distresses included cracking (longitudinal, fatigue, and transverse) along with some weathering and raveling. The pavement design was a 2.5-inch (6.4 cm) mill and 2.5-inch (6.4 cm) overlay. After milling, there was generally no evidence of any of the distresses observed on the milled surface. The distresses were primarily on the surface, although there were still some limited fatigued areas and transverse cracks visible. The 10-year design was based on 4.85 million 18-kip ESALs. This was calculated with 30,000 annual average daily traffic (AADT) with 10% trucks.

1.4.3 Climate

Extreme winter conditions exist at the project site. This project is in mountainous terrain with elevations ranging from 8,800 to 11,100 feet (2,680 to 3,380 m) above sea level. There are over 35 inches (90 cm) of precipitation annually and over 200 inches (500 cm) of annual snowfall. For example, from Dec. 1, 2007, to Feb. 14, 2008, it snowed 65 of the 76 days. Chains were required on trucks for 128 days during winter 2007–2008.

2. CHAPTER 2 EXPERIMENTAL DESIGN

2.1 WMA Additives

There were at least five different WMA technologies that were developed in Europe and the United States. The project specifications called for three different WMA technologies that were currently available in the United States:

- *Advera WMA*, marketed by PQ Corp (Formerly *Aspha-min zeolite*, developed by Eurovia Services GmbH) which is a synthetic zeolite added during mixing at the plant to create a foaming effect in the binder,
- *Sasobit*, developed by Sasol International (Sasol Wax) which is an organic additive, a low molecular weight esterified wax (type of paraffin wax),
- *Evotherm DAT*, developed by MeadWestvaco Asphalt Innovations which is an asphalt emulsion product which uses a chemical additive technology and a dispersed asphalt technology delivery system.

These were required by the project specifications so that they could be evaluated as part of the experimental feature.

Advera WMA is a manufactured natrium-aluminum silicate that contains approximately 20 percent water by weight. When the Advera WMA is added to the mix at the same time as the binder in the temperature range of 185˚F to 360˚F (85˚C to 180˚C), the water is released, which causes the asphalt binder to foam while mixing with the aggregate. The manufacturers recommend the addition of 0.3% by mass of the mix to enable approximately a 54˚F (30˚C) reduction in production and placement temperatures.

Sasobit is a synthetic long-chain wax produced from coal gasification using the Fischer-Tropsch process. It can be added to the mix by blending with the binder in a contractor's tank or by pneumatically blowing it into the drum through a modified fiber feed line. Sasobit has a melting temperature of about 212˚F (100˚C) and is completely soluble in binders at temperatures above 248˚F (120˚C). Sasobit lowers the viscosity of the binder at the mixing and compaction temperatures, which decreases working temperatures by 32˚F to 97˚F (18˚C to 54˚C) with the addition of 0.8 to 3% by mass of the binder. However, the original viscosity of the binder is maintained at the in-service pavement temperatures.

Evotherm DAT is a chemical additive package that can be used in any traditional HMA application. Evotherm DAT is a low-viscosity liquid at 77˚F to 86˚F (25˚C to 30˚C). It can easily be added using a pump at the asphalt terminal or at the mix plant. The manufacturer recommended the addition of Evotherm DAT at 0.25 to 0.75% by weight asphalt cement. Mix temperatures should remain greater than 220˚F (104˚C) with final compaction temperatures over 150˚F (66˚C). Evotherm DAT allows mix producers and pavement contractors to realize temperature reductions of 63˚F to 90˚F (35C to 50C) compared to conventional HMA, while lowering energy costs and job-site emissions.

2.2 Test Section Layouts

The HMA control and WMA test sections were all placed in the middle lane of the three uphill, eastbound lanes on the project. They were also placed adjacent to each other to ensure similar site conditions. When paving operations began each evening, the HMA control sections were produced and placed first, and then the plant transitioned into producing the WMA test sections.

Approximately 1,000 tons (900 tonnes) of WMA were produced with each of the three additives. This was enough quantity to pave approximately 1 mile (1.6 km) with each additive. One test section was constructed with each additive. The location and paving dates of each control and test section are shown in Table 1.

Table 1 Control and Test Section Locations and Paving Dates

Paving Start Date	Section	Starting MP	Ending MP	Starting Station	Ending Station	Length (feet)
7-24-07	HMA Control	207.42	207.80	179+20	199+20	2000
7-24-07	Advera WMA	207.80	208.86	199+20	255+30	5610
7-26-07	HMA Control	208.86	209.07	255+30	266+20	1090
7-26-07	Sasobit WMA	209.07	210.17	266+20	324+30	5810
8-13-07	HMA Control	210.17	210.28	324+30	330+60	630
8-13-07	Evotherm WMA	210.28	211.38	330+60	388+50	5790

3. CHAPTER 3 FIELD AND LABORATORY DATA

3.1 Mix Design: Laboratory-Produced, Laboratory-Compacted Data

The contractor was responsible for submitting a mix design that needed approval by CDOT. The HMA control mix was a Superpave dense-graded mix. It was a CDOT Grading SX, ½-inch (12.5 mm) nominal maximum aggregate size. It was designed at 75 gyrations with a PG 58-28 binder.

The aggregate used for the mixture was from Everist Materials' Maryland Creek Ranch pit. It was a crushed river rock. The gradation was on the fine side of the maximum density line. Hydrated lime was used for the antistripping additive at 1% by mass of the aggregate blend.

The volumetric properties of the HMA control mix design were:

- Asphalt Content (AC) = 6.3%
- Voids in the Total Mix (VTM) = 3.6%
- Voids in the Mineral Aggregate (VMA) = 16.8%

The mix design submitted by the contractor had an optimum asphalt content of 6.2%. CDOT approved the mix design at an optimum asphalt content of 6.3% based on the range of volumetrics specified. The full mix design and CDOT's project-produced job mix formula (Form 43) are in Appendix A. The design mixing and compaction temperatures were 310˚F and 280˚F (154˚C and 138˚C), respectively. There were no separate mix designs for the WMA mixtures. The same aggregate and binder recipe used for the HMA control mix was also used for the WMA test mixes. It was believed that the additives would have a negligible effect on the volumetrics.

The laboratory-produced, laboratory-compacted HMA may have properties that would differ from the field-produced, laboratory-compacted HMA. Therefore, the field acceptance specification was based on volumetrics. The basis of payment included the properties of AC, VTM, VMA, mat density, and longitudinal joint density. All of these properties normally affect the pay factor. However, for this experimental feature, the pay factor for the field-produced, laboratory-compacted volumetrics was set to 1.0 and did not apply.

3.2 Construction Data: Placement

3.2.1 General Production and Placement

The plant used to produce the HMA control and WMA test mixes was the Everist Materials plant in Silverthorne, Colorado. It was an Astec Double Barrel drum plant with a production rate of 250 tons (225 tonnes) per hour. It was approximately 5 to 15 miles (8 to 24 km) from the paving site. The truck haul time ranged from approximately 10–25 minutes. The HMA and WMA were delivered to the project in belly-dump trucks and then placed in a windrow.

The paving equipment included a Terex MS-2 material transfer device (elevating loader) and a Terex 562 paver. The mat texture was uniform, and there was no evidence of segregation or tearing of the mat behind the screed. Three rollers were used: a Bomag BW 141 vibratory roller for breakdown rolling, a Hypac C530AH pneumatic roller for intermediate rolling, and a Hypac C766C drum roller for finish rolling. The roller pattern generally consisted of five vibratory passes followed by six static passes. The breakdown roller was able to come close to the back of the screed without pushing the mixture. It was observed that the mixture was picked up on the drum on two separate occasions.

3.2.2 HMA Control Sections

The HMA was mixed at a temperature of approximately 305˚F (152˚C). No problems with the mixing process were reported. Smoke and fumes were visible from the plant during the mixing process of HMA production, as shown in Figure 2.

Figure 2 Visible Smoke and Fumes from HMA Production at the Plant

The temperature readings, summarized in Table 2, were taken at various locations using infrared digital thermometers. During HMA placement, smoke and fumes were visible at the paver, as shown in Figure 3.

Figure 3 Visible Smoke and Fumes during HMA Placement

Table 2 Surface Temperature Readings of HMA Control Sections

Location	Temperature (F)
In front of paver	Approximately 300˚
Just behind the screed	Approximately 267˚
After vibratory roller	Approximately 235˚
After pneumatic roller	Approximately 200˚

3.2.3 Advera WMA Test Section

Materials. In order to produce WMA for this test section, the Advera WMA material was added to the mix at 0.3% by mass of the mixture, or 6 lbs (2.7 kg) per ton of the mix. No other changes were made to the mix design. Advera WMA was supplied by PQ Corporation in the powder form in 1,000-lb (450-kg) bags, as shown in Figure 4. The target mixing and compaction temperatures for the WMA mixture were 255˚F and 235˚F (124˚C and 113˚C), respectively.

Figure 4 Advera WMA Material Supplied in 1,000-lb Bag

Production and Placement. Weather conditions were good on the evening of construction. At the plant, ambient temperatures were 72˚F (22˚C) at 7:00 p.m. and decreased to 60˚F (16˚C) by 12:00 a.m. The paving site was approximately 10.5 miles (17 km) from the plant. The truck haul time was approximately 15 to 20 minutes. The thermometer used to check the mixing temperature at the plant was not functioning properly.

Production started at 7:45 p.m. with 100 tons (90 tonnes) of the control mixture produced at approximately 305˚F (152˚C). Then the temperature was adjusted to the target mixing temperature of 255˚F (124˚C), and the Advera WMA material was added to the drum in the same location as the binder. A modified fiber feeder, shown in Figure 4, and a modified fiber feed line, shown in Figure 5, were used.

Figure 5 Feeding Advera WMA through Fiber Feed Line

The plant produced 200 tons (180 tonnes) of WMA per hour, and the Advera WMA material was added into the drum at 20 lbs (9 kg) per minute. This was equal to 6 lbs (2.7 kg) per ton of the mix. Since the thermometer used for mixing malfunctioned, the mixing temperature was adjusted manually. The mixing temperatures in the first hour were in the range of 245˚F to 267˚F (118˚C to 131˚C). After that, WMA was produced at the range of 250˚F to 259˚F (121˚C to 126˚C) without any problems.

At 10:15 p.m., the production rate was increased to 250 tons (225 tonnes) of WMA per hour to meet the paving rate. The feeder was also adjusted for the addition of Advera WMA at 25 lbs (11.3 kg) per minute. However, the feeder was clogged, and the actual addition of Advera WMA was 23 lbs (10.4 kg) per minute. This was approximately equal to 5.5 lbs (2.5 kg) per ton of the mix for approximately 30 minutes. After the feeder was fixed, the addition was at approximately 25 lbs (11.3 kg) per minute. The mixing temperatures ranged from 247˚F to 257˚F (119˚C to 125˚C). No other WMA mixing problems were reported during this period.

At 11:30 p.m., mix tenderness was reported at the paving site. The addition of Advera WMA was reduced from 6 lbs (2.7 kg) to 5 lbs (2.3 kg) per ton of the mix.

The final production of WMA was finished at 12:10 a.m. Approximately 930 tons (844 tonnes) of Advera WMA were produced for the test section. The natural gas consumption for this test section was approximately 844 ft^3 (23.9 m^3) per 1,000 tons (900 tonnes) of WMA. No smoke or fumes were observed from the mix when it was loaded onto trucks, as shown in Figure 6.

During the Advera WMA production for this test section, the temperature in the baghouse was approximately 200˚F (93˚C), which was lower than the baghouse temperature of approximately 212˚F (100˚C) during HMA production. At the lower temperature, moisture was not vaporized, and there was concern about dust being caked in the baghouse. However, no problems were reported.

Figure 6 No Visible Smoke or Fumes from WMA Production at the Plant

3.2.4 Sasobit WMA Test Section

Materials. The Sasobit material was added to the mix to produce WMA for this test section at 1.5% by mass of the binder. No other changes were made to the mix design. Sasobit was supplied by Hi-Tech Asphalt Solutions Inc. in the granular form in 44-lb (20-kg) bags. This is shown in Figure 7. The target mixing and compaction temperatures for the Sasobit WMA mixture were 255˚F and 235˚F (124˚C and 113˚C), respectively.

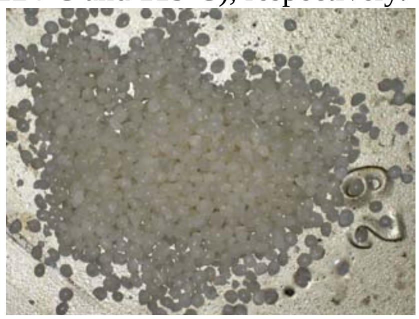


Figure 7 Sasobit Material in Form of Prills

Production and Placement. It rained before the production and placement of WMA for the Sasobit test section. The aggregate stockpiles were damp. At the plant, ambient temperatures were 56˚F (13˚C) at 7:00 p.m. and decreased to 46˚F (8˚C) by 12 a.m.

The same plant used for the previous trial section was used to produce WMA for this section. The paving site was approximately 12 miles (19 km) from the plant. The truck haul time was approximately 20 minutes. The thermometer used to check the mixing temperature at the plant was still not functioning properly, so the mixing temperature was checked manually using an infrared digital thermometer.

Production started at 7:00 p.m. with 225 tons (200 tonnes) of the HMA control produced at approximately 305˚F (152˚C). Then the temperature was adjusted to the target mixing temperature of 255˚F (124˚C) for WMA. The Sasobit WMA additive was added to the drum at the same time as the binder using a modified fiber feeder through a fiber feed line, as shown in Figure 8.

Figure 8 Feeding Sasobit through Fiber Feed Line

The plant produced 250 tons (225 tonnes) of WMA per hour, and the Sasobit material was added into the drum at 7.8 lbs (3.5 kg) per minute, which was calculated based on the application rate of 1.5% by mass of the binder. With experiences from the Advera WMA production, the mixing temperature was adjusted more easily this time. The WMA was produced at the temperature range of 253˚F to 257˚F (123˚C to 125˚C) without any temperature problems. The Sasobit feeder had problems at least three times during the mixing process, which shut down the plant. After the problems were fixed by a technician from Hi-Tech Asphalt Solutions Inc., the WMA production quickly returned to normal.

The final batch of WMA was finished at 12:35 a.m. Approximately 1,020 tons (925 tonnes) of Sasobit WMA were produced for the test section. The natural gas consumption for this test section was approximately 910 ft^3 (25.8 m^3) per 1,000 tons (900 tonnes) of WMA. The gas consumption during this test was higher than that of the previous WMA test section, perhaps due to the damp aggregates. During the WMA mixing, no smoke or fumes were observed, as shown in Figure 9.

During the WMA production for this test section, the temperature in the baghouse was approximately 211˚F (99˚C), which was similar to the baghouse temperature during HMA mixing.

Figure 9 No Visible Smoke or Fumes from Sasobit WMA Production at the Plant

3.2.5 Evotherm WMA Test Section

Materials. The same Superpave mix design used for the HMA control, Advera WMA, and Sasobit WMA test sections was also used for the Evotherm WMA test section. Evotherm DAT additive in the liquid form was added with the binder to the aggregate blend at 0.5% by weight of the binder. The Evotherm DAT additive was supplied by MeadWestvaco Asphalt Innovations in approximately 2,200-lb (1,000-kg) tankers. Figure 10 shows the supplied Evotherm tankers and a pump used to add the Evotherm DAT additive into the binder line. The target mixing and compaction temperatures for the Evotherm WMA mixture were 250˚F and 230˚F (121˚C and 110˚C), respectively.

Figure 10 Adding Evotherm DAT Additive with Binder into Mixing Drum

Production and Placement. It rained slightly before the production of the Evotherm WMA test section. The average moisture content for the aggregate blend was about 2.9%. At the plant, ambient temperatures were 72˚F (22˚C) at 7:00 p.m. and decreased to 58˚F (14˚C) by 12 a.m.

The same plant used for the HMA control and previous WMA test sections produced the Evotherm WMA test section. The plant still had a problem with the thermometer used to check the mixing temperature, so the mixing temperature was again checked manually using an infrared digital thermometer. The paving site was approximately 13 miles (21 km) from the plant. The truck haul time was approximately 23 minutes.

Production started at 7:45 p.m. with 100 tons (90 tonnes) of HMA produced at temperatures ranging from 305˚F to 310˚F (152˚C to 154˚C). At 8:15 p.m., the plant temperature was reduced to a mixing temperature of 250˚F (121˚C) for the Evotherm WMA production. Prior to entering the drum, the Evotherm DAT additive was added to the binder through a modified ½-inch (12.7 mm) inlet, as shown in Figure 11. The additive and binder blend then entered the drum.

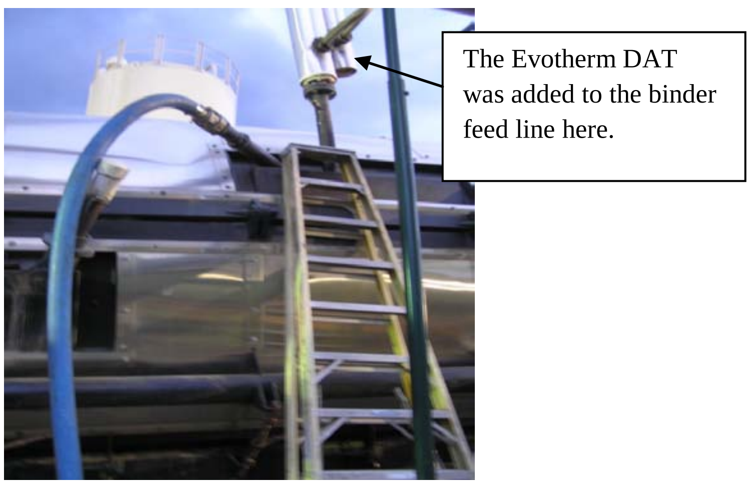


Figure 11 Evotherm DAT Additive Injection Inlet into the Binder Feed Line

With 250 tons (225 tonnes) of Evotherm WMA produced per hour, the additive was blended with the binder at a rate of approximately 3.0 lbs (1.4 kg) per minute. This was calculated based on the application rate of 0.5% by weight of the binder. The temperature of

WMA was measured at 30-minute intervals. The temperature range was from 242˚F to 257˚F (117C˚ to 125˚C), shown in Table 3.

Table 3 Temperature Readings of Evotherm WMA at the Plant

Time	Air Temp (F)	WMA Temp (F)	Time	Air Temp (F)	WMA Temp (F)
8:15 PM	70˚	250˚	10:30 PM	59˚	242˚
8:30 PM	70˚	245˚	11:00 PM	59˚	248˚
9:00 PM	65˚	250˚	11:30 PM	58˚	248˚
9:30 PM	63˚	254˚	12:00 AM	58˚	253˚
10:00 PM	61˚	257˚	12:10 AM	58˚	254˚

The production of WMA was complete at 12:10 a.m. Approximately 1,016 tons (922 tonnes) of Evotherm WMA were produced for the test section. Then, the plant temperature was increased to the target HMA mixing temperature of 310˚F (154˚C), and production of HMA resumed for the rest of the project.

The natural gas consumption for this test section was approximately 861 ft^3 (24.4 m^3) per 1,000 tons (900 tonnes) of Evotherm WMA. During the production of WMA, no smoke or fumes were observed. During the production of WMA, the temperature in the baghouse was approximately 219˚F (104˚C), which was similar to the baghouse temperature when HMA was produced.

3.2.6 Fuel Usage Summary

The natural gas consumption of the plant for each of the WMA test sections was measured. The natural gas consumption of the plant for the HMA was not measured. The results for the natural gas usage per 1,000 tons (900 tonnes) of WMA are shown in Table 4.

Table 4 Summary of Natural Gas Usage of the Plant for Each WMA Test Section per 1,000 tons (900 tonnes)

	Natural Gas Usage (ft^3)
Advera	844
Sasobit	910*
Evotherm	861

* more energy was used likely because of wetter aggregates

3.2.7 Temperature Summaries

The target field mixing and compaction temperatures for the HMA control were 305˚F and 280˚F (152˚C and 138˚C), respectively. The target field mixing and compaction temperatures for all three WMA test sections were 250˚F and 230˚F (121˚C and 110˚C), respectively. The targets for the WMA sections were about 50˚F (30˚C) cooler than the HMA sections. A summary of the actual ambient and mixing temperatures for the construction of the HMA control and WMA test sections is shown in Table 5.

Table 5 Summary of Actual Ambient and Mix Temperatures at the Paver

	7-24-07 Control HMA	7-24-07 Advera WMA	7-26-07 Control HMA	7-26-07 Sasobit WMA	8-13-07 Control HMA	8-13-07 Evotherm WMA
Low Air Temp (F)	54˚	54˚	50˚	50˚	36˚	36˚
Mix Delivery Temp (F)	300˚	260˚	300˚	235˚	300˚	243˚
Mix Temp at Screed (F)	267˚	243˚	267˚	230˚	267˚	235˚

The cooling rate of the HMA control, Advera WMA (1), and Sasobit WMA (2) is shown in Figure 12. The temperatures were measured as these mixes exited the screed of the paver and then approximately every 2 minutes for just over 30 minutes.

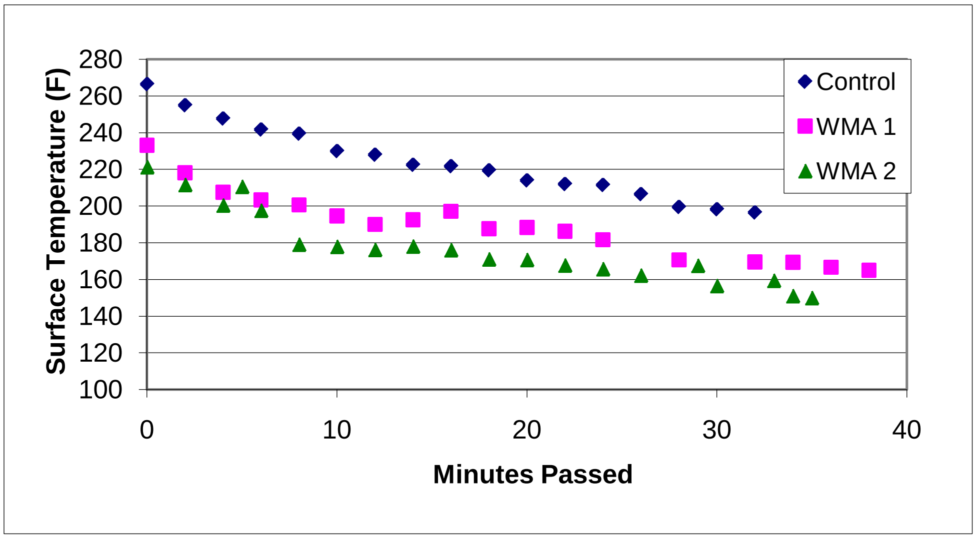


Figure 12 Cooling Rate of the HMA Control, Advera WMA 1, Sasobit WMA 2

The temperature loss after 30 minutes from the time the mixtures exited the screed is shown in Table 6. The WMA exited the screed at approximately 30˚F (17˚C) cooler than the HMA. At the time compaction was finished, the WMA was 30˚F to 50˚F (17˚C to 28˚C) cooler than the HMA.

Despite the different starting temperatures, all the mixtures had approximately the same rate of temperature loss over a 30-minute period, as shown on Table 6. However, the WMA was still successfully compacted at the lower temperatures due to the effects of the additives.

Table 6 Temperature Loss at 30 Minutes After Mixture Exited Screed

Mixture	**Temperature Loss After 30 Minutes**
Control HMA	68˚F
Advera WMA	63˚F

Sasobit WMA	64˚F

3.3 Construction Data: Field-Produced, Field-Compacted Data

3.3.1 In-Place Densities

The in-place densities were measured with a nuclear, moisture-density gauge that was correlated to cores. The percent relative compaction (%G_{mm}) was calculated based on the theoretical maximum specific gravity (G_{mm}). The G_{mm} used in the calculation of the percent relative compaction was measured in each section. The average %G_{mm} is shown in Table 7. All values are acceptable and consistent with typical paving projects.

Table 7 Average Percent Relative Compaction After Construction

	Control HMA	Advera WMA	Control HMA	Sasobit WMA	Control HMA	Evotherm WMA
%G_{mm}	93.8	93.3	95.7	93.2	93.7	94.7
Number of Tests	4	4	1	4	2	4
Std. Dev.	0.21	0.74	Not Applicable	1.03	0.28	0.81

The specification requirement for the %G_{mm} was 92% to 96%. The statistically calculated percent-within-limits of the test results impacted the pay factor. The pay factor did apply for %G_{mm}.

3.3.2 Indirect Tensile Strength Testing

Cores were taken from the pavement in the second and third years. The top lift of pavement was removed from the rest of the core by sawing. The top lift was tested for indirect tensile strength according to ASTM D6931 at 25˚C (77˚F). The tensile strength results are shown in Table 8. All testing was done after three years. The cores taken after the second year were stored in the laboratory for one year.

Table 8 Average Tensile Strength (psi) of Pavement Cores

	Tensile Strengths after 2 Years	Tensile Strengths after 3 Years
Control HMA	94	63
Advera WMA	97	56
Sasobit WMA	98	60
Evotherm WMA	97	61

The tensile strengths for each year are consistent. There is not a large difference between the HMA and WMA for any given year. However, all the tensile strengths decreased by approximately 38% from the second year to the third year. It is hypothesized that this may have occurred for two reasons. First, the cores from the second year were stored in the laboratory for one year, exposing the surface area for that length of time and, thus, possibly resulting in more oxidation. This could have caused the cores from the second year to have higher strengths than those from the third year. Second, some friable aggregates were observed in the pavement. The cores taken from the third year would have had one more harsh winter that could have caused additional aggregate degradation. This could have caused the cores from the third year to have lower strengths.

Regardless of the differences in the tensile strengths from the second to the third year, the tensile strengths from each year are consistent. It does not appear that the WMA additive had any effect on the tensile strengths when compared to the control HMA from the same year.

3.4 Construction Data: Field-Produced, Laboratory-Compacted Data

3.4.1 Volumetric and Strength Results

Test results were obtained from CDOT's Quality Assurance laboratory and included asphalt content (AC), voids in the total mix (VTM), voids in the mineral aggregate (VMA), and Hveem Stability (Stability). The results are shown in Table 9. The tolerance for AC was +/- 0.3% and +/- 1.2% for VTM and VMA. The statistically calculated percent-within-limits of the test results impacted the pay factor. However, it was agreed at the pre-paving conference that the field-produced, laboratory-compacted volumetrics of the WMA would not affect the pay factor. The Quality Control results from the contractor were very similar to those shown in Table 9 but were not included here. Since only one or two sets of volumetrics were tested for each section only the averages are reported. The standard deviations were not calculated.

Table 9 Volumetric and Strength Results for Field Produced, Laboratory-Compacted HMA Control and WMA Test Sections

	Target	Control HMA	Advera WMA	Control HMA	Sasobit WMA	Control HMA	Evotherm WMA
AC	6.3 %	6.23 %	6.38 %	6.41 %	6.32 %	6.04 %	6.38 %
VTM	3.6 %	3.1 %	1.8 %	3.0 %	2.4 %	3.6 %	2.2 %
VMA	16.8 %	16.5 %	15.7 %	16.5 %	15.9 %	16.3 %	15.8 %
Stability	39	36	34	35	36	35	34

The HMA samples were laboratory compacted at 280˚F (138˚C), and the WMA samples were laboratory compacted at 250˚F (121˚C). The samples did not cool to room temperature and require reheating. They were compacted immediately after reaching the laboratory compaction temperature.

Based on the target and tolerances, the asphalt content of the field-produced mixes was acceptable for the HMA control and all the WMA test sections. The VTM and VMA for the field-produced HMA control sections were also acceptable. However, the VTM and VMA for the field-produced, laboratory-compacted WMA test sections were curiously low. The VTM of the WMA was approximately 1.0% lower than that of the HMA, and the VMA of the WMA was approximately 0.5% lower than that of the HMA. Although there are slight differences, it is unknown why these differences occurred. Never-the-less, all results are acceptable. The Hveem stability values were all acceptable.

The low values of the VTM and VMA for the WMA mixes relative to the HMA mix may have several causes, two of which are discussed here. First, a mix design was not performed with the WMA additive. It is possible that the addition of a small amount of WMA additive could have caused the change. Second, the laboratory compaction temperature was set somewhat arbitrarily. The purpose of the WMA additive is to make the WMA more compactable at lower temperatures. It is possible the laboratory compaction temperature should have been even lower than the 250˚F (121˚C).

It is important to note that the field compaction was the same for the HMA control and WMA test sections. The air voids in the pavement after the field compaction for the HMA control was similar to the WMA test sections. It is hypothesized here that the low laboratory-compacted VTM and VMA may have resulted from the use of a laboratory compaction temperature that was too high. This will be analyzed in more detail when the rutting data and air voids of the cores after three years of performance are discussed.

3.4.2 Moisture-Susceptibility Results

Moisture susceptibility testing was conducted in accordance with CDOT's modified Lottman procedure, which is very similar to AASHTO T 283 with a freeze cycle. The samples did not cool to room temperature and did not require reheating. They were compacted immediately after they reached the laboratory compaction temperature. The tensile strength ratios (TSRs) are shown in Table 10.

CDOT's acceptance specifications require that the mix design have a minimum TSR of 80% and the field-produced samples have a minimum TSR of 70%. Based on these specifications, all of the TSRs were acceptable.

The Hamburg Wheel-Track Testing was also conducted. Samples were cooled and shipped to Denver, where they were reheated and compacted for testing. The test results are shown in Table 10. The specification requires that there be less than 4 mm of rutting after 10,000 cycles. At this high-elevation, low-temperature environment the testing temperature was 45˚C (113˚F). None of the samples from the HMA control or WMA test sections passed. It should be noted that CDOT does not typically test mixes on the Hamburg device that were designed at less than 100 gyrations. The device was only calibrated locally for mix designs with 100 gyrations and higher. The mix design on this project was a 75-gyration design. Even though all the samples tested failed, it is important to note that visual observation of the samples indicated that they failed primarily and initially due to plastic flow, not moisture susceptibility. This is an encouraging sign for the field performance related to moisture susceptibility. It should be mentioned that this is not uncommon when the Hamburg device is used for testing mixes designed below 100 gyrations. The stripping inflection point is included for information in Table 10.

Table 10 Moisture-Susceptibility Test Results

	Control HMA	Advera WMA	Control HMA	Sasobit WMA	Control HMA	Evotherm WMA
TSR (%)	100	83	97	111	94	80
Hamburg rut (mm)	9.0	9.5	16.0	10.0	10.0	13.5
Hamburg cycles	9,700	5,100	7,650	9,400	9,650	7,750
Hamburg stripping inflection point (cycles)	7,800	3,300	5,000	5,700	8,400	6,200

3.4.3 Binder Grading

The Federal Highway Administration (FHWA) mobile asphalt mixture testing trailer was on the site for the experimental feature. To supplement the test results from the on-site trailer, some samples were sent back to FHWA's Turner-Fairbanks Highway Research Center. The on-site trailer was present for the placement of the Advera and Sasobit WMA test sections. Due to scheduling, the on-site trailer was not available for the Evotherm WMA test section. The Evotherm WMA was produced and placed 2 1/2 weeks later. Evotherm samples were sent to FHWA for subsequent testing.

A sample of the base asphalt binder was obtained from the project. The base binder was tested for performance grading (PG). The base binder was then blended with the WMA additives in the laboratory and tested for PG. This testing allowed classification of the binder with and without the WMA additives. The results are shown in Table 11.

Table 11 Virgin Binder Grading at Time of Construction

	M 320 Continuous Performance Grade	M 320, Table 2 Performance Grade	Additive Rate by weight of binder
HMA Control	59.9 – 30.3	58 - 28	No data
Advera WMA	60.7 – 30.4	58 - 28	4.33%
Sasobit WMA	64.2 – 29.2	64 - 28	1.5%
Evotherm WMA	No data obtained due to schedule		

The base asphalt binder used in the HMA control was graded as a PG 58-28. As can be observed from the test results, the small amount of WMA additive had minimal effects on the PG of the binder. It was generally a shift of less than 1˚C (2˚F) higher on the high and low temperatures. The largest impact of the additive was seen with Sasobit, which had a 4˚C (7˚F) shift higher on the high temperature and a 1˚C (2˚F) shift higher on the low temperature.

In addition to the grading of the virgin binder at the time of construction, the binder was also graded after two and three years in the field. Cores were taken from the pavement after two and three years. The binder was extracted from the cores, recovered, and graded. The results are shown in Table 12.

Table 12 Recovered Binder Grading after Two and Three Years

	Year Two		Year Three	
	M 320 Continuous Performance Grade	M 320, Table 2 Performance Grade	M 320 Continuous Performance Grade	M 320, Table 2 Performance Grade
Control HMA	69.5 – 28.7	64 - 28	59.2 - 32.1	58 – 28
Advera WMA	63.4 - 27.6	58 - 22	60.6 - 30.7	58 – 28
Sasobit WMA	66.4 - 27.4	64 - 22	66.0 - 29.0	64 – 28
Evotherm WMA	63.1 - 30.3	58 - 28	59.9 - 30.9	58 - 28

As shown and discussed for Table 11, the effect of the additives on the virgin binder was negligible. This same trend was observed for the recovered binder after three years in the field, as shown in Table 12. There was generally a shift of less than 1˚C (2˚F) higher on the high and low temperatures. Once again, the largest impact of the additive was seen with Sasobit, which had a 7˚C (13˚F) shift higher on the high temperature and a 3˚C (5˚F) shift higher on the low temperature. It appears that the aging of the Control HMA occurred at the same rate as the WMA test sections. It should be noted that the cores taken in the second year were stored in the laboratory for one year prior to testing. The aging of the cores in the laboratory may have impacted those results.

3.4.4   Dynamic Modulus and Flow Number

The FHWA mobile asphalt mixture testing trailer was also able to provide dynamic modulus (E*) and flow number (F_n) testing. Dynamic modulus testing was conducted in accordance with AASHTO TP 62 to evaluate the stiffness of the mixes from the HMA control and WMA test sections. The test was run at multiple temperatures and frequencies, as shown in Table 13, within the elastic response range of a mix. Tall cylindrical specimens were tested and confined for this evaluation. The confining pressure was 138 kPa (20 psi). Three specimens per mix were tested. All specimens were compacted from reheated mix.

Table 13 Frequencies and Temperatures for Dynamic Modulus Testing

Frequency, Hz	Temperatures, C
25	4.4˚
10	21.1˚
5	37.8˚
1	54.4˚
0.5	
0.1	

The data from the dynamic modulus test was used to construct a master curve for each mix, which related a material's stiffness over a range of frequencies. Master curves were developed to compare the response of the HMA control to the responses of the WMA test sections. Figure 13 illustrates the dynamic modulus master curves. For the mixes used in this experimental feature, there were few impacts on the dynamic modulus due to the WMA additives. The HMA control mix was slightly stiffer than the WMA test mixes. Based on dynamic modulus, the WMA test sections may be slightly more susceptible to rutting than the HMA control sections.

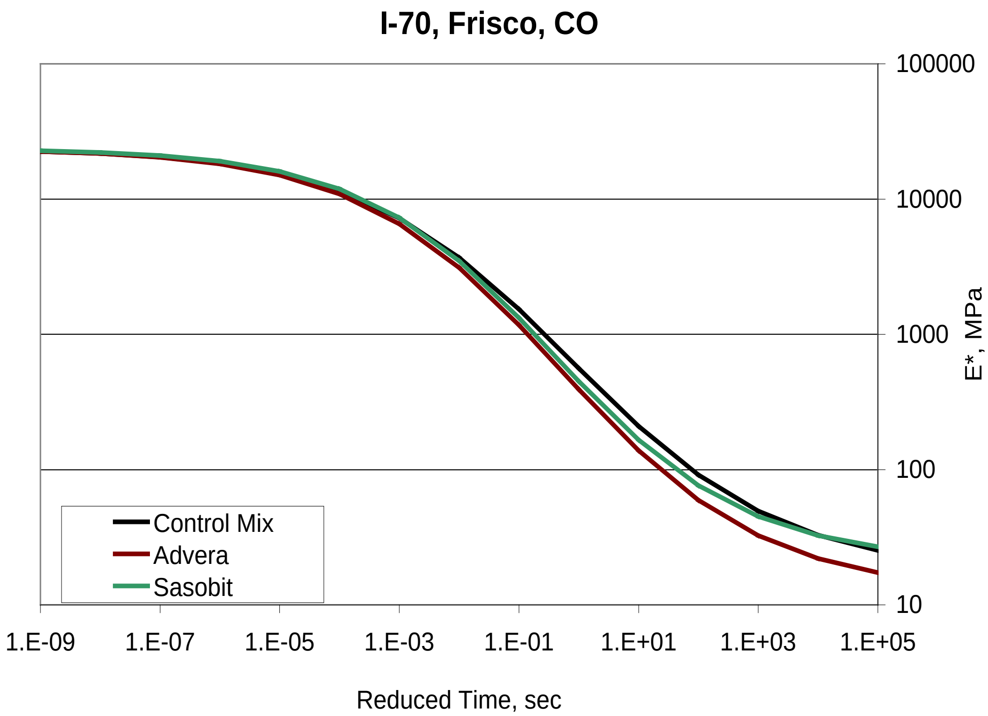


Figure 13 Dynamic Modulus (E*) Master Curves

The flow number was also measured with the Asphalt Mixture Performance Tester (AMPT). This procedure used a 100-mm (4-inch) diameter by 150-mm (6-inch) height test specimen that had been cut from a larger compacted specimen or core. The specimen was tested at the selected high pavement temperature for the project. Permanent deformation was measured in the specimen until the point where the specimen exhibited tertiary flow. Tertiary flow was a condition where shear deformation occurred in the specimen under constant volume, like what happens in the field when rutting occurred. The number of test cycles it took until tertiary flow started was called the flow number. The deviator stress was 690 kPa (100 psi), and the confining pressure was 69 kPa (10 psi).

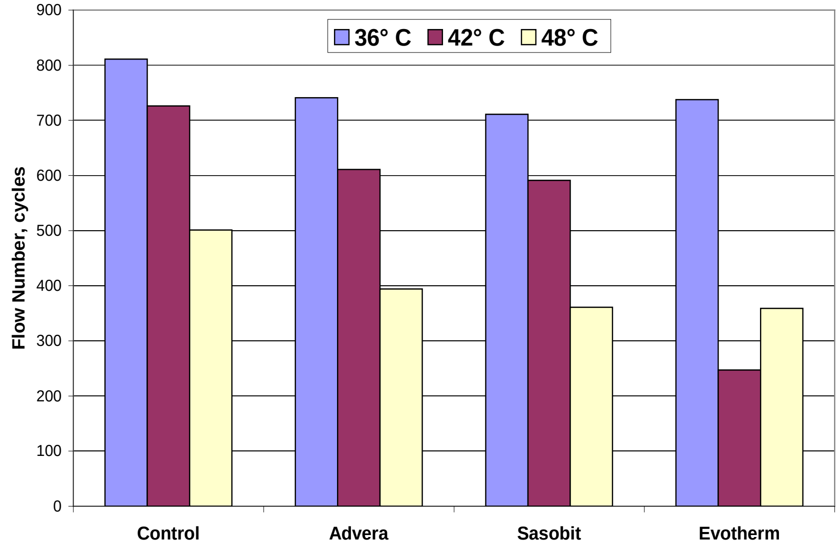


Figure 14 Flow Number Results

The flow numbers for various temperatures are shown in Figure 14. Regardless of the temperature, the WMA mixtures reached tertiary flow sooner than the HMA mixtures. Based on flow number, the WMA may be slightly more susceptible to rutting than the HMA.

4. CHAPTER 4 THREE-YEAR EVALUATION OF FIELD PERFORMANCE

Field-performance evaluations were conducted annually for three years after construction. Data regarding rutting, cracking, and raveling were gathered to document the performance. "Data sections" that were 200-foot (61-m) long were randomly selected within the control and test sections for the field-performance evaluation. There were three HMA control sections that were each approximately 0.1 to 0.4 miles (0.16 to 0.64 km) long. For each HMA control section, one 200-foot (61-m) "data section" was randomly selected to monitor performance. The same "data section" was used each year. There were three WMA test sections that were each approximately 1 mile (1.6 km) long. For each WMA test section, three 200-foot (61-m) "data sections" were randomly selected to monitor performance each year. A summary of the evaluations is discussed below.

4.1 Rutting

The rut depths were measured with a 6-foot (2-m) straight edge. The rut depths were measured in the middle lane at the beginning, middle, and end of each 200-foot (61-m) "data section." The rut depths were generally measured in the right wheel path. However, in some cases there were surface irregularities at the longitudinal joint. For these rare cases, the rut depth in the left wheel path was believed to be more representative of the pavement performance. The average rut-depth measurements are shown in Table 14. An example of the rutting is shown in Figure 15.

Table 14 Rut Depths (mm) of HMA Control and WMA Test Sections

	Sept. 2008	Oct. 2010
Control HMA	No Data	5
Advera WMA	< 5	4
Control HMA	< 5	5
Sasobit WMA	< 5	6
Control HMA	5	8
Evotherm WMA	6	6

Figure 15 Example of Rutting in WMA Test Sections

The rut depths were very consistent throughout the HMA control and WMA test sections. They measured approximately 6 mm (0.2 inches), a low severity. All the control and test sections are performing very well with respect to rutting.

It should be mentioned that all these results were from test sections in the middle lane. The outside lane was the truck-climbing lane and was not part of the evaluated test. This was constructed entirely of the HMA control. It was consistently rutting 13mm (0.5 inches), and in several areas the rutting was greater: 18 mm to 25 mm (0.75 inches to 1 inch). The truck-climbing lane was constructed with the same mix as the evaluated control test sections and not performing very well. Concentrated truck loading, with chained tires during winter months, was reported to historically result in more rapid distress in the outside truck lane.

4.2 In-Place Void Monitoring

Three 6-inch (150-mm) diameter cores were taken in the wheel path (IWP), and four 6-inch (150-mm) diameter cores were taken between the wheel paths (BWP). All cores were taken at the same location. The HMA control and WMA test mixes were separated from the rest of the core, and their densities were measured. They were then broken down, and the G_{mm} was measured for the respective mixes. The $\%G_{mm}$ and air voids were then calculated. The air void results are shown in Table 15. Since these results were only obtained at one location within the appropriate test and control sections, it was not possible to statistically analyze the data.

Table 15 Air Voids (%) from Pavement Cores

	Nov. 2009		Oct. 2010	
	IWP	BWP	IWP	BWP
Advera WMA	2.4	1.6	1.7	2.2
Sasobit WMA	2.6	2.0	2.9	3.9
Control HMA	3.1	2.9	3.3	2.3
Evotherm WMA	2.7	3.4	2.9	3.1

At the time of construction the air voids were measured with the nuclear gauge and ranged from 4% to 6%. After three years of traffic, the pavement had consolidated. The change in air voids was about 2% to 3%. This minor amount of consolidation is consistent with the minor amount of rutting that was measured on the surface.

4.3 Cracking

Cracks were mapped throughout the entire length of the "data sections." The length, severity, and type of crack were recorded. The information is summarized in Table 16. For example, "3-T-H" indicated that 3 feet (0.9 m) of cracking were measured in the "data section," which was a transverse crack with high severity. Overall, the cracking was not very frequent, and it was generally low severity when it did occur. All the HMA control and WMA test sections were performing well with respect to cracking. An example of a transverse crack on the project is shown in Figure 16.

The fatigue cracking in the Evotherm WMA test section was believed to be reflective cracking from a soft area deeper in the pavement.

Table 16 Cracking Lengths (Feet), Cracking Type, and Cracking Severity in Data Sections

	Sept. 2008	Nov. 2009	Oct. 2010	General Notes from the Entire Section During the 2010 Evaluation
HMA Control	0	0	0	No cracking observed in the 0.4 miles
Advera WMA	0	3-T-H	1-T- L	3 to 4 transverse cracks in the mile
HMA Control	0	0	0	No cracking observed in the 0.2 miles
Sasobit WMA	0	0	3-T-L	3 to 4 transverse cracks in the mile
HMA Control	0	9-T-H	30-T-L	3 to 4 transverse cracks in the 0.1 mile
Evotherm WMA	0	0	3-F-L	5 to 7 fatigue cracks in the mile

T = Transverse Crack L = Low Severity
L = Longitudinal Crack M = Moderate Severity
F = Fatigue Crack H = High Severity

Figure 16 Example of Transverse Crack in WMA Test Section

4.4 Raveling and Weathering – Sand Patch

The surface textures of the HMA control and WMA test sections were measured with the sand patch test, ASTM E965. The test was conducted in the field on the pavement during the third year of the evaluation at the beginning and end of each of the "data sections." The tests were conducted between the wheel paths. Sand patch tests were also conducted in the laboratory on the cores taken during the third-year evaluation.

The mean texture depth (mm) of the sand patch is reported in Table 17. The smaller texture depth indicates a pavement with less surface texture, or a smoother pavement. The larger texture depth indicates a pavement with more surface texture, or a rougher pavement. Test results indicate that pavements with larger texture depths likely experienced more raveling than those with smaller texture depths. Since tests were only taken at two locations within each section, the standard deviation of the results was not caluclated.

The results were very consistent between the HMA control and its associated WMA test section. The WMA test sections performed equally as well as the HMA control sections. Based on visual observation, all the HMA control and WMA test sections were performing very well with respect to raveling and weathering. An example of the pavement surface texture is shown in Figure 17.

Table 17 Mean Texture Depth (mm) of Sand Patch Test in the Third Year

	Measured in the Field on the Pavement	Measured in the Laboratory on the Cores (IWP)	Measured in the Laboratory on the Cores (BWP)
HMA Control	0.369	0.267	0.297
Advera WMA	0.337	0.239	0.267
Sasobit WMA	0.334	0.287	0.312
Evotherm WMA	0.379	0.255	0.242

Figure 17 Overall Surface Texture of HMA Control and WMA Test Sections: Excellent Performance

There appeared to be some pop-outs in all project sections. It is believed that friable aggregates weathered and created these small pop-outs. The pop-outs were infrequent and had low severity. It is not believed that these were a result of the WMA since they occurred throughout the project.

5. CHAPTER 5 CONCLUSIONS

Three test sections of WMA were produced as part of a CDOT experimental feature and compared to HMA control sections. The WMA additives used were Advera, Sasobit, and Evotherm DAT. The production, constructability, laboratory performance testing, and field performance of the mixes were documented. The following observations were made.

- After three years of evaluating their field performance, the Advera, Sasobit, and Evotherm WMA test sections were performing comparably to the HMA control sections. All the HMA control sections and WMA test sections were in excellent condition regarding rutting, cracking, and raveling. It is important to note that this location has a very harsh winter climate.

- No problems were encountered during the production or placement of any of the WMA or HMA mixes.

- The WMA had field compaction that was comparable to the HMA control at approximately 30˚F to 50˚F (17˚C to 28˚C) lower temperatures. The use of Advera, Sasobit, and Evotherm DAT facilitated cold-temperature placement. However, the rate of temperature loss for the WMA and HMA mixes was the same.

- The field-produced, laboratory-compacted VTM and VMA of the WMA mixes were lower than those of the HMA mixes. The VTM of the WMA was approximately 1.0% lower than that of the HMA, and the VMA of the WMA was approximately 0.5% lower than that of the HMA. Since the WMA had similar field compaction as the HMA control sections and similar rutting performance over three years, it is believed that the reduced volumetrics were related to the WMA laboratory compaction temperature and compaction in the Superpave gyratory compactor. More research may be needed to identify the appropriate laboratory compaction temperature of WMA mixes.

- Moisture-susceptibility testing using the modified Lottman test indicated that WMA may be more prone to moisture damage than the HMA control. The TSRs for the WMA samples were lower than those of the HMA but still passing. The Hamburg wheel-tracking test results are not conclusive because the test was not calibrated to lower gyration mixes.

- The grading of the base asphalt in the HMA control was not changed significantly with the addition of the WMA additives. The shift was generally less than 1˚C (2˚F) higher on the high and low temperatures. The small amount of WMA additive had minimal effects on the PG of the binder. The largest impact was with Sasobit, which had a 4˚C (7˚F) shift higher on the high temperature and a 1˚C (2˚F) shift higher on the low temperature.

- Both dynamic modulus and flow number testing indicated that the HMA control mix was slightly stiffer than the three WMA test mixes.

Overall, the production and construction of the WMA test sections with Advera, Sasobit, and Evotherm DAT were comparable to the production and construction of the HMA control sections. The WMA test sections were compacted about 30˚F to 50˚F (17˚C to 28˚C) cooler than the HMA control. The laboratory performance testing showed that all the WMA test mixes were comparable to the HMA control mix. However, the laboratory performance testing indicated the WMA test mixes were slightly more susceptible to rutting and to moisture damage than the HMA control mix. After three years of field evaluations in a location with a harsh winter climate, the performance of the WMA test sections was comparable to the HMA control sections in regards to rutting, cracking, and raveling. The field performance was excellent.

6. CHAPTER 6 RECOMMENDATIONS AND FUTURE RESEARCH

The main question that arises in this study is: Is the performance of the asphalt mix affected by using a WMA technology? If pavement performance is adversely affected, then the potential environmental, production, and economic benefits could be negated. If the performance of WMA pavement is as good as or better than HMA pavement, then the change in production practices would likely be very worthwhile.

After three years of field evaluations in a location with a harsh winter climate, the performance of the WMA test sections was comparable to the HMA control sections in regard to rutting, cracking, and raveling. The field performance was excellent. WMA did cost substantially more than HMA, but WMA materials and procedures were an experimental feature, and as a result, the producers had significantly lower quantities on hand, dealt with additional equipment, and material processes at the plant. It is expected that larger quantities and more familiarities with handling the material will result in lower upfront costs.

Based on the results from this study, the use of WMA via the three technologies evaluated in this study is recommended to extend the paving season. More data should be collected on the cost of WMA when used in larger quantities. The WMA cost can then be compared to traditional HMA before making WMA a standard.

APPENDIX A: **Mix Design and CDOT's Project Produced Job Mix Formula (Form 43)**

COLORADO DEPARTMENT OF TRANSPORTATION
PROJECT PRODUCED JOB MIX FORMULA

Project: IM0702-262
Location: I-70 FRISCO TO EJMT EB RESURF
Region: 01 Project Code (SA#): 15832
From Project No:
From Project SA#: 14347

Mix Design: 161825
Date: 6/5/2007

This Job Mix Formula defines the specified gradation, asphalt cement content, and admixture dosage for the grading and project shown.

Contractor: Asphalt Paving
Supplier: Everist Materials, LLC
Plant: Maryland
Pit: Maryland
Grading & Compaction: SX 75
% RAP: .00 % Lime: 1.00

Components:

1. 15 1/2 in Rock, Maryland
2. 10 #8 Rock, Maryland
3. 54 Crushed Fines, Maryland
4. 20 Washed Sand, Maryland.
5. 1 Hydrated Lime, Pete Lien
6.
7.
8.

Remarks:

Gradation (% Passing)

☐ Specification ☒ Voids Acceptance

Seive mm (in)	% Pass Min	% Pass Max
37.5 (1 1/2):	100	100
25.0 (1):	100	100
19.0 (3/4):	100	100
12.5 (1/2):	90	100
9.5 (3/8):	89	100
4.75 - #4:	68	78
2.36 - #8:	49	59
1.18 - #16:		
600 mic - #30:	25	33
300 mic - #50:		
150 mic - #100:		
75 mic - #200:	4.70	8.70

% AC: 6.30 +/- .3
Grade of AC: PG 58-28
Source of AC: SEM MATERIALS
Max. Sp. Gr. at % AC: 2.446 +/- .01
Bulk Sp. Gr. of Combined Agg: 2.659
Bulk Sp. Gr. of Fine Agg: 2.667
Angularity (T 304): 48.6
% Agg Absorp (SSD): 0.8

Property	Voids Data at Nds Target Value	Tolerance
Stability	28	Minimum
% Voids	3.60	+/- 1.2
% VMA	min 15.6	max 18.0
% VFA	min 65	max 80

☒ New Mix design with no change

Signed [signature] Date 6/6/07
Project Engineer:

Signed William Schiebel Date 6/5/07
Regional Materials Engineer: SCHIEBELB

Signed Date
Contractors Representative:

Distribution:
Staff Materials
Region Materials Engineer
Resident Engineer (2)
Contractor

CDOT Form #43 01/07

WESTEST

845 Navajo Street • Denver, CO 80204

SPECIALISTS TO THE PAVING INDUSTRY

Phone: 303.975.9959 • Fax: 303.975.9969 • email:office@westest.net

Everist Materials, LLC
P.O. Box 1150
28755 Hwy. #9
Silverthorne, CO 80498

June 1, 2007

Attention: Mr. Nathaniel L. Thomas

Subject: Hot Mix Asphalt Mix Design
Superpave Design Method
Grading SX, $N_{DESIGN} = 75$
Maryland Creek Ranch Pit Aggregate, SemMaterials PG 58-28 Binder
Mix Design No. 184107

Gentlemen:

Enclosed are the results of a hot mix asphalt mix design done in general accordance with Colorado, AASHTO, and/or ASTM procedures, using the Superpave Gyratory Compactor for specimen compaction. The aggregate used in the mix design is from Maryland Creek Ranch pit. The asphalt cement used in the mix design consisted of a PG 58-28, with a specific gravity of 1.032, supplied by SemMaterials. The antistripping additive used consisted of 1% hydrated lime.

The aggregate was blended to meet CDOT Grading SX criteria by combining 15% 1/2" Rock, 10% No. 8 Rock, 54% Crusher Fines, 20% Washed Sand and 1% Lime. The individual gradations, combined blend and aggregate physical properties are presented on Figure 1, along with a graphical presentation of the combined gradation plotted on a 0.45 Power Graph.

This design was performed using Superpave technology incorporating 100mm diameter molds and design gyrations of 75. The design was performed at asphalt cement contents of 5.5, 6.0, 6.5 and 7.0 percent. The results of the tests performed at each asphalt content are outlined on Table 1 and graphically presented on Figures 2 and 3. Based on these test results, and CDOT design criteria, an optimum asphalt cement content of 6.2% was determined. This asphalt cement content indicates a theoretical maximum specific gravity of 2.450, 3.9% voids in total mix, 16.9% voids in mineral aggregate, 77.0% voids filled with asphalt and a Hveem stability of 40. The effective specific gravity of the aggregate in the mix is 2.695. The coarse aggregate bulk specific gravity is 2.637, the fine aggregate bulk specific gravity is 2.667 and the combined bulk specific gravity is 2.659.

This hot mix asphalt mix design is based on specific materials and laboratory preparation of the test specimens. Variations between laboratories and variation between laboratory produced and field produced samples should be anticipated. It is recommended the mix design be field verified during initial production. Field verification often results in the optimum asphalt cement content being adjusted to meet design voids in total mix or voids in mineral aggregate criteria.

If you have any questions on the design presented, please contact us at your convenience.

Sincerely,
WesTest

COLORADO REGISTERED ERIC R. WEST 20475 6/1/07 PROFESSIONAL ENGINEER

Eric R. West, P.E.

AAP

WESTEST
Specialists to the Paving Industry

Client:	Everist Materials	June 1, 2007
Mix Design No.:	184107	
Mix Design Method:	Superpave	
CDOT Grading:	SX	
Aggregate Source:	Maryland Creek Ranch Pit	

AGGREGATE BLEND

PERCENT OF BLEND	15%	10%	54%	20%		1%	100%	Grading	PRODUCTION
DESCRIPTION	1/2" Rock	No. 8 Rock	Crusher Fines	Washed Sand		Lime	Combination	SX	GRADATION
SOURCE	Maryland Creek	Maryland Creek	Maryland Creek	Maryland Creek		Pete Lien	Job Mix	Spec.	TOLERANCE
1 1/2"	100	100	100	100		100	100		
1"	100	100	100	100		100	100		
3/4"	100	100	100	100		100	100	100	100
1/2"	98	100	100	100		100	100	90 - 100	90 - 100
3/8"	73	95	100	100		100	95		89 - 100
#4	12	20	90	100		100	73		68 - 78
#8	5	2	65	87		100	54	28 - 58	49 - 59
#16	3	1	47	66		100	40		
#30	3	1	35	42		100	29		25 - 33
#50	2	1	24	20		100	18		
#100	2	1	15	7		100	11		
#200	1.3	0.6	9.2	2.3		98.0	6.7	2 - 10	4.7 - 8.7

AGGREGATE PHYSICAL PROPERTIES

BULK SPECIFIC GRAVITY	2.661	2.621	2.664	2.675		2.380	2.659		
APPARENT SPECIFIC GRAVITY	2.730	2.707	2.712	2.748		2.380	2.718		
WATER ABSORPTION (%)	0.9	1.2	0.7	1.0			0.8		
MICRO-DEVAL (CP-L 4211) (% LOSS)							9.9	18.0 Max.	COMBINED
L.A. ABRASION (% LOSS)	26						26	45 Max.	
FRACTURED FACES, 2+ (%)							99	80 Min.	
FINE AGGREGATE ANGULARITY (%)							48.6	45.0 Min.	
SAND EQUIVALENT (%)							69	45 Min.	
LIQUID LIMIT (%)			NV	NV			NV		
PLASTIC LIMIT (%)			NV	NV			NV		
PLASTICITY INDEX			Non-Plastic	Non-Plastic			Non-Plastic	Non-Plastic	

0.45 POWER GRAPH

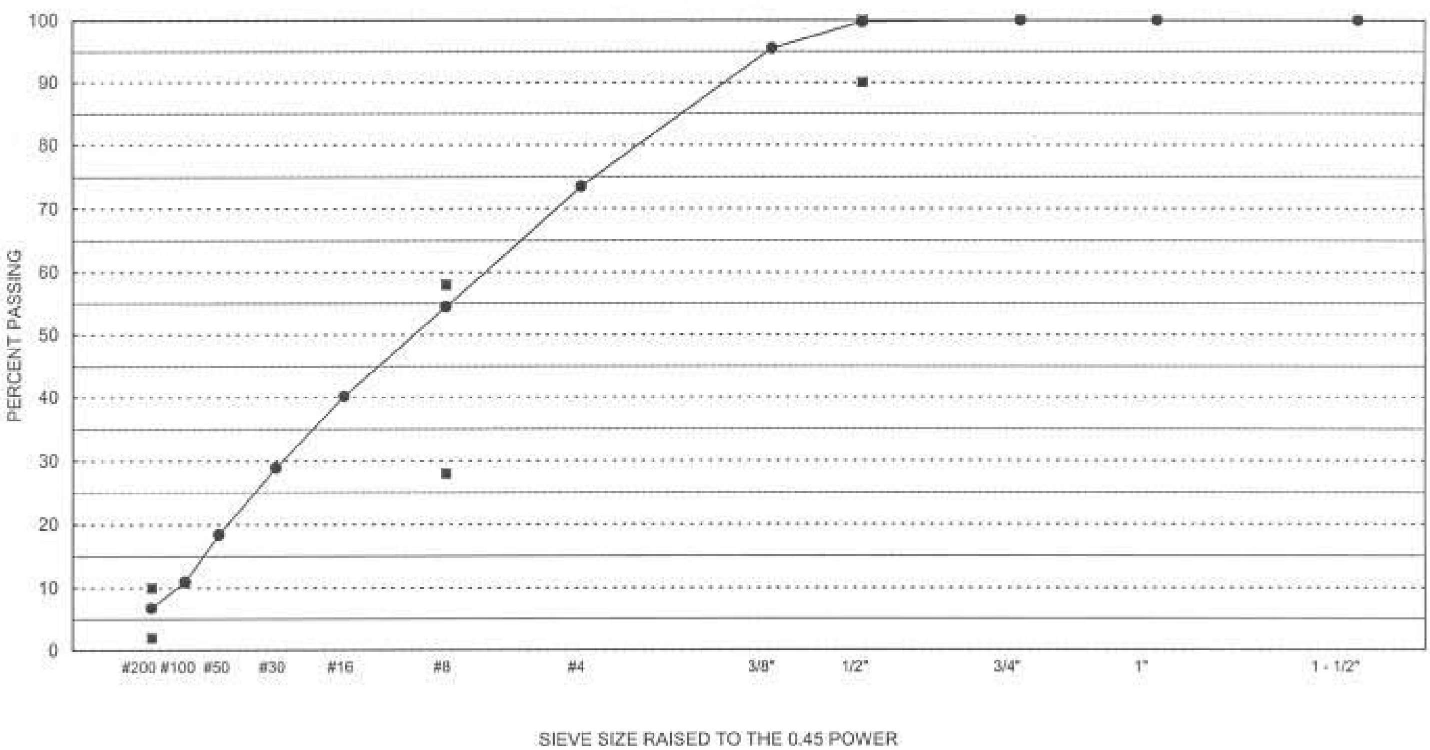


FIGURE 1

WESTEST
SPECIALISTS TO THE PAVING INDUSTRY

Client:	Everist Materials		June 1, 2007
Mix Design No.:	184107		
Mix Design Method:	Superpave		

CDOT Grading:	SX	Mixing Temperature:	310 °F
Aggregate Source:	Maryland Creek Ranch Pit	Compaction Temperature:	280 °F
		Gyrations (Initial - Design):	7 - 75
A.C. Source & Grade:	SemMaterials PG 58-28		

ASPHALT CONTENT DETERMINATION

MIX PROPERTIES		LABORATORY TRIAL DATA				SPEC.	OPTIMUM
ASPHALT CEMENT CONTENT (% BY WEIGHT OF MIX)		5.5	6.0	6.5	7.0		6.2
THEORETICAL MAXIMUM SPECIFIC GRAVITY		2.475	2.457	2.439	2.421		2.450
THEORETICAL MAXIMUM DENSITY (PCF)		154.1	152.9	151.8	150.7		152.5
TEST DATA @ $N_{INITIAL}$ GYRATIONS (information only)							
	BULK SPECIFIC GRAVITY	2.169	2.170	2.177	2.181		2.173
	% VOIDS IN TOTAL MIX	12.4	11.7	10.7	10.0	9.5 Min.	11.3
TEST DATA @ N_{DESIGN} GYRATIONS							
	BULK SPECIFIC GRAVITY	2.320	2.347	2.367	2.370		2.354
	DENSITY (PCF)	144.4	146.1	147.3	147.5		146.5
	% VOIDS IN TOTAL MIX	6.3	4.5	3.0	2.1	3.5 - 4.5	3.9
	% VOIDS IN MINERAL AGGREGATE	17.5	17.0	16.8	17.1	15.7 Min.	16.9
	% VOIDS FILLED WITH ASPHALT	64.2	73.7	82.4	87.5	65 - 80	77.0
	HVEEM STABILITY	38	40	39	38	28 Min.	40
DUST TO ASPHALT RATIO (CP-50)		1.1	1.0	0.9	0.9	0.6 - 1.2	1.0

MOISTURE SENSITIVITY TEST

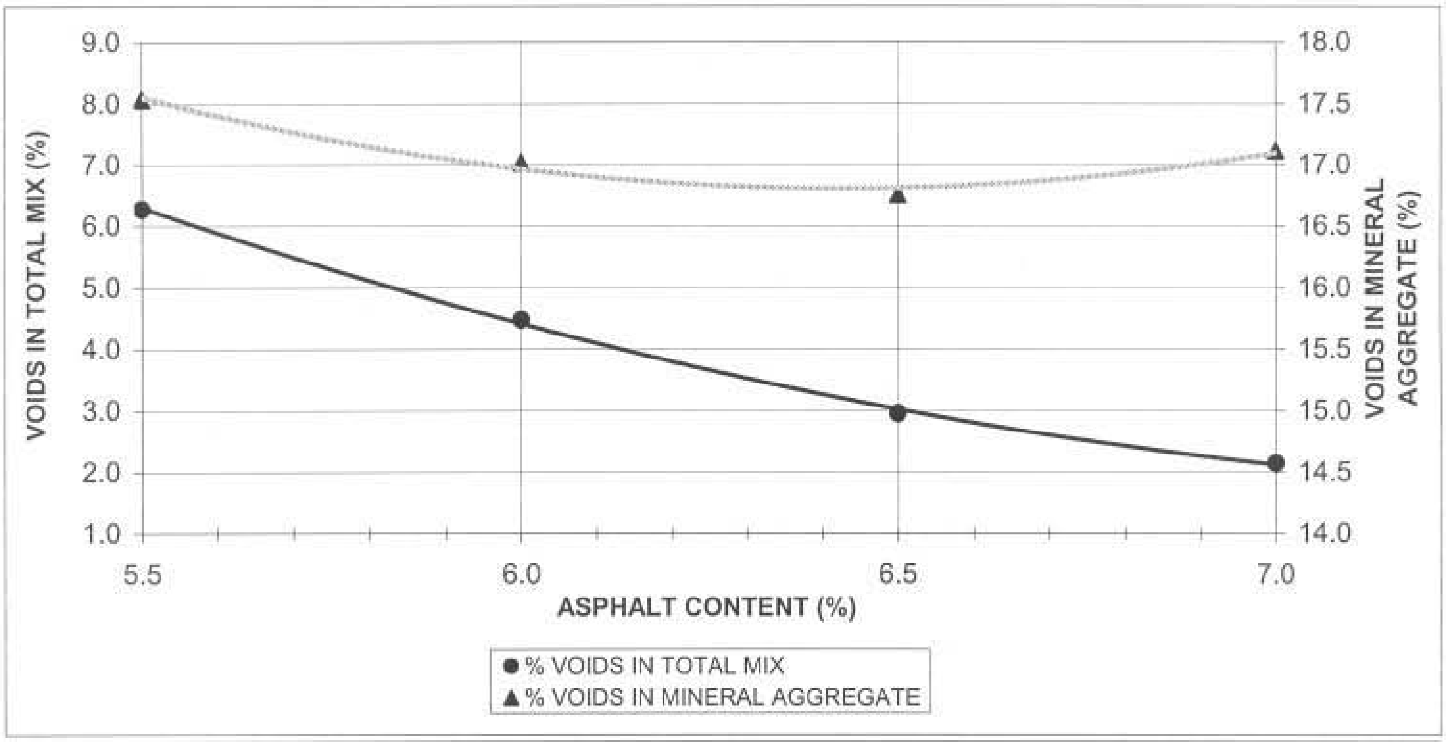
LOTTMAN MOISTURE SENSITIVITY TEST RESULTS (CP-L 5109, METHOD B)			
	AVERAGE SPECIMEN VOIDS (%)	6.0 - 8.0	6.8
	AVERAGE SATURATION (%)		89
	AVERAGE DRY TENSILE STRENGTH (PSI)	30 Min.	64
	AVERAGE CONDITIONED TENSILE STRENGTH (PSI)		58
	TENSILE STRENGTH RATIO (%)	80 Min.	91

TABLE 1

Client:	Everist Materials	June 1, 2007
Mix Design No.:	184107	
CDOT Grading:	SX	
Mix Design Method:	Superpave	

SPECIALISTS TO THE PAVING INDUSTRY

VOLUMETRIC PROPERTIES



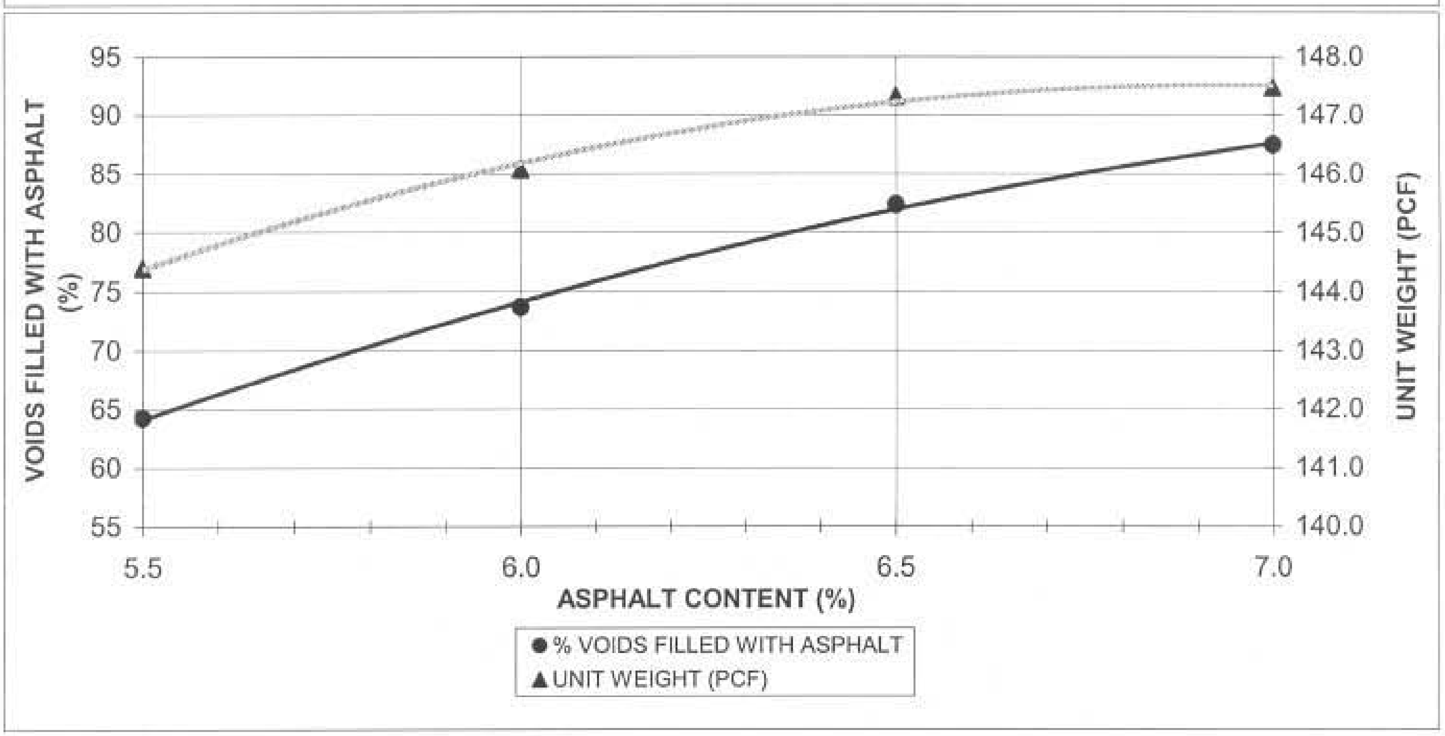


FIGURE 2

SPECIALISTS TO THE PAVING INDUSTRY

Client:	Everist Materials	June 1, 2007
Mix Design No.:	184107	
CDOT Grading:	SX	
Mix Design Method:	Superpave	

HVEEM STABILITY

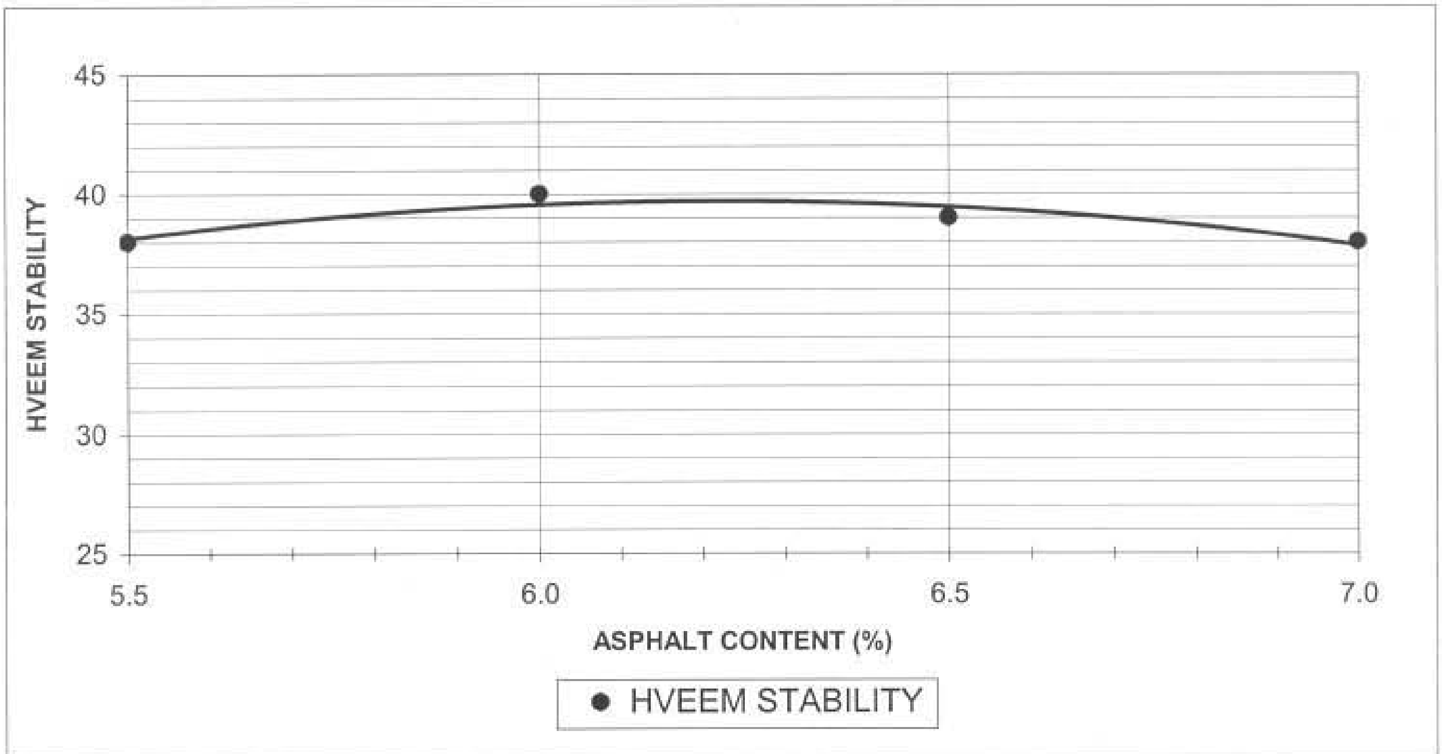


FIGURE 3