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Placement of Warm Mix Asphalt on the East Entrance Road of Yellowstone National Park

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16. Abstract

In an effort to deploy the warm mix asphalt (WMA) technology to Federal Lands Highway (FLH) and cooperating agencies, a Coordinated Technology Implementation Program (CTIP) proposal was approved by agency representatives. This CTIP project allowed FLH to take the lead in working with our client agency and contractors to evaluate the viability of warm mix technology as a standard construction practice. The demonstration evaluated two different WMA technologies (Advera and Sasobit) on a construction project on the East Entrance Road of Yellowstone National Park. The mixtures were placed in August/September 2007.

This report documents the results and summarizes the findings of this technology deployment.

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Placement of Warm Mix Asphalt on the East Entrance Road of Yellowstone National Park

Technology Deployment Program
Western Federal Lands Highway Division
Federal Highway Administration
610 East 5th St.
Vancouver, WA 98661

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Introduction

In an effort to deploy the warm mix asphalt (WMA) technology to Federal Lands Highway (FLH) and cooperating agencies, a Coordinated Technology Implementation Program (CTIP) proposal was approved by agency representatives. This CTIP project allowed FLH to take the lead in working with our client agency and contractors to evaluate the viability of warm mix technology as a standard construction practice. The demonstration evaluated two different WMA technologies (Advera and Sasobit) on a construction project on the East Entrance Road of Yellowstone National Park. The mixtures were placed in August/September 2007.

The goals of this WMA project were to:

- Document the use, performance, and construction processes associated with WMA.
- Enhance FLH laboratory testing experience and testing methodologies necessary for the construction of WMA pavements.
- Document the economic impacts/ benefits of WMA.
- Develop understanding for inspection and monitoring processes needed for quality placement and compaction of WMA.
- Place a large enough quantity of material to be able to fully understand construction processes, issues, and possible field adjustments.

The implementation of warm mix technology substantially reduces the temperatures at which asphalt mixtures are produced. This product has environmental, economic, and manufacturing benefits that would be realized by the agencies implementing this technology and the contracting community. Since the performance of this material is stated to be equal to or better than hot mix asphalt, there would be no concerns of using a product that has inferior performance characteristics.

The deliverables from this technology deployment effort are increased knowledge and experience in the construction of warm mix asphalt. This includes knowledge in the construction, manufacturing, placement, testing, and design of warm mix asphalt. By placing this material on a FLH construction project, FLH and client agencies are exposed to the use, construction practices, limitations, and overall benefits of using this product. The contracting community becomes more familiar with the technology and the means to provide this material to a construction project.

Environmental Details

The project was to reconstruct a portion of the East Entrance Road of Yellowstone National Park. The beginning of the project area was at Sylvan Pass and from there progressed to the east to the boundary of the national park with the Shoshone National Forest. The project was 6.93 miles

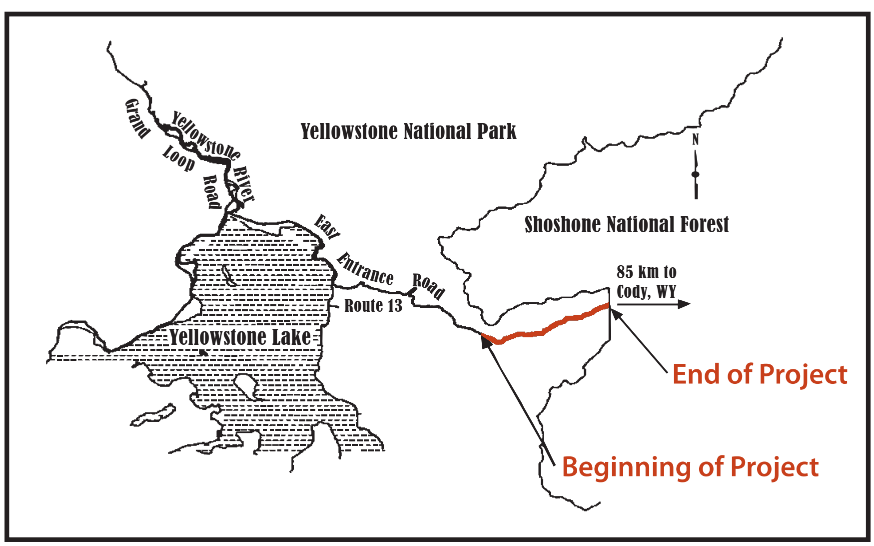

Figure 1 ~ Map of project.

(11.15 km) long and ranged in elevation from 8,500 feet (2,591 m) at the pass to 6,950 feet (2,118 m) at the east boundary. The project has a steady downhill grade that reaches a maximum grade of 7% in the most severe case. Figure 1 provides the project location.

The climate in the project area is moderately dry with cool summers and cold winters. During the summertime average high temperatures are in the 70s (25 °C), and nights are cool with temperatures in the upper 30s to low 40s (5 to 10 °C). Winter temperatures often hover near zero (-20 °C) throughout the day, and nighttime lows are subzero. Yellowstone typically experiences periods of bitter cold weather. Annual snowfall averages near 150 inches (380 cm) in most of the park; however, 200 to 400 inches (5 to 10 m) have been recorded at higher elevations such as Sylvan Pass.

Pavement Structure

The pavement structure was determined utilizing the DARWin pavement structure design program. The traffic loadings for a 20-year design life were estimated at 1,000,000 equivalent single axle loads (ESALs).

The pavement structure consisted of three layers. The subbase was constructed using recycled aggregates and pavement from the existing in-situ pavement structure. This material was placed and compacted to a depth of 6 inches (150 mm). The subsequent layer was a crushed aggregate base that was treated with 1% emulsified asphalt. This material was compacted to a finished depth of 8 inches (200 mm) and provided an excellent paving platform for the asphalt concrete pavement. The final layer was 4 inches (100 mm) of asphalt concrete pavement placed in two equal lifts. The plan quantity for the asphalt concrete was 31,300 tons (28,430 metric tons).

Figure 2 ~ Control mix placement.

Figure 3 ~ Depositing control mix in windrow.

It was desired to have an approximately equal amount of asphalt concrete placed by the three different methodologies: control (conventional hot mix), Advera WMA, and Sasobit WMA. A contract modification was initiated to provide for minor hot plant modifications to allow for introduction of the additives into the mixture. This modification covered the cost for delivery and support activities for the placement of the WMA mixtures. As part of the contract negotiations, it was desired that the change to the WMA mixtures would have minimal effect on the production. In other words, full and continuous production of the mixtures was desired, although not necessarily at the same production rate. Based on this criterion, the final placed quantities were not equal but provided for an equal number of production days for the two warm asphalt mixtures.

Figure 4 ~ Control mix paving operation.

Construction Process and Equipment

The contractor utilized the same equipment and construction process for the placement of the three different mixtures. Additionally all three of the mixtures were placed and compacted in an identical manner. Paving was accomplished by belly dumps depositing mixture in a windrow and a pick-up machine depositing the mix into the paver hopper. This is the conventional method that is typically done throughout this region. The paver was a Caterpillar model AP-1055B that used a sonic ski and slope control device to provide grade and slope control. The pick-up machine was a Barber Green BG-650.

Compaction was accomplished using two Ingersoll Rand vibratory steel drum rollers, model number DD-130HF, working in echelon as the breakdown rollers. Seven vibratory passes (a pass is defined as one trip of a roller in one direction) were needed to compact the mixture above the minimum density specification of 91 percent of maximum theoretical density. Finish rolling was provided by three passes of an Ingersoll Rand single steel wheel roller model SD-77DA. Based on nuclear gage readings, a small increase in density was provided by the finish rolling; however, the majority of the compaction effort was accomplished during breakdown rolling. No intermediate rolling was needed or provided during construction.

The roller pattern was established during the construction of a control strip. The specifications required that a control strip be placed and evaluated prior to full scale production. The evaluation of the control strip ensured that the plant was producing mixture within the tolerances of the mix design and the roller pattern used provided sufficient density. Upon completion and evaluation of the control strip, it was determined that the established roller pattern presented above would provide the necessary compactive effort. The control strip was placed and evaluated on August 21, 2007.

Paving Operations

Control Mixture

Production paving of the control mix began on August 22, 2007 and continued for four days. The plant was located in Cody, Wyoming approximately 53 miles (85 km) from the project. The distance provided for a 90 minute one-way haul primarily uphill.

In general, mixture laydown temperatures ranged from 300 to 325 °F (149 to 160 °C). Paving weather was favorable for this time of year in Yellowstone National Park therefore only minimal heat loss occurred during the transportation of the mix. Morning temperatures were in the mid 40s (7 °C) with daytime temperatures

Figure 5 ~ Control mix laydown.

reaching highs in the upper 70s (25 °C). The days were primarily sunny with some scattered clouds in the afternoon.

During these 4 days of paving, approximately 9,200 tons (8,350 metric tons) of the control mixture were placed. Aside from a few minor mechanical breakdown issues, the paving operations were smooth and uneventful.

Typical paving operations for the control mix are shown in Figures 2, 3, 4, and 5.

Advera Mixture

Placement of the Advera WMA began on August 26, 2007 and continued for four days. The Advera was added at a rate of 0.3% by weight of mix and was introduced at the plant via a port located just below the asphalt binder port (Figure 6). This allowed the zeolite powder additive to be blown into the binder during mix production thereby preventing any additive from escaping through the exhaust.

The placement of the mixture followed the same process as for the control mixture, as shown in Figures 7 & 8. The roller pattern was the same as the one that was established during the construction of the control strip.

The weather for the paving of the Advera WMA was similar to that for the control mix. The mornings were cool but clear, and the days were primarily sunny with some build up of clouds in the afternoon. For this time of year in Yellowstone National Park, the paving conditions were near ideal.

The initial target laydown temperature for the Advera WMA was 275 °F (135 °C). The laydown temperatures for the first day of paving ranged between 265 to 275 °F (130 to 135 °C). Because of the success in laydown and compaction of this mix, it was determined to lower the mix temperature in subsequent days. Eventually the mix was placed at a temperature of 250°F (121°C).

Figure 6 ~ Injection ports at the end of the drum: top port — asphalt binder, bottom port — warm mix additive.

Figure 7 ~ Advera WMA deposited in windrow.

Figure 8 ~ Advera laydown operation.

Figure 9 ~ Sasobit deposited in windrow.

The biggest issue in regard to the laydown temperature was obtaining consistency. During the production of the Advera WMA, it was difficult to maintain a constant production temperature. The cause of this was not definitively determined. Needing higher temperatures due to moisture in the aggregate or the burner not being properly adjusted to function properly at lower temperatures may have been contributing factors.

The workers noticed no handling differences using the Advera WMA compared to the control mix. The mixture was still easy to rake and manipulate when required and handled similarly to hot mix even at the lowest placement temperatures. The roller operators stated that the mix did not seem as tender as the hot mix and compaction was easily obtainable.

Compared to the control mix, the major difference was the lack of visible smoke and fumes. Although no worker exposure testing was conducted during these trials, anecdotal information from the paving crew suggested better working conditions with the Advera WMA.

A total of 9,650 tons (8,750 metric tons) of Advera WMA were placed.

Sasobit Mixture

Placement of the Sasobit WMA (Figures 10 & 11) began on August 30, 2007 and was completed on September 7, 2007. There were four days of production paving during this interval with time off for the Labor Day holiday as well as one day of heavy rain on September 6. The weather for paving was similar to that of the control mix and Advera WMA; however, one of the days was cut short due to an afternoon rain storm.

The Sasobit wax prills were added to the mixture using the same drum port that the Advera product used with the exception of the port size. A reduction collar was needed to change the port connection from a 4-inch line used for the Advera to a 2-inch line for the Sasobit. This was needed due to the addition rate for the Sasobit being much lower than the rate for Advera. To produce the Sasobit WMA, Sasobit was added at a rate of 1.5% by weight of binder.

Figure 10 ~ Sasobit laydown operation.

Figure 11 ~ Sasobit laydown operation.

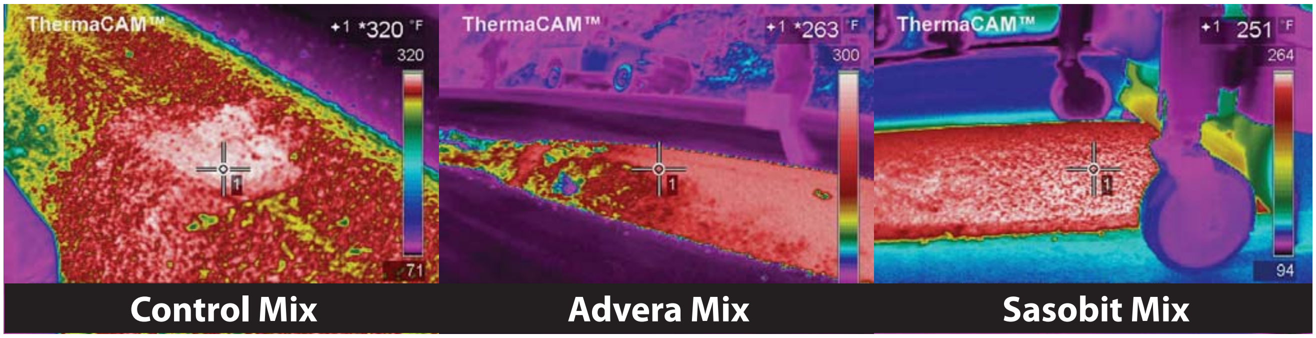

Figure 12 ~ Thermal images of mixes in the windrow.

Manufacturing conditions at the plant were similar to those of the Advera WMA. The plant initially established a target temperature of 275 °F (135 °C). After the first round of trucks, which provided approximately 600 tons (545 metric tons), the temperature was reduced to 250 °F (121 °C). Similar to the Advera WMA, the production temperatures fluctuated between 250 and 275 °F (121 and 135 °C), and it was difficult to maintain a consistent lower production temperature.

The workers noticed no handling differences between the Sasobit WMA and the control mix, even at temperatures as low as 230 °F (110 °C). The mix could be easily raked and leveled and had the same handling characteristics as hot mix even in the most difficult circumstances such as barrier wall tapers. The roller operator noted that density was easily achieved and felt that the mixture behaved similar to the Advera WMA. The roller pattern was the same as that used for the other two mixtures.

Again the major difference from a worker perspective was the reduced visible smoke and fumes. No worker exposure testing was conducted as part of this evaluation.

A total of 8,210 tons (7,450 metric tons) of Sasobit WMA was placed.

Infrared Imaging

During the laydown operations, thermal images were taken of the three mixtures (Figures 12 & 13). These images can be used to detect thermal segregation in the windrow or in the placed mat.

From a review of these images, both of the warm mixes exhibited a more uniform temperature in the placed mat than the control hot mix. This is potentially an advantage of using these particular warm mix additives because they provided a more uniform product upon remixing and laydown.

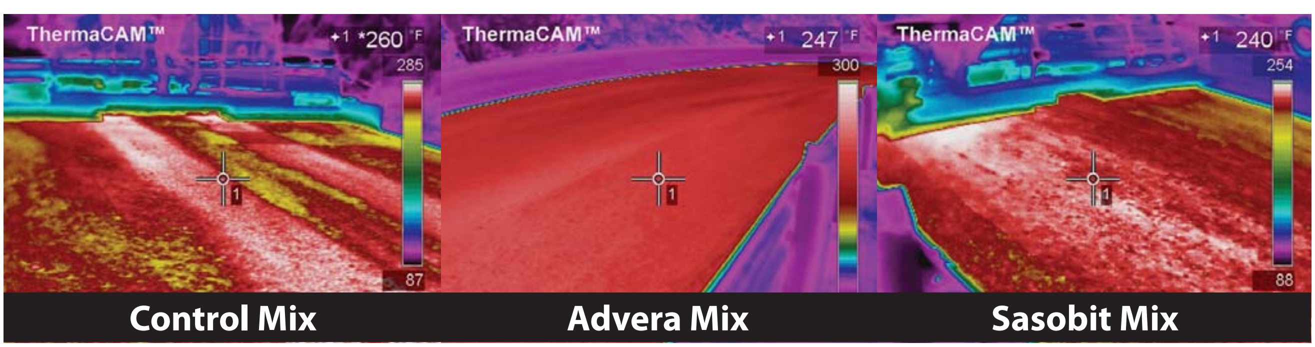

Figure 13 ~ Thermal images of mixture immediately behind the paver.

Sieve Size	Target Value
1" (25 mm)	100
¾" (19 mm)	99
½" (12.5 mm)	85
3/8" (9.5 mm)	71
#4 (4.75 mm)	46
#8 (2.36 mm)	30
#40 (425 µm)	12
#200 (75 µm)	6.0

Table 1 ~ Control mix gradation.

Mix Design and Material Properties

Mixture Properties

The contract specified that a Hveem mix design be performed by the contractor and verified by the Government. The contractor had the responsibility of selecting the aggregate gradation and proper asphalt content to ensure compliance with the mix design criteria. As part of the mix design process, it was determined that the aggregate source was moisture sensitive and required treatment to meet the retained strength requirement. The contract required that hydrated lime, added at a rate of 1.0%, be used as the anti-strip additive. The specifications for the approved gradation and mix design of the control mixture are shown in Tables 1 & 2. The two WMA mixtures were designed using the same gradation target values.

Asphalt Content by Weight of Mix	5.3%
Air Voids	4.0%
Voids in Mineral Aggregate	12.6%
Stabilometer Value	36
Dust / Asphalt Ratio	1.1
Immersion-Compression (1% lime added)	91.0%

Table 2 ~ Hveem control mix design.

After completion of the Hveem mix design, 75-gyration Superpave specimens were manufactured and analyzed. Based on the data obtained from the Superpave specimens, the asphalt content (AC) would have been reduced to 5.2% by weight of mix. This would yield 4.0% air voids and a slightly reduced amount (12.4%) of voids in mineral aggregate (VMA).

Control Mix	Advera Mix	Sasobit Mix
5.2% AC by Mix	5.2% AC by Mix	5.2% AC by Mix
4.0% Air voids	3.4% Air voids	3.2% Air voids
12.4% VMA	12.1% VMA	12.0% VMA

Table 3 ~ 75-gyration Superpave mix design comparison.

In addition, 75-gyration Superpave specimens were manufactured using the two warm mix additives. The mix design procedure was modified to accommodate the lower mixing and compaction temperatures. In order to manufacture these specimens, the aggregate was heated to a temperature of 275 °F (135 °C). Asphalt binder along with the warm mix additive was then added and properly mixed. The mixture was then short-term aged according to AASHTO R 30 but at a reduced temperature. The specimens were then compacted. A comparison of the mix design data is shown in Table 3.

From the comparison of the Superpave gyratory data, the warm mix additives provide a compaction benefit even at the reduced temperatures. This data indicates that some type of modified procedure will be needed in order to design mixtures using warm mix additives of this type. If the method is not modified, there would be a reduction in asphalt content for mixtures that use these types of additives which could lead to pavement durability issues.

Property	No Additive	With 1.5% Sasobit
Rotational Viscosity	0.535 Pa•s	0.480 Pa•s
Mass Change	-0.387%	-0.364%
DSR, Original	1.316 kPa	2.468 kPa
DSR RTFO	2.551 kPa	4.719 kPa
DSR PAV	1,414 kPa	1,917 kPa
BBR, Stiffness, S	265 MPa	287 MPa
BBR, Slope, m-value	0.318	0.275

Table 4 ~ Comparison of binder characteristics.

Binder Properties

The asphalt binder for the project was a PG 58-34 as specified in AASHTO M 320. This binder met the 98% reliability as stated in the LTPPBind asphalt binder selection program for this extremely cold environment. The binder supplied to the project met the requirements for the specified grade.

	Control		Advera		Sasobit	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
1"	100.0	0.00	100.0	0.00	100.0	0.00
1/2"	85.8	2.15	83.2	2.09	85.0	1.92
3/8"	69.2	2.47	67.1	2.54	68.5	2.45
#4	42.8	2.10	43.6	2.22	43.0	2.11
#8	27.6	1.41	28.9	1.56	28.9	1.68
#40	10.5	0.76	11.3	0.86	11.8	0.72
#200	4.6	0.40	5.1	0.44	5.4	0.22
AC Content	5.28	0.296	5.16	0.219	4.88	0.188
SE	66	3.99	66	2.92	65	2.20
% Fracture	99.8	0.24	99.8	0.31	99.9	0.18
Core Density	93.2	1.07	93.9	1.39	93.4	1.20
Moisture Content	0.35	0.16	0.41	0.06	0.53	0.10

Table 5 ~ Conventional mix properties.

It had been reported that the addition of Sasobit can have an effect on the binder properties. For this project, the asphalt binder supplied for the mix design was tested with and without the additive to determine the extent of stiffening, if any, on the binder. The results of the test are shown in Table 4.

From the data, it can be seen that in this case the Sasobit additive did stiffen the binder. It would no longer meet a PG 58-34 grade, but would be at higher temperatures at both the upper and lower values. Additional testing was not performed to determine the actual binder grade.

Production Mixture Testing

During the production of the three mixtures, samples were taken periodically from the windrow. One sample was taken at random for every 770 tons (700 metric tons). These samples were shipped from the project to the Western Federal Lands Highway Division (WFLHD) laboratory in Vancouver, Washington for testing. Based on the produced quantities for the project, 12 mixture samples were obtained for the control mixture, 12 samples were obtained from the Advera mixture, and 10 samples were obtained from the Sasobit mixture. The sand equivalent (SE), percent fracture, and core density values were determined from samples obtained by the contractor as part of the quality control/quality assurance process established in the contract.

Once these samples arrived at the laboratory in Vancouver, they were tested for asphalt content and gradation. Additionally specimens were fabricated for Superpave volumetric testing. Table 5 summarizes the conventional mix

	Control		Advera		Sasobit	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Gmb	2.298	0.0147	2.315	0.0160	2.311	0.0159
Gmm	2.438	0.0080	2.440	0.0092	2.452	0.0071
Va	5.8	0.78	5.1	0.92	5.7	0.69
VMA	15.0	0.54	14.3	0.53	14.2	0.60
VFA	61.7	4.22	64.3	5.27	59.8	3.56

Table 6 ~ Superpave mix properties.

Control Mixture								
	Specimen #	Air voids	Strength (kPa)			Specimen #	Air voids	Strength (kPa)
Dry	2	9.6	434		Dry	2	7.6	490
	4	8.8	428			5	7.1	510
	6	9.9	421			6	7.4	490
Wet	1	9.8	338		Wet	1	7.6	400
	3	9.4	365			3	7.1	448
	5	9.3	372			4	7.2	414
		Average Dry	428				Average Dry	497
		Average Wet	358				Average Wet	421
		TSR	0.84				TSR	0.85

Table 7 ~ Tensile strength ratio data for the control mix.

properties and Table 6 depicts the Superpave volumetric properties.

The gradations for the three different mixtures were fairly consistent. The most significant difference was that the asphalt content was below the targeted value of 5.3%. There was also higher than normal amounts of moisture content. During production the contractor obtained lower moisture content values due to an oven malfunction and insufficient heating; this unfortunately led to lower asphalt contents. The low asphalt contents also contributed to the high air voids and VMA values that were obtained from the Superpave specimens.

In spite of the low asphalt contents, the core density values indicate that density was achieved in the final placed mat. The standard deviation of the core density values was higher for the Advera and Sasobit, but the average is only marginally higher than the control mixture. Based on the data, the range was greater for the warm mixes than the control mix. Despite lower average asphalt contents, the highest in-place density values were from cores taken from the warm mix sections. Since the same compactive effort was applied in each case, this would suggest that the warm mix additives enhance the compaction of the mixture.

Additional specimens were fabricated for moisture sensitivity testing including tensile strength ratio (TSR), Hamburg rut testing, and Asphalt Pavement Analyzer (APA) rut testing. In order to provide sufficient material for specimens

Advera Mixture								
	Specimen #	Air voids	Strength (kPa)			Specimen #	Air voids	Strength (kPa)
Dry	1	8.0	441		Dry	1	7.1	469
	2	7.7	455			4	6.6	531
	4	7.6	476			6	7.6	476
Wet	3	7.9	359		Wet	2	7.2	400
	5	7.6	352			3	6.7	428
	6	8.0	372			5	7.2	420
		Average Dry	457				Average Dry	492
		Average Wet	361				Average Wet	416
		TSR	0.79				TSR	0.85

Table 8 ~ Tensile strength ratio data for the Advera Mix.

Sasobit Mixture								
	Specimen #	Air voids	Strength (kPa)			Specimen #	Air voids	Strength (kPa)
Dry	2	7.1	517		Dry	Only one data set was run.		
	4	7.2	538					
	6	7.6	517					
Wet	1	7.3	428		Wet			
	3	7.3	441					
	5	7.3	448					
		Average Dry	524					
		Average Wet	439					
		TSR	0.84					

Table 9 ~ Tensile strength ratio data for the Sasobit mix.

to be fabricated for various moisture sensitivity tests, material was combined from individual samples.

The tensile strength ratio test results were very similar, although one of the Advera WMA results would not pass the nationally established minimum ratio of 0.80. All of the dry strength values were fairly low, averaging approximately 70 psi (480 kPa) primarily due to the relatively soft grade of binder that was used on the project. Tables 7, 8, & 9 contain the data for this testing.

The Hamburg rut testing also provided very similar performance results between the three mixtures. The specimens were tested at 40 °C in a wet condition. The data indicates that all mixtures would meet current agency maximum rut limits as the maximum rut value observed was 4.00 mm. The plots of all of the rutting data also indicate that stripping is not occurring in any of the mixtures tested. This may be due to the 1% hydrated lime that was a necessary additive in all of the mixtures as an anti-stripping agent as indicated from the mix design.

The Sasobit WMA did show an average rut depth almost 1 mm less than the control; however, with the limited number of samples tested it is difficult to determine the statistical significance. This lower rutting may be attributed to a stiffening of the asphalt binder that was noted earlier. Table 10 provides the data from the Hamburg rut tests.

Mixture	Specimens	Air Void Content	Rut Depth @ 5,000 Passes (mm)	Rut Depth @ 10,000 Passes (mm)	Rut Depth @ 15,000 Passes (mm)	Rut Depth @ 20,000 Passes (mm)
Control	C-1 & C-2	6.6 & 6.2	2.30	2.90	3.61	3.82
Control	C-3 & C-4	8.0 & 7.8	2.50	3.00	3.62	4.00
		Control Average =	2.40	2.95	3.62	3.91
Advera	A-1 & A-2	8.0 & 8.2	2.70	3.00	3.62	3.80
Advera	A-3 & A-4	6.1 & 6.4	2.20	2.50	2.90	3.25
		Advera Average =	2.45	2.75	3.26	3.53
Sasobit	S-1 & S-2	7.4 & 7.4	2.20	2.80	2.97	3.28
Sasobit	S-3 & S-4	6.8 & 6.6	1.90	2.50	2.59	2.60
		Sasobit Average =	2.05	2.65	2.78	2.94

Table 10 ~ Wet Hamburg rut test at 40 °C.

Mixture	Specimens	Average Air Void Content	Average Rut Depth
Control	C-1 to C-6	7.0%	2.6 mm
Control	C-7 to C-12	7.4%	2.4 mm
Control Average =		7.2%	2.5 mm
Advera	A-1 to A-6	7.8%	2.8 mm
Advera	A-7 to A-12	6.4%	2.7 mm
Advera Average =		7.1%	2.8 mm
Sasobit	S-1 to S-6	8.0%	2.1 mm
Sasobit	S-7 to S-12	6.9%	1.7 mm
Sasobit Average =		7.5%	1.9 mm

Table 11 ~ Asphalt Pavement Analyzer rut test at 58 °C.

Rut testing was also performed using the Asphalt Pavement Analyzer (APA) rut testing device. The testing was performed in a dry condition and at the temperature of 58 °C in accordance with the binder grade selected for the project.

The rut data parallels the results of the Hamburg rut testing. The Sasobit WMA indicated the best rutting resistance, but none of the mixes performed poorly in the test. All rutting values were low. The fact that the Sasobit WMA provided the best results may again be indicative of the stiffening effect of the binder. The APA rut data is provided in Table 11.

Recovered Asphalt Binder Testing

Asphalt binder was recovered from the mixture samples that were obtained during the production of the mixtures. In order to provide sufficient material for the extraction and recovery, mixture samples needed to be combined. The binder was recovered using the centrifuge extraction and rotovapor recovery methods (ASTM D2172 and ASTM D5404). The results of the recovery are listed in Table 12.

Property	Control Mixture (avg. of 4 samples)	Advera Mixture (avg. of 4 samples)	Sasobit Mixture (avg. of 3 samples)
DSR, G*/sin δ @ 58 °C	5.495 kPa	3.786 kPa	4.202 kPa
DSR after PAV, G* (sin δ) @ 16 °C	3,252 kPa	2,770 kPa	2,848 kPa
BBR, Stiffness, @ -24 °C	280 MPa	246 MPa	254 MPa
BBR, Slope, m-value @ -24°C	.302	.310	.313

Table 12 ~ Recovered binder properties.

The data indicates that the binder from both of the warm mixes experienced a reduced amount of aging and stiffening. One of the inconsistencies noted is that the Sasobit recovered binder did not show the same stiffening effect that was noted in testing of the original binder sample with 1.5% Sasobit added. However, the results do indicate that the warm mixtures did experience less aging during the manufacturing process due to the reduced hot plant temperatures. For the location of this project, less aging of the binder could be a significant benefit in pavement performance by reducing thermal cracking potential.

Additional Testing

Additional samples were tested by the Federal Highway Administration (FHWA) Office of Pavement Technology's Mobile Asphalt Mixture Testing Laboratory (MAMTL) and also by Western Research Institute. The results and analysis of this testing is not part of this report but will be published independently.

Fuel Reductions

As part of the contract modification, the contractor monitored the fuel usage at the hot plant for the three different mixtures. The Advera WMA and the Sasobit WMA both exhibited a reduction in fuel consumption by 24% and 15%, respectively. It should be noted that the aggregate condition for the last day of paving with the Sasobit WMA was substantially wetter than the previous days of production of the control and Advera WMA due to a heavy rainstorm. The increased moisture content of the aggregate stockpiles would have increased the fuel consumption for this last day of paving.

Summary of Findings

- Visible smoke and fumes were substantially reduced in both of the warm asphalt mixes. Workers noted no handling difficulties of the warm asphalt mixtures at the reduced temperatures.
- Temperatures at the hot plant were difficult to regulate at the lower warm mix asphalt temperatures. Hot plant operators may need to make specific burner adjustments when producing mixtures at reduced temperatures.
- From a review of infrared thermal images, both of the warm mixes exhibited a more uniform windrow and mat temperature when compared to the control mix.
- Both warm mix additives examined in this technology deployment aided in the compaction process of the mix. This was exhibited both in mix design specimens that exhibited lower air void content than the control, as well as the as constructed pavement with average core densities higher than the control. All mixtures met the density requirement established in the contract with the warm asphalt mixtures providing the highest density values.
- Tests of the virgin binder that was modified with 1.5% Sasobit indicated a stiffening of the binder both on the upper and lower temperature values. This was not consistent with the results from the testing of the recovered binder from produced mix which did not indicate significant stiffening.
- The TSR testing provided consistent results with all three of the mixtures. Based on these results, none of the mixtures exhibited stripping characteristics. The results also indicate that the addition of 1% hydrated lime as an anti-strip agent in all of the mixes proved to be effective.
- The Hamburg rutting results indicate generally good performance by all of the mixtures; however, it was noted that the Sasobit mixture had the lowest rutting depths.
- Similar to the Hamburg results, the APA rutting results indicated good rut resistance for all of the mixtures with the Sasobit mixture having the lowest rut depth.
- There is definite fuel savings realized when using Advera and Sasobit as warm mix additives due to a reduction in the fuel used to heat the aggregates. Additional factors such as construction processes, hot plant operations, plant modifications, and location of project will certainly have an impact on the cost benefit analysis of using these additives. A complete cost benefit analysis was not performed on this project.

Conclusions and Recommendations

This technology deployment effort provided knowledge and experience in the placement and evaluation of warm mix asphalt. In doing so, it provided specific information to the agency and construction industry in the potential for this technology to be used in future FLH construction projects. This roadway will be monitored to evaluate the performance of these mixtures in order to evaluate the long-term performance of the warm mix asphalt when compared to conventional hot mix.

It was beneficial to provide an opportunity for the contractor to be in "full production" mode for the placement of these materials as this provided a valuable evaluation of this technology. This technology shows promise and could have a large impact in the paving industry.

At this point in time it is premature to advance to a standard specification; however, FLH will continue to pursue the placement and evaluation of warm mix technologies. As these evaluations continue, FLH will use this information to develop a standard specification for use.

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