Warm Mix Asphalt Final Report

WA-RD 723.2

Keith Anderson
Mark Russell
Jeff Uhlmeyer
Jim Weston
Jerry Roseburg
Tim Moomaw
Joe De Vol

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WSDOT Research Report

Experimental Feature Report

Final Report
Experimental Features WA 08-01

Warm Mix Asphalt Final Report

Contract 7419
I-90
West of George Paving
MP 137.82 to 148.45




Washington State
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Engineering and Regional Operations
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16. ABSTRACT

The performance of pavements constructed using warm mix asphalt (WMA) technology were compared to the performance of conventional hot mix asphalt (HMA) pavements placed on the same project. Measurements of friction resistance, rutting/wear, ride and pavement condition (alligator, longitudinal and transverse cracking) did not show that the WMA either improved or worsened performance. WMA is an allowable substitute for conventional HMA on all projects using less than 20 percent recycled asphalt pavement (RAP). WMA is not allowed when the RAP content exceeds 20 percent or when any percentage of recycled asphalt shingles (RAS) is incorporated.

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Introduction

Several new technologies are available that reduce asphalt plant emissions and energy consumption by allowing the production and placement of asphalt paving mixtures at lower temperatures. These lower temperature asphalt paving mixtures are designated Warm Mix Asphalt (WMA) and can be produced at temperatures 35-100°F lower than conventional hot mix asphalt (HMA) (Prowell and Hurley, 2013). Potential advantages of WMA include:

- Reduced mixing temperatures decrease fuel consumption thereby lowering plant emissions and energy costs.
- Decreased binder viscosity at compaction temperatures means less effort is needed to compact the mix.
- Lower mixing temperatures may reduce aging of the binder leading to increased fatigue life.
- Lower temperatures improve working conditions for paving crews through decreased smoke and odors.
- Compaction can be achieved at lower temperatures allowing paving during cooler weather or on projects with long haul times.
- Lower binder viscosities allow the use of higher percentages of reclaimed asphalt pavement (RAP) reducing the need to produce additional aggregate and binder.

One of the most widely used methods developed to produce WMA is to add an organic wax to the binder. An organic wax reduces the viscosity of the binder above the melting point of the wax allowing mixing and compaction to occur at lower temperatures. This experimental feature incorporates an organic wax marketed as Sasobit® by Sasol Wax to produce the WMA. When added to an asphalt binder, Sasobit® reduces the viscosity of the asphalt above its melting point of about 216°F allowing mixing and placement temperatures to be reduced by 32-97°F (Hurley and Prowell, 2005).

Sasobit® has the advantage of being easily implemented without major changes to mix design or production. If added directly into the binder, plant modifications are unnecessary. Adding Sasobit® during mixing is also an option requiring only minor plant modifications. Mix design testing can be performed without Sasobit® in the mix, making the mix design procedure for WMA with Sasobit® identical to that of a conventional HMA mix. The only consideration when designing a mix with Sasobit® is that it increases the temperature range of performance graded (PG) binders. The National Center for Asphalt Technology (NCAT) found that a PG58-28 binder graded out at PG64-22 with the addition of 2.5% Sasobit® and recommends the binder be engineered to ensure the final grade meets design requirements (Hurley and Prowell, 2005).

The purpose of this experimental feature is to evaluate the long and short term performance of WMA produced with Sasobit®. WSDOT will monitor the overlay for a period of five years using conventional survey techniques consisting of friction, rutting and ride measurements as well as overall pavement condition assessments (see Appendix A, Work Plan). Special emphasis will be placed on the overlay's ability to resist cracking and rutting.

Project Background

Contract 7419, I-90 West of George Paving, rehabilitated the pavement on Interstate 90 between the Columbia River at Milepost (MP) 137.82 and the town of George at MP 148.45. The first section of the project consists of a steep grade (5%) where the roadway climbs out of the Columbia River Gorge. The steep grade continues for approximately 1.5 miles, then moderates, eventually becoming rolling terrain from about MP 143.5 to the end of the project. Within the project limits Interstate 90 is made up of two lanes with paved shoulders in each direction separated by either concrete barrier or unpaved median. Average Daily Traffic (ADT) ranges between 6448 and 7327 with 27 percent trucks according to traffic data from the 2008 Washington State Pavement Management System (WSPMS).

Paving was limited to the right (outside) lane of eastbound Interstate 90. The remaining lanes were in good condition allowing their rehabilitation to occur at a later time. Distress in the eastbound right lane consisted of low severity alligator and transverse cracking. Severe rutting was also present between milepost 139.0 and 139.8. The higher level of distress in the eastbound right lane was attributed to higher pavement stresses caused by slow moving trucks going up the steep grade.

Figure 1. I-90 West of George Paving project map.

Rehabilitation consisted of grinding the existing pavement to a depth of 0.25 feet and inlaying with the same depth of HMA or WMA. The inlay consisted of HMA from the west end of the project at MP 137.82 to MP 144.53 and WMA from MP 144.53 to the end of the project at MP 148.45 (see Figure 2). The milepost limits allowed both an HMA control section and the WMA section to be on the flatter rolling portion of the project. It was felt that the first evaluation of WMA by WSDOT should not be placed on the steep grade where it would be exposed to the more severe loading conditions of the slow moving uphill truck traffic.

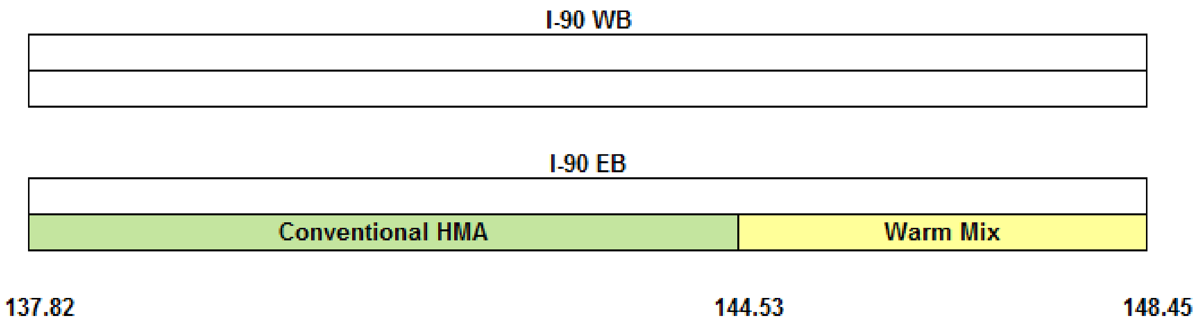

Figure 2. Plan map showing location of warm mix.

WMA was not included in the project when originally bid and had to be added by change order. Central Washington Asphalt (CWA), the successful bidder, agreed to a price of $64.00 per ton of WMA, an increase of $6.00 per ton over the bid price of $58.00 per ton for HMA. A total of 4,724.12 tons of WMA were placed resulting in a cost increase of $28,344.72.

Materials

Except for the inclusion of Sasobit in the WMA the materials and mix design for the HMA and WMA were identical. The following descriptions of materials apply to both mix types unless otherwise noted.

Aggregate

Pit site GT-318 was the aggregate source for the project. The Washington State Department of Transportation (WSDOT) tested and approved the aggregate from the pit site on September 22, 1998 (approval is good for ten years). Table 1 shows the aggregate durability test results for pit site GT-318.

Table 1. Aggregate properties.

Test	Result	Spec.
LA Wear – AASHTO T-96	17	30 Max.
Degradation – WSDOT T-113	84	30 Min.

The mix included recycled asphalt pavement (RAP) at a rate of 20 percent. The RAP for the project came from the material recovered from the grinding of the existing pavement.

Figure 3. Three quarter inch to No. 4 stockpile.

Figure 4. RAP Stockpile.

Binder

SEM Materials supplied PG76-28 binder for both the HMA and WMA. Sasobit was added to the virgin binder at a rate of two percent to produce the WMA. With the inclusion of 20 percent RAP, the percentage of Sasobit in the total mix was 1.6 percent which is within the 1.3 to 1.7 percent recommended by Sasol Wax (Shaw, 2008).

The WSDOT Bituminous Materials Section tested the binder to determine the affect of adding Sasobit to the high and low temperature specifications of the binder. The results revealed a slight increase in the average seven-day maximum pavement temperature with 1.5 percent Sasobit and almost a full grade increase in the average seven-day maximum pavement temperature with 2.0 percent (Table 2). Complete testing results are included in Appendix B.

Table 2. Change to binder grade with addition of Sasobit.

Test Condition	Binder Grade
Specified Binder Grade	PG76-28
Binder with no Sasobit	PG78-28
With 1.5 percent Sasobit	PG80-28
With 2.0 percent Sasobit	PG83-28

Mix Design

WSDOT tested the Class ½ inch mix design using Superpave volumetric design procedures (WSDOT SOP 732 - Standard Operating Procedure for Superpave Volumetric Design for Hot-Mix Asphalt). The target air voids were 4.0 percent with a gyration level of 100. The job mix formula (JMF) resulting from the mix design is shown in Tables 3 and 4. WSDOT does not include RAP in the mix during mix design testing so the properties in the tables are for the virgin mix. A copy of the mix design is included in Appendix C.

Table 3. JMF for volumetric properties.

Property	Value
Pb	5.5%
Va	3.7%
VMA	14.9%
VFA	75%
Pbe	4.7%

Table 4. JMF for gradation.

Sieve	Percent Passing
3/4”	100
1/2”	95
3/8”	84
U.S. No. 4	55
U.S. No. 8	34
U.S. No. 16	22
U.S. No. 30	15
U.S. No. 50	11
U.S. No. 100	8
U.S. No. 200	6.3

Construction

The HMA was placed between June 11 and June 16 and the WMA section on June 23 and 24, 2008. The Contractor, CWA, used a Gencor® portable drum plant to produce the HMA and WMA. SEM Materials added the Sasobit to the binder prior to shipment making modifications to the plant unnecessary.

Placement of the HMA and WMA used the same equipment and methods (Figures 5 through 8). End dumps with trailers delivered the mix to the project. Haul times varied from 30 to 45 minutes during placement of the HMA and from 25 to 35 minutes during placement of the WMA. Loads were not covered. Once delivered to the site, the trucks dumped the mix into a windrow device to form a windrow. A windrow elevator delivered the mix from the windrow into the hopper of an Ingersoll-Rand PF-5510 paving machine equipped with an Omni 3E screed. The paving machine was forced to stop on occasion to wait for the delivery of mix. Otherwise the placement operation proceeded smoothly. Placement dates, location and tonnage are shown in Table 5.

Figure 5. Truck dumping into the windrow device and forming windrow.

Figure 6. Windrow elevator picking up mix in windrow.

Figure 7. Windrow elevator delivering mix to machine.

Figure 8. Paving machine spreading the mix.

Table 5. Placement dates, location and tonnage.

Mix Type	Paving Dates	Mileposts	Tonnage Placed
HMA	June 11 - June 16, 2008	137.82 – 144.53	7,813.08
WMA	June 23 – June 24, 2008	144.53 – 148.45	4,724.12

The compaction train consisted of three double drum vibratory rollers (Figures 9 and 10). The breakdown and intermediate rollers worked together to make a total of five passes down each side of the mat. The finish roller made two passes down each side and one down the center. Table 6 displays the manufacturer, model number and capacity of the rollers.

Table 6. Roller information.

Position	Manufacturer	Model	Approximate Weight (lbs.)	Drum Width (in.)
Breakdown	Ingersoll-Rand	DD-138HF	30,000	84
Intermediate	Ingersoll-Rand	DD-130HF	30,000	84
Finish	Dynapac	CC 412	21,000	66

Figure 9. Breakdown roller.

Figure 10. Breakdown and intermediate rollers.

The only potential problem encountered was clumps of mix sticking together in the WMA. The clumps first appeared on June 19 during a test section of the WMA in a new subdivision in Quincy, WA (Figure 11). It was reported that the clumps in the test section occurred every few feet and were the result of excessive cooling of the mix during the approximately 40 minute haul (Hoffman, 2009). The lumps continued to appear during production paving on Interstate 90 but were much less frequent (Figure 12).

Figure 11. Clumps removed from WMA during test section near Quincy.

Figure 12. Clumps in windrow during placement of WMA on I-90.

The source of the lumps was not verified but one theory is that mixing temperatures may not have been high enough to break up large chunks of RAP. Figure 13 shows the RAP passing through a screen before it entered the drum and Figure 14 shows the RAP which was unable to pass through the screen. This process made it unlikely that large chunks of RAP made it into the mix. Furthermore the RAP came from a ¾ inch NMAS mix with 3.2 percent of the aggregate retained on the ¾ inch sieve. Gradation test results for the HMA and WMA showed no aggregate retained on the ¾ inch sieve indicating the CWA did a good job of keeping the larger aggregate out of the mix. If large chunks of RAP were entering the drum some of the ¾ inch or larger aggregate would have made it into the mix and showed up as retained on the ¾ inch sieve.

Figure 13. Screening RAP.

Figure 14. Material that did not pass trough the RAP screen.

Thermal images of WMA in the truck and in the windrow are shown in Figures 15 and 16. The crust on the mix in the truck was at 115°F and the cool mix in the windrow at 176°F. The location of the temperature readings are denoted by a numbered symbol consisting of a circle with four bars at 0, 90, 180, and 270 degrees. The temperature at that point is noted in the upper right hand corner of the image. Mix at temperatures shown in the two photos would have hardened since Sasobit® loses its viscosity reduction ability below its melting point of about 216°F. The hardened mix could show up as clumps in the windrow. Remixing before placement in order to reheat the clumps would be the solution to this problem. The fact that no clumps were seen in the completed mat may be because the windrow elevator remixed the HMA sufficiently to eliminate the clumps.

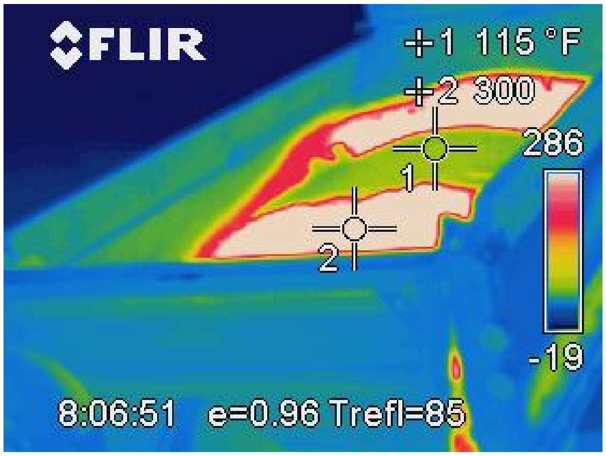

Figure 15. WMA crust temperature of 115°F leaving truck.

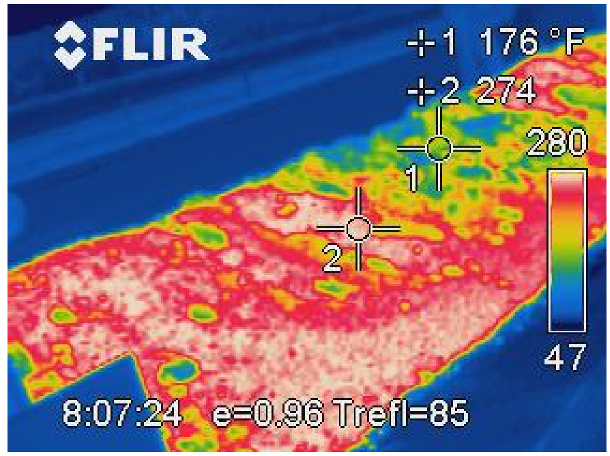

Figure 16. Cool WMA in windrow.

Temperature Observations

The temperature of the mix was measured using a FLIR ThermaCAM™ E4 infrared camera. The infrared camera can only measure the external temperature of the mix which is not representative of the internal temperature once a cooler crust has formed. For that reason this report only uses temperatures taken immediately after the breaking of the crust or immediately after remixing of the HMA. This occurred at three locations, when trucks dumped the mix into the windrow machine (Figure 17), when windrow elevator transferred the mix to the paving machine hopper (Figures 18), and when the augers distributed the mix to the screed (Figure 19).

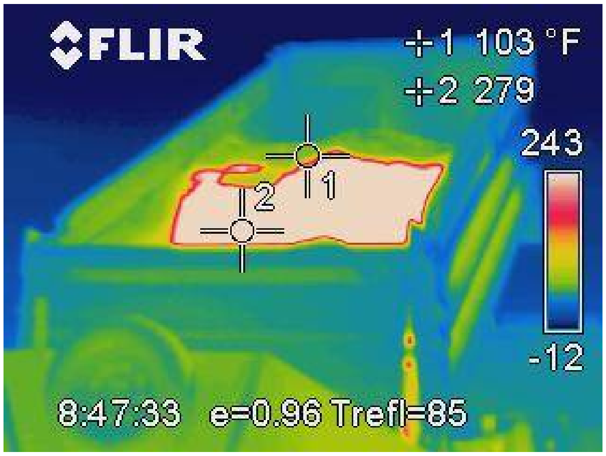

Figure 17. Thermal image of first load of WMA as it is being dumped into windrow device.

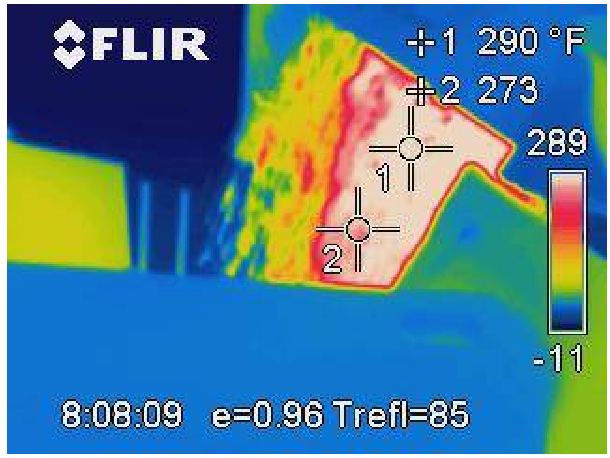

Figure 18. Thermal image of windrow elevator delivering WMA to the hopper.

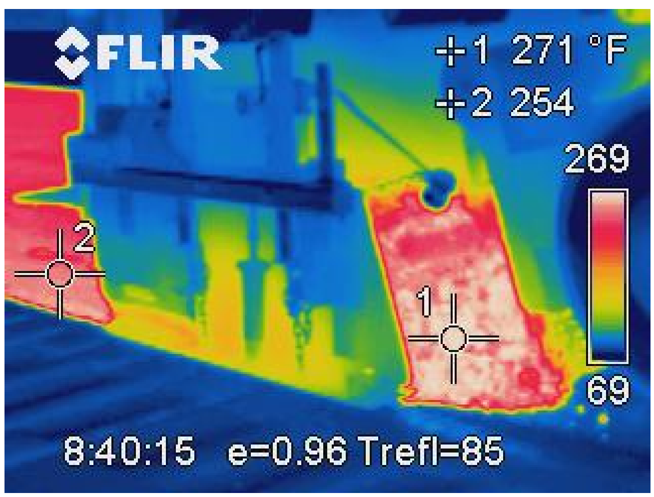

Figure 19. Thermal image of WMA in front of augers.

Table 7 lists HMA paving temperatures recorded on June 16 between 9:30 a.m. and 11:30 a.m. and WMA temperatures recorded between 8:00 a.m. and 10:30 a.m. on June 23. Due to WMA being a new technology, production started out at a higher temperature than necessary and the Contractor incrementally lowered mixing temperature until it reached 290°F. The higher mixing temperature resulted in the first several loads of WMA being around 300°F when delivered to the roadway. Once mixing temperatures stabilized at their lower level, delivery temperatures averaged 286°F. The temperature ranges for the WMA in the table represent those recorded once the temperature stabilized. The table shows that WMA paving temperatures were about 30 to 50°F lower than HMA.

Table 7. Summary of temperature readings.

HMA		
Location	**Temperature Range °F**	**Average Temperature °F**
Leaving Truck	325-333	328
Windrow Elevator	322[1]	322
Paving Machine Augers	287-325	306
WMA		
Location	**Temperature Range °F**	**Average Temperature °F**
Leaving Truck	276-294	286
Windrow Elevator	249-297	272
Paving Machine Augers	250-288	276

[1]Only two readings were taken each reading being 322 °F.

Temperature differentials up to 30°F were observed in both the HMA and WMA (Figures 20 and 21. Temperature differentials were attributed to a jump in temperature in the windrow where the mix placed by one truck ended and the mix placed by the next truck began. The mix from the first truck would have sat in the windrow longer and cooled more than the mix from the next truck resulting in a change in mix temperature. The windrow elevator provided minimal remixing so the jump in mix temperatures showed up as temperature differentials behind the paving machine.

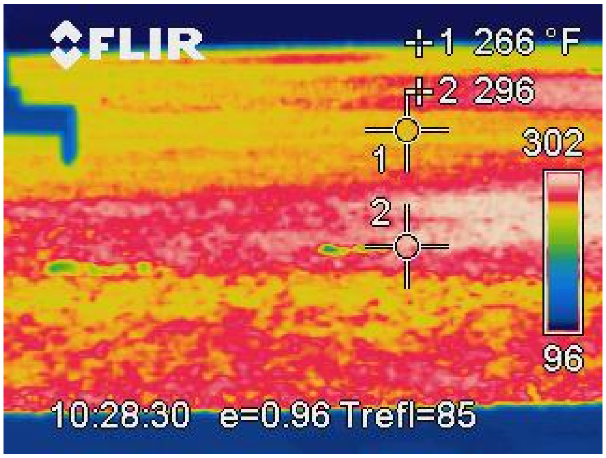

Figure 20. Thirty degree temperature differential in HMA.

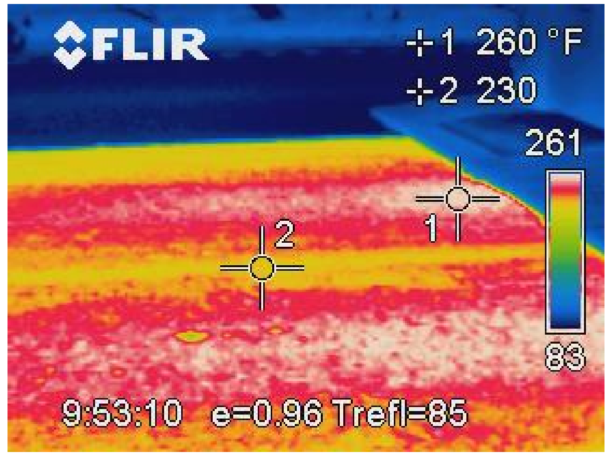

Figure 21. Thirty degree temperature differential in WMA.

Test Results

Gradation and Volumetric Properties

Gradation and volumetric properties of the HMA and WMA were similar and average test results conformed to the job mix formula (JMF). Table 7 shows the average gradation and volumetric results from the nine HMA and five WMA sublots. All gradation tests were within tolerance, and the only out of tolerance volumetric properties were the air voids in two HMA sublots. Both out of tolerance air void test results were 5.7 percent which is above the tolerance band of 2.5 to 5.5 percent. The dust to asphalt ratio was also out of tolerance in one HMA sublot (1.7 versus 0.6 to 1.6 tolerance band) and one WMA sublot (1.7 versus 0.6 to 1.6 tolerance band). Individual test results are shown in Appendix D.

Table 8. Production gradation and volumetric test results.				
Test Property	**JMF**	**HMA Average**	**WMA Average**	**Tolerance Limit**
3/4	100.0	100.0	100.0	99-100
1/2	95.0	93.8	95.2	90-100
3/8	84.0	83.1	85.0	78-90
No. 4	56.0	54.1	55.2	51-61
No. 8	35.0	34.2	35.0	31-39
No. 16	22.0	22.1	22.4	n/a
No. 30	15.0	15.3	15.8	n/a
No. 50	11.0	11.4	12.0	n/a
No. 100	8.0	8.7	9.0	n/a
No. 200	6.3	6.4	6.7	4.3-7.0
% Binder	5.2	5.1	5.4	4.7-5.7
% Va	3.7	4.9	4.5	2.5-5.5
VMA	14.9	14.8	14.7	12.5 min.
VFA	75.0	67.2	69.4	n/a
D/A	1.4	1.5	1.6	0.6-1.6

Density

Density results of the HMA and WMA were similar (Figure 22). The distribution of the actual results illustrated by the bars is somewhat erratic due to the small number of tests. The average test result for HMA was 93.5 percent with a standard deviation of 1.58 versus 93.7 percent and a standard deviation of 1.36 for WMA. The size of the standard deviations as compared to the difference in average density indicates that the variation is statistically insignificant. The one notable difference was that the number of failing density tests was significantly lower with WMA. Out of 95 density tests on the HMA, six (6.3 percent) failed to reach the 91.0 percent minimum specified density. Only one out of 55 (1.8 percent) density tests on the WMA was below 91.0 percent. The compactability of the WMA was probably improved by 0.3 percent higher asphalt content. Overall the results indicate that the same level of density is achievable at lower compaction temperatures with WMA. Density test results are in Appendix E.

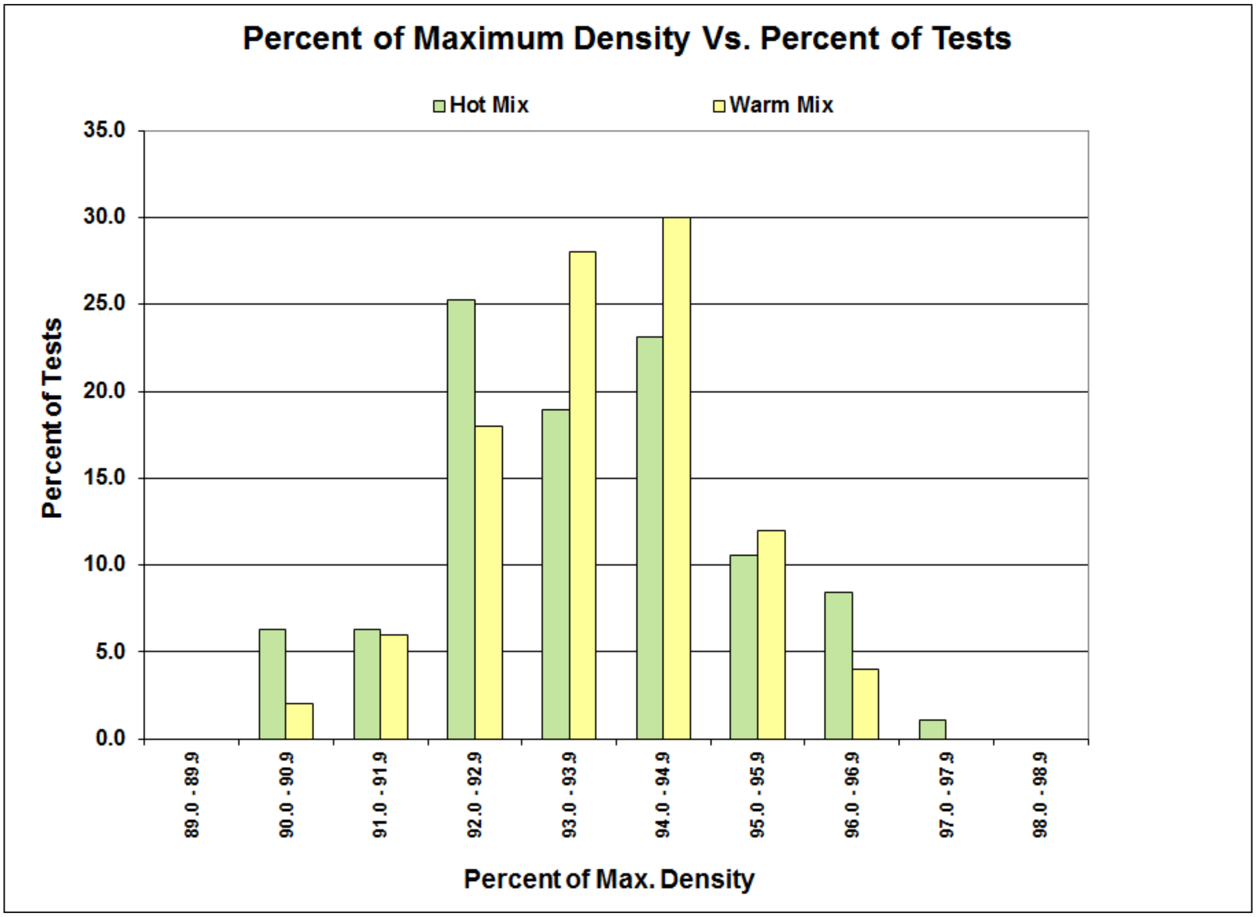

Figure 22. Distribution of compaction test results.

Stockpile Moisture Testing

Moisture content is important when producing WMA because it is believed that the lower mixing temperatures may not adequately dry the aggregate if the moisture content is high. Moisture content testing yielded an average moisture content of 1.66 percent in the ¾ inch to No. 4 stockpile and 2.48 percent in the ⅜ inch minus stockpile. These moisture contents are low considering that WSDOT allows 2 percent moisture in HMA when discharged from the plant.

Federal Highway Administration Testing

In order to assist in evaluating the performance of WMA, WSDOT requested the aid of the Federal Highway Administration's (FHWA) mobile asphalt testing laboratory (MATL).

Samples of both the HMA and WMA were tested for dynamic modulus, flow number and with the Hamburg Wheel Tracking Device (HWTD). Results of the MATL testing are summarized below. The full report is included in Appendix F.

Dynamic Modulus

Dynamic modulus is a measure of stiffness of an HMA sample. The test procedure involves applying a sinusoidal load to the sample at various frequencies and temperatures. The ratio of the applied stress to the measured strain is the dynamic modulus (Roberts et al, 1991, Huang 2004). The MATL testing showed that the WMA with Sasobit® was stiffer than the HMA. The MATL reported that the stiffening affect of Sasobit® was similar to stiffening observed on other projects and was consistent with a one grade increase of the WMA binder due to the addition of Sasobit® (Corrigan, 2009).

Flow Number

The flow number test measures the permanent strain of an HMA sample under repeated loads. The flow number is defined as the number of loads at which the change in permanent deformation is at a minimum during the test. The flow number has been found to correlate with rutting resistance of HMA test sections (Bonaquist, Christensen and Stump, 2003). The flow number values for the WMA with Sasobit® were higher than the HMA indicating that the WMA was slightly stiffer than the HMA (Corrigan, 2009).

Hamburg Wheel Track Device

The HWTD measures both the rutting resistance and stripping resistance of an HMA mixture. The MATL testing did not find a significant difference in rut depth between the HMA and WMA. The test results showed that resistance to permanent deformation of both mixed was very good. Neither mix was shown to be susceptible to stripping (Corrigan, 2009).

Performance

The performance of the HMA and WMA sections on the I-90 George project was monitored over a period of five years with measurement of friction resistance, rutting/wear, ride (roughness) and pavement condition. Following the discussion of this data, information is presented on research done by Washington State University (WSU) on four WMA projects including the I-90 George project. Pavement condition data is then presented on five conventional HMA projects constructed by WSDOT between 2008 and 2010 that included test sections of WMA. Finally, a discussion is presented on the performance comparison of the WMA and HMA pavements on all projects. First, we will examine data from the I-90 George project.

Friction Resistance

The friction resistance measurements for the sections are listed in Table 9 and shown graphically in Figure 23. The average values for the WMA section was always slightly higher than the average HMA value for every period of measurement. The differences, which range from 0.4 to 1.8, were small and indicate no significant difference in performance between the two sections.

Table 9. Friction resistance of HMA and WMA sections.

Section	Spring 2009	Fall 2009	Spring 2010	Fall 2010	Spring 2011	Spring 2012	Spring 2013
HMA	59.0	55.1	56.2	53.8	56.6	58.2	58.4
WMA	60.8	56.5	56.6	56.9	57.8	59.2	59.0
Difference	**1.8**	**1.4**	**0.4**	**3.1**	**1.2**	**1.0**	**0.6**

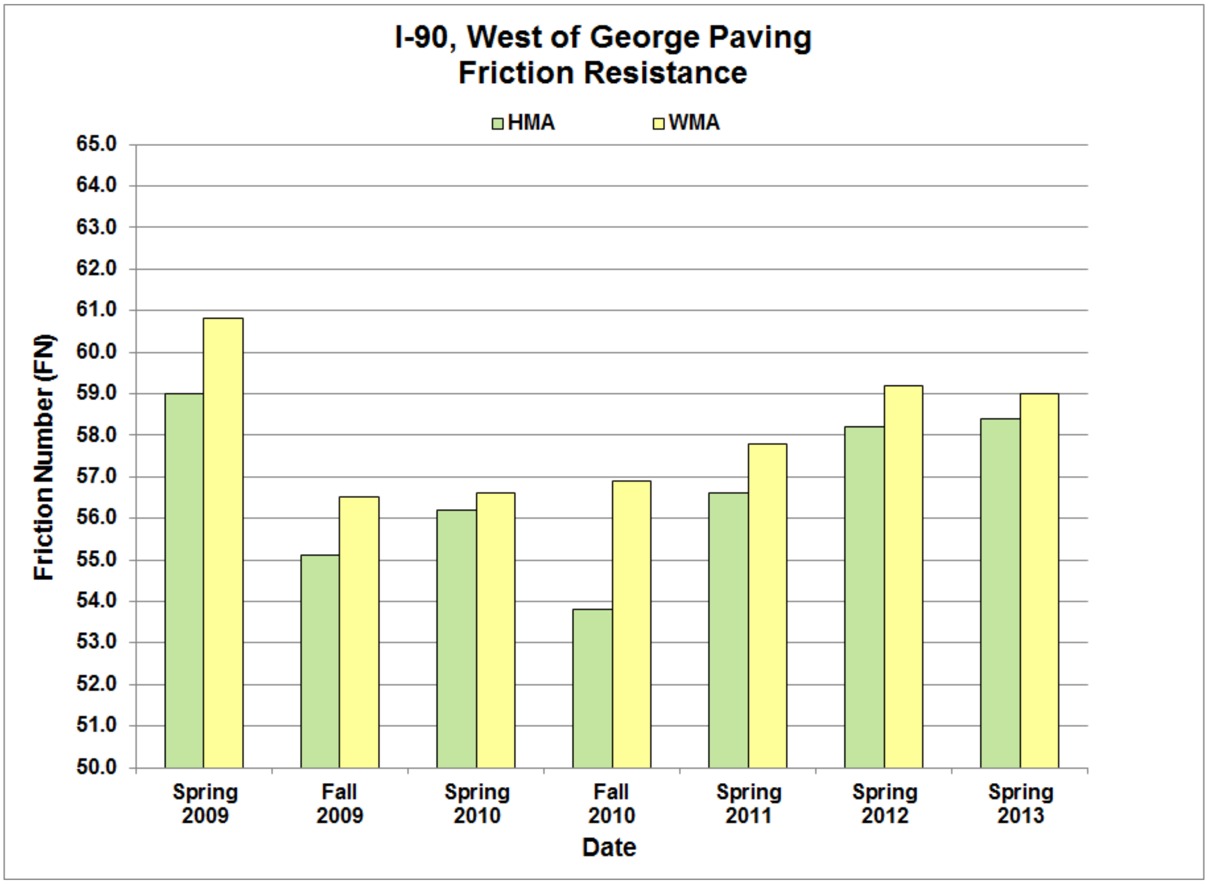

Figure 23. Friction resistance measurments over time for HMA and WMA sections.

Wear/Rutting

Wear/rutting measurements from the Pathway Road Rater are listed in Table 10 and shown graphically in Figure 24. Normal increases in wear/rutting were noted between the 2009 and 2014 data. The differences in wear/rutting between the two sections ranged from -0.3 to +0.5 mm. The small differences indicate no significant difference in wear/rutting between the two sections.

Table 10. Wear/rutting measurements (mm).

Section	2009	2010	2011	2012	2013	2014
HMA	3.0	3.4	3.8	4.4	4.7	6.2
WMA	2.7	3.3	3.8	4.4	4.7	6.7
Difference	**-0.3**	**-0.1**	**0.0**	**0.0**	**0.0**	**+0.5**

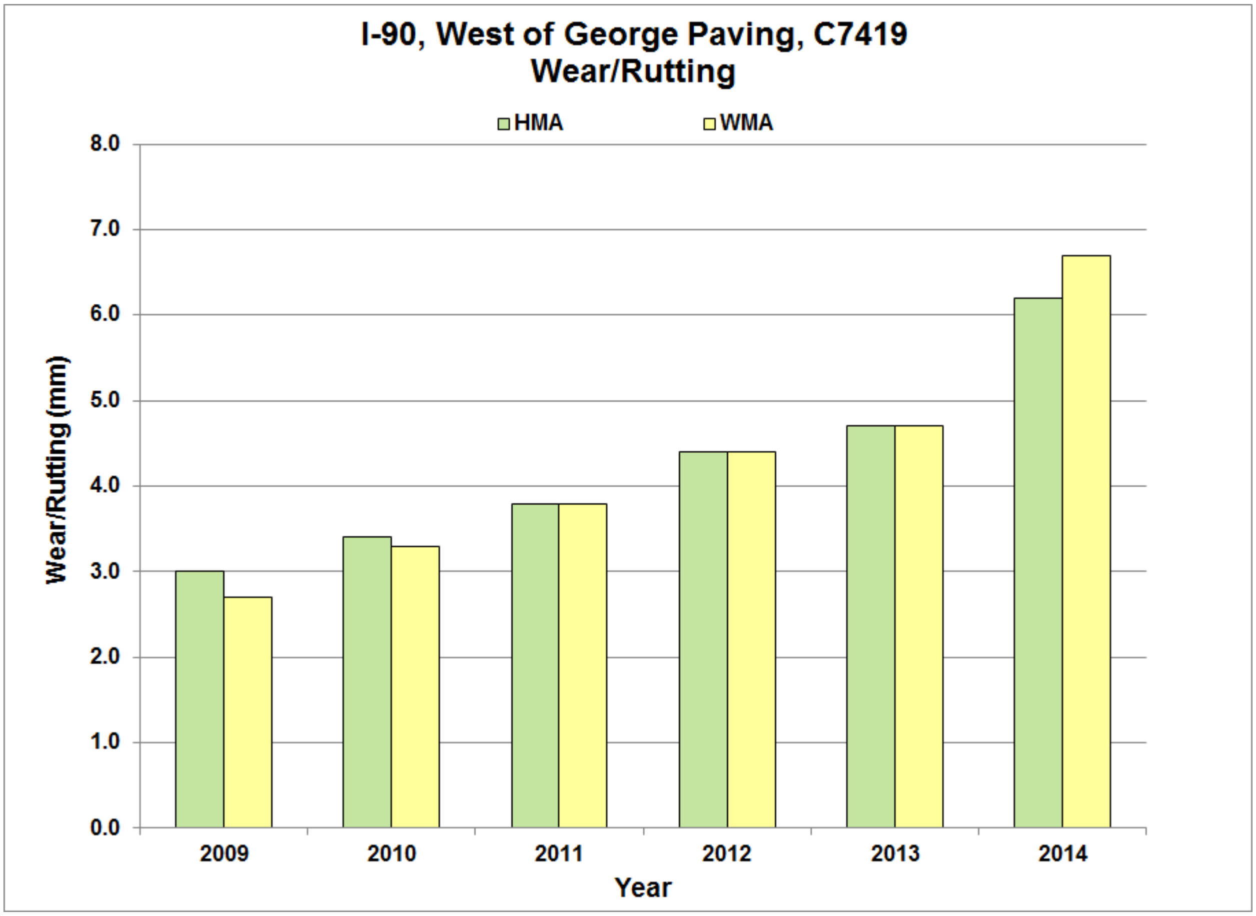

Figure 24. Wear/rutting measurements.

Ride

Ride measurements, also from the Pathway Road Rater, are listed in Table 11 and shown graphically in Figure 25. The ride is reported in International Roughness Index (IRI) readings of inches/mile. The IRI for the HMA section were slightly higher than the WMA section for each set of measurements. The differences, which ranged from -3 to -5 in/mile, were small and indicate no significant difference in performance between the two sections.

Table 11. Ride measurements IRI (in/mile).						
Section	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
HMA	54	56	56	57	59	57
WMA	51	53	53	54	54	52
Difference	**-3**	**-3**	**-3**	**-3**	**-5**	**-5**

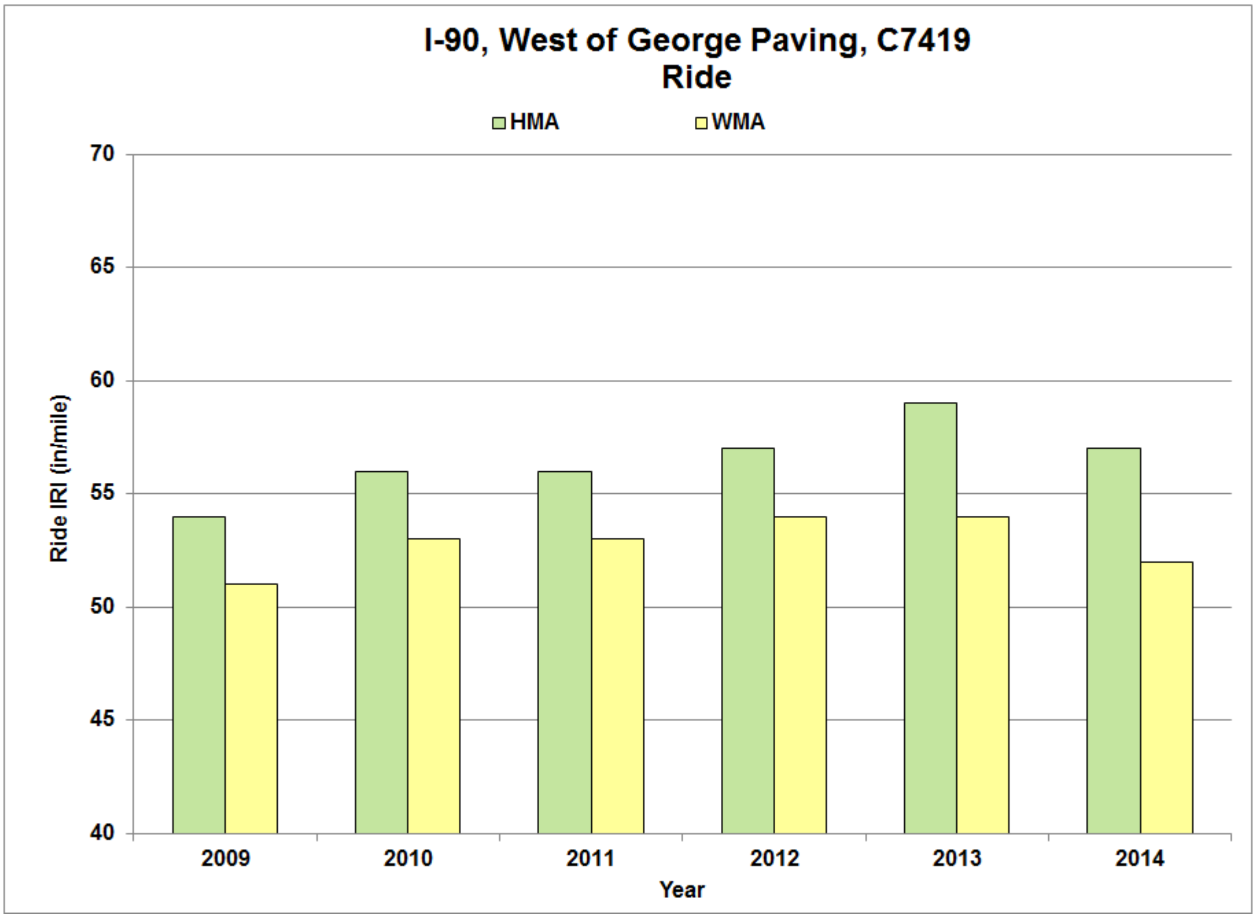

Figure 25. Ride measurements.

Pavement Condition

Pavement condition information is presented for each category of distress for the condition of the pavement in 2007 (prior to construction) and for 2013 (Table 12). The percent of cracking that returned to the sections after five years was then compared. Less than one percent of the low severity alligator cracking returned to both sections. The WMA had nine percent of its low severity longitudinal cracking return as compared to only three percent for the HMA section. Over 100 percent of the low severity transverse cracking returned to the WMA section as compared to 41 percent for the HMA. Both sections had over 100 percent of the medium severity transverse cracking return, however, the HMA section had a large return of medium transverse cracking. The HMA pavements in the eastern part of the state are subject to transverse cracking due to cold winter temperatures. Alligator cracking which is caused by fatigue is not likely to show up at the age of five years, therefore, the primary performance indicator is transverse cracking. For the I-90 George project the HMA section had a slightly better performance.

Table 12. Comparison of pavement defect before and after paving.

Defect	HMA			WMA		
	2007	2013	% Change	2007	2013	% Change
Low severity alligator cracking (ft. per wheel path)	33,673	10	<1	31,780	25	<1
Medium severity alligator cracking (ft. per wheel path)	0	0	0	21	0	0
High severity alligator cracking (ft. per wheel path)	0	0	0	10	0	0
Low severity longitudinal cracking (ft.)	4,195	142	3	1,905	180	9
Medium severity longitudinal cracking (ft.)	0	16	<1	0	0	0
Low severity transverse cracking (number)	414	169	41	101	103	>100
Medium severity transverse cracking (number)	10	216	>100	1	18	>100

Note: The severity of the cracking is determined by its width. Low severity is <1/4 inch or hairline in the case of alligator cracking, medium severity is >1/4 or spalled in the case of alligator cracking, and high severity is spalled or spalled and pumping and the case of alligator cracking.

Conclusions – HMA slightly better performance

WSU Report Findings

The next performance comparisons are from a research study done by WSU on four WMA projects that included I-90 George (Bower et al. 2012). Each project used a different WMA technology including Gencor® Green Machine Ultrafoam GX™, Aquablack™, and water injection in addition to the Sasobit® used on the George project (see Table 13). Cores from each project were tested for dynamic modulus, fatigue and thermal cracking, rutting and moisture susceptibility (Table 14). The Hamburg Wheel-Tracking Device (HWTD) was used to measure the samples resistance to rutting and moisture intrusion. Tests on the binders extracted from the cores included shear modulus, fatigue and thermal cracking, and rutting (Table 15).

Table 13. Projects included in the WSU research study.

Route	Contract Number, Project Title	Process	Construction Date	Milepost Limits
90	7419, George Vicinity Paving	Sasobit®	June 2008	137.82 to 148.45
28	7645, Quincy Area Paving	Water Injection	June 2009	27.73 to 36.57
12	7474, Frenchtown Vicinity to Walla Walla	Aquablack™	April 2010	327.20 to 335.95
12	7755, Naches to Mitchell Rd Vicinity	Gencor®	August 2009	189.38 to 197.75

Table 14. Laboratory test results on mixes from WMA and HMA sections. (Bower et al. 2012)

WMA Process	Dynamic Modulus	Fatigue Cracking	Thermal Cracking	Rutting	Moisture Susceptibility
Aquablack™	**Lower**	Equal	Equal	Equal	Equal
Sasobit®	Equal	**Lower**	Equal	Equal	Equal
Gencor®	Equal	Equal	**Higher**	**Lower**	Equal
Water Injection	Equal	Equal	**Higher**	**Lower**	Equal

Table 15. Laboratory binder test results from WMA and HMA sections. (Bower et al. 2012)				
WMA Process	**Complex Shear Modulus**	**Fatigue Cracking**	**Thermal Cracking**	**Rutting**
Aquablack™	**Lower**	**Lower**	Equal	**Lower**
Sasobit®	**Lower**	**Lower**	**Higher**	Equal
Gencor®	**Lower**	**Lower**	Equal	**Lower**
Water Injection	**Lower**	**Lower**	Equal	**Lower**

The results showed that the Sasobit® mix had equivalent stiffness and resistance to thermal cracking, rutting and moisture damage, but lower resistance to fatigue cracking than the conventional HMA mix. The tests on the extracted binders showed that the Sasobit® binder was less resistant to fatigue cracking and rutting (complex shear modulus, but showed better resistance to thermal cracking) than the HMA binder.

The WSU study also examined the early age field performance of the WMA and HMA pavements. Rutting/wear and ride measurements were equal for the Sasobit® and conventional HMA sections, which agrees with the longer term data reported previously. The WSU report indicated less reflective transverse cracking in the Sasobit® section, however, the authors indicated that this may not hold true into the future. Figure 26-29 show the condition of the Sasobit® and HMA section 31 months after paving.

Figure 26. Sasobit® section. (Jan. 2011)

Figure 27. Sasobit® section close-up. (Jan. 2011)


Figure 28. HMA section. (Jan. 2011)


Figure 29. HMA section close-up. (Jan. 2011)

The final conclusion drawn by the authors was that the lower fatigue resistance of the WMA observed in the laboratory testing was not in evidence in the examination of the field performance of the pavement. The observation of less reflective cracking in the WMA section was tempered with the caution that the WMA may only delay the cracking. The caution was born out by our data (Table 16) which showed that the improved transverse cracking performance of the WMA section was temporary.

Table 16. Number of transverse cracks per survey year for HMA and WMA.

Section	Number of Cracks					
	2007	2009	2010	2011	2012	2013
HMA	419	143	192	252	378	385
WMA	101	13	15	44	24	121

Additional WMA Project Performance Data

WSDOT used WMA processes on a number of additional projects after its initial use on the I-90 George project. Table 17 lists five of these conventional HMA projects that incorporated test sections of WMA.

Table 17. Projects with WMA test sections.

Route	Contract Number, Project Title	Milepost Limits	
		WMA	HMA
520	7419, I-405 to WLSP I/C - Paving	WB MP 8.74 to 10.74	EB MP 8.74 to 10.74
28	7645, Quincy Area Paving	EB MP 27.73 to 34.64	EB MP 34.64 to 36.57
5	7669, 52nd Ave W to SR 526 NB Paving	NB MP 186.70 to 188.70	NB MP 180.10 to 186.70
101	7748, SR 6 to Grays Harbor Co. Line Paving.	SB MP 60.84 to 65.39	NB MP 59.81 to 60.84
12	7755, Naches to Mitchell Vic. Paving	EB MP 193.96 to 197.77	WB MP 193.96 to 197.77

Pavement condition distress information prior to construction was compare to the most current 2013 data for the WMA and HMA sections on each project to determine if any difference in performance could be detected (Tables 18-22). A listing of each distress and how it is measured follows:

(The ratings are accumulated for the length of the section)

LSAC – low severity alligator cracking – total length of hairline cracks in both wheel paths (BWPs)
MSAC – medium severity alligator cracking – total length of spalled cracks in BWPs
HSAC – high severity alligator cracking – total length of spalled and pumping cracks in BWPs
LSLC – low severity longitudinal cracking – total length of <1/4 inch width cracking
MSLC – medium severity longitudinal cracking – total length of >1/4 inch width cracking
HSLC – High severity longitudinal cracking – total length of spalled cracking
LP – low severity patching – total length of chip seal patches
MP – medium severity patching – total length of blade patching
HP – high severity patching – total length of dig out patches
LSTC – low severity transverse cracking – number of <1/4 inch width cracks
MSTC – medium severity transverse cracking – number of >1/4 inch width cracks
HSTC – high severity transverse cracking – number of spalled cracks

Table 18. SR 520, I-405 to WLSP I/C – Paving, C7640 distress information.						
Distress	WMA		Percent Change	HMA		Percent Change
	2008	2013		2008	2013	
LSAC	545	0	0	2,036	0	0
MSAC	10	0	0	0	0	0
HSAC	0	0	0	0	0	0
LSLC	1,746	0	0	1,937	87	**4**
MSLC	13	0	0	0	0	0
HSLC	0	0	0	0	0	0
LP	0	0	0	0	0	0
MP	450	9	**2**	745	8	**1**
HP	0	0	0	0	0	0
LSTC	4	4	**100**	4	4	**100**
MSTC	0	0	0	1	0	0
HSTC	0	0	0	1	0	0

Conclusion – equal performance

Table 19. SR 28, Quincy Area Paving, C7645 distress information.						
Distress	WMA		Percent Change	HMA		Percent Change
	2008	2013		2008	2013	
LSAC	9,386	0	0	7,784	0	0
MSAC	6,740	0	0	2,372	0	0
HSAC	0	0	0	0	0	0
LSLC	591	16	**3**	640	52	**8**
MSLC	11	0	0	194	54	**28**
HSLC	0	0	0	0	0	0
LP	0	0	0	0	0	0
MP	0	0	0	0	0	0
HP	0	0	0	0	0	0
LSTC	141	387	**>100**	69	168	**>100**
MSTC	463	0	0	210	1	0
HSTC	2	0	0	0	0	0

Conclusion – WMA slightly better performance

Table 20. I-5, 52nd Ave W to SR 526 NB Paving, C7669 distress information.

Distress	WMA		Percent Change	HMA		Percent Change
	2008	2013		2008	2013	
LSAC	1,316	0	0	6,297	0	0
MSAC	0	0	0	41	0	0
HSAC	0	0	0	0	0	0
LSLC	1,116	0	0	6,346	10	**1**
MSLC	0	80	**>100**	27	61	**>100**
HSLC	0	0	0	0	0	0
LP	0	0	0	0	0	0
MP	0	0	0	12	0	0
HP	0	0	0	0	0	0
LSTC	10	0	0	98	1	**1**
MSTC	1	0	0	14	0	0
HSTC	0	0	0	0	0	0

Conclusion – equal performance

Table 21. SR 101, SR 6 to Grays Harbor Co. Line - Paving, C7748 distress information.

Distress	WMA		Percent Change	HMA		Percent Change
	2008	2013		2008	2013	
LSAC	41	0	0	1,085	14	**1**
MSAC	0	0	0	97	0	0
HSAC	0	0	0	77	0	0
LSLC	129	45	**35**	548	269	**49**
MSLC	0	0	0	107	0	0
HSLC	0	0	0	2	0	0
LP	0	0	0	3,243	0	0
MP	54	33	**61**	4,809	764	**16**
HP	0	0	0	0	0	0
LSTC	12	7	**58**	48	22	**46**
MSTC	3	0	0	7	1	**14**
HSTC	1	0	0	3	0	0

Conclusion – WMA slightly better performance

Table 22. SR 12, Naches to Mitchell Vic. Paving, C7755 distress information.

Distress	WMA		Percent Change	HMA		Percent Change
	2009	2013		2009	2013	
LSAC	17,139	0	0	222	0	0
MSAC	823	0	0	1,940	0	0
HSAC	0	0	0	1,436	0	0
LSLC	7,524	519	**7**	2,174	72	**3**
MSLC	124	22	**18**	15,246	0	0
HSLC	0	0	0	1,278	0	0
LP	0	0	0	0	0	0
MP	0	0	0	0	0	0
HP	0	0	0	0	0	0
LSTC	534	312	**58**	336	180	**54**
MSTC	2	99	**>100**	88	20	**23**
HSTC	0	0	0	3	0	0

Conclusion – HMA slightly better performance

If the pavement condition results are combined from the I-90 project and these five additional projects, the results show two projects with equal performance, WMA slightly better on two projects and HMA slightly better on two projects. These results are tempered by the caveat that these performance comparisons are for pavements that are between two and five years in age.

Discussion of Results

The I-90 George project data showed equal performance between the WMA and HMA sections for friction resistance, rutting/wear and ride. A slight edge in performance goes to the HMA section with respect to reflective transverse cracking, however, this is tempered with the short-term nature of the data. The results from the WSU report indicated mixed results on the four projects with neither the WMA nor the HMA sections having an edge on performance. Finally, the examination of the additional WSDOT projects showed mixed results with no edge in performance for either WMA or HMA sections.

Conclusions

The WMA technologies examined in this and other studies neither improved nor worsened the performance of a pavement as compared to a pavement built with conventional HMA construction processes.

WMA Implementation

The recommendations from the post-construction report are noted below. All of these have been followed and accomplished with the result that warm mix technologies were tried on a large number of HMA projects. After an initial experimentation with various WMA processes, the water forming technologies have been the dominant choice by most contractors to produce warm mix (WSDOT Technote, 2012).

- Assess the long term performance of WMA in different areas of the state. *Results are presented in this report indicating no long term gain or loss from the use of WMA technologies.*
- Evaluate other WMA technologies. *Evotherm was used on one project, but water foaming technologies have been the choice of most Contractors.*
- Develop and refine specifications for WMA. *Current specifications allow the substitution of WMA for HMA. Specifications do not require the use of WMA.*
- Investigate the use of higher percentages of recycled asphalt pavement (RAP) in WMA. *The General Special Provisions prohibit the use of WMA technologies when the RAP percentage exceeds 20 percent or when any percentage of recycled asphalt shingles (RAS) is used.* (WSDOT GSP, 2014*).*
- Investigate the formation of clumps in the WMA. Both fractionating the RAP to prevent clumping and better remixing should be looked into to see if these solve the clumping problem. *This problem has not occurred on other project.*
- Include provisions to allow substitution of WMA in place of HMA in future editions of the Standard Specifications (WSDOT is currently working toward incorporating this in the 2010 edition). *The 2010 Standard Specifications allowed the use of WMA processes. The Contractor is required to receive approval from the Engineer for the process and how it will be used in his operation.*

- The actual use of WMA has decreased greatly in recent years due to Contractors using higher percentages of RAP (>20%) in their mix designs. WSDOT General Special Provisions do not allow the use of WMA when the percentage of RAP exceeds 20 percent or when any percentage recycled asphalt shingles (RAS) are incorporated (WSDOT 2014).

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Appendix A

Work Plan

Washington State Department of Transportation

WORK PLAN

Warm Mix Asphalt

State Route 90
West of George Paving
Milepost 137.82 to Milepost 148.45

Mark A. Russell
Pavement Research and New Technology Engineer
Washington State Department of Transportation

Introduction

Several new technologies are available that reduce asphalt plant emissions and energy consumption by allowing the production and placement of asphalt paving mixtures at lower temperatures. These lower temperature asphalt paving mixtures are designated Warm Mix Asphalt (WMA) and are produced at temperatures of 250°F or less, which is much lower than the production temperatures of near 300°F typically seen in hot mix asphalt in North America (1). WMA technologies work by reducing binder viscosity at mixing and placement temperatures. Advantages of WMA have been reported to include:

- Reduced mixing temperatures reduce fuel consumption thereby lowering plant emissions and reducing energy costs.
- Decreased binder viscosity at compaction temperatures means less effort is needed to compact the mix.
- Lower mixing temperatures may reduce aging of the binder leading to increased fatigue life.
- Lower temperatures improve working conditions for paving crews through decreased smoke and odors.
- Compaction can be achieved at lower temperatures allowing paving during cooler weather or on projects with long haul times.
- Higher percentages of reclaimed asphalt paving (RAP) can be used in WMA thus reducing the need to produce additional aggregate and binder.

Reduction of the binder viscosity is accomplished either by introducing water into the mixture or by the use of an organic additive or wax. Water introduced into the mixture either directly or by adding hydrophilic material to the mix will cause the binder to expand leading to a decrease in its viscosity. Organic waxes added to a binder will reduce the viscosity above the melting point of the wax (2).

This experimental feature incorporates an organic wax made by Sasol Wax and marketed as Sasobit® to produce the WMA. Sasobit® is a Fischer-Tropsch organic wax produced during coal gasification. It is capable of reducing working temperatures of an asphalt mixture by 32 to 97°F and can be used as a modifier to the binder or added directly to the asphalt mixture (3). Sasobit® will be incorporated into the mix either directly or in the form of Sasoflex® a combination of Sasobit® and an SBS polymer.

Plan of Study

The objective of this experimental feature is to evaluate the long and short term performance of the WMA produced with Sasobit®. The overlay will be monitored for a period of five years using conventional survey techniques that will consist of friction measurements, rutting and ride measurements, and overall pavement condition assessment. Special emphasis will be placed on the overlays ability to resist cracking and rutting.

Scope

This project removes 0.25 feet of the existing HMA from the outside lane of eastbound Interstate 90 and replaces it with 0.25 feet of WMA. Approximately 5,000 tons of WMA will be placed. The WMA will incorporate RAP at the same percentage as used in the hot mix asphalt.

Control Section

Approximately 9,000 tons of HMA will be placed in the eastbound outside lane of Interstate 90 immediately west of the WMA section.

Staffing

This research project will be constructed as a North Central Region programmed rehabilitation project. Therefore the Region Project office will coordinate and manage all construction aspects. Representatives from and WSDOT Materials Laboratory (1 – 3 people) and the North Central Region Materials Laboratory (1 - 2 people) will also be involved with the process.

<u>Contact and Report Author</u>

Mark A. Russell
Pavement Research and New Technology Engineer
Washington State DOT
(360) 709-5479
FAX (360) 709-5588
russelm@wsdot.wa.gov

Testing

All testing will be in accordance with current WSDOT tests for material acceptance (density, gradation, asphalt content, etc.) and will be conducted by the Region Project Office.

Reporting

An "End of Construction" will be written following completion of the test section. This report will include construction details, construction test results, and other details concerning the overall process. Annual summaries will also be conducted over the next five years. At the end of the five-year period, a final report will be written which summarizes performance characteristics and future recommendations for use of this process.

Cost Estimate

CONSTRUCTION COSTS

WMA is estimated to cost $2.35 per ton more than HMA. The total added cost for placing the WMA is estimated at $11,750 (5,000 tons x $2.35 / ton = $11,750). This project will be constructed as a Region pavement preservation (P1 program) project.

TESTING COSTS

- Field-testing will be conducted as part of the Region overlay project
- Condition Survey, friction, rutting and ride – will be conducted as part of statewide annual survey
- Friction: One full day at $105/hr., six times over the 5 year evaluation period, ($105 x 8 x 6 = 5,040).

REPORT WRITING COSTS

Initial Report – 60 hours = $4,800
Annual Report – 20 hours (4 hours each) = $1,600
Final Report – 100 hours = $8,000

Report Writing Cost: $14,400

Total Evaluation Cost: $19,440

Schedule

Project Ad. Date – September 24, 2007
Construction – June 2008

Date	Condition Survey (Annual)	Friction Measurement	End of Construction Report	Annual Report	Final Report
Fall 2007	X				
Fall 2008	X	X	X		
Fall 2009	X	X		X	
Fall 2010	X	X		X	
Fall 2011	X	X		X	
Fall 2012	X	X		X	
Fall 2013	X	X		X	
Spring 2014					X

References

(1) Hurley, Graham C. and Brian Prowell. “Evaluation of Sasobit® for Use in Warm Mix Asphalt”, NCAT Report 05-06, National Center for Asphalt Technology, Auburn University, (pp. 1), 2005.

(2) D’Angelo, John, Eric Harm, John Bartoszek, Gaylon Baumgardner, Matthew Corrigan, Jack Cowsert, Thomas Harman, Mostafa Jamshidi, Wayne Jones, Dave Newcomb, Brian Prowell, Ron Sines, and Bruce Yeaton, “Warm-Mix Asphalt: European Practice”, Federal Highway Administration, Washington DC, February 2008.

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Appendix B

Binder Grade Testing

Table 23. Binder grade testing results.

Sasobit Percent	Brookfield Viscosity @ 135 C	Original DSR	Elastic Recovery	RTFO DSR	PAV DSR	BBR “S”	BBR ”m”	True Grade
0	1.35	1.21	78.8	2.870	562	222	0.336	78-28
1.5	1.20	1.38	72.5	3.27	711	268	0.304	80-28
2.0	1.14	2.09	67.5	4.100	824	265	0.304	83-28

Appendix C

Mix Designs

Washington State Department of Transportation - Materials Laboratory
PO Box 47365 Olympia / 1655 2nd Ave. Tumwater / WA 98504
BITUMINOUS SECTION MIX DESIGN VERIFICATION REPORT

HMA CLASS:	1/2"	WORK ORDER NO:	007419
DATE SAMPLED:	3/19/2008	LAB ID NO:	0000225192
DATE RECV'D:	3/24/2008	TRANSMITTAL NO:	512862
SR NO:	I-90	MIX ID NO:	G82068
SECTION:	WEST OF GEORGE PAVING	CONTRACTOR:	C.W.A.

VALID FOR 2008

CONTRACTOR'S MIX DESIGN TEST DATA

						Specifications
Pb		5.0	5.5	6.0		
% Gmm @ Nini:	8	84.3	85.5	87.1	≤	89.0
% Va @ Ndes:	100	5.8	4.2	2.4	Approximate	4.0
% VMA @ Ndes:	100	15.5	15.4	15.3	≥	14.0
% VFA @ Ndes:	100	63	73	85		65 - 75
% Gmm @ Nmax:	160		97.3		≤	98.0
D/A		1.5	1.3	1.2		0.6 - 1.6
Pbe		4.1	4.7	5.4		
Gmm		2.604	2.578	2.545		
Gmb		2.454	2.469	2.485		
Gb		1.033	1.033	1.033		
Gse		2.831	2.833	2.807		

CONTRACT 7419 ONLY

STATE MATERIALS LABORATORY VERIFICATION TEST DATA

						Specifications	Tolerance ± 0.5%
Pb		5.0	5.5	6.0			
% Gmm @ Nini:	8	85.2	86.4	87.8	≤	89.0	
% Va @ Ndes:	100	5.2	3.7	2.1	Approximate	4.0	2.5 - 5.5
% VMA @ Ndes:	100	15.0	14.9	14.7	≥	14.0	≥12.5
% VFA @ Ndes:	100	66	75	86		65 - 75	
% Gmm @ Nmax:	160		97.7		≤	98.0	
D/A		1.5	1.4	1.2		0.6 - 1.6	
Pbe		4.2	4.7	5.2			
Gmm		2.600	2.577	2.554			
Gmb		2.465	2.482	2.501			
Gb		1.033	1.033	1.033			
Gse		2.825	2.823	2.819			

VERIFIED

STRIPPING EVALUATION

% Anti-Strip:	0.0%	0.25%	0.50%	0.75%	1.0%
Visual Appearance:	NONE	NONE	NONE	NONE	NONE
% Retained Strength:	99	100	100	101	101

STATISTICAL

STATE MATERIALS LABORATORY RECOMMENDATIONS

Asphalt Binder Supplier	SEM	Remarks:
Asphalt Binder Grade	PG76-28	Verification of Volumetric Properites determined by SGC internal angle.
Percent Binder (Pb) (By Wt. Total Mix)	5.5	
% Anti-Strip (By Wt. Asphalt Binder)	0.00%	
Type of Anti-Strip		
Mix ID Number	G82068	
Sample Wt. (grams)	4885	(Informational Only)
Sample Height @ Ndes	115.0	(Informational Only)
Ignition Calibration Factor	0.53	(Informational Only)
Optimum Mixing Temperature	343°F	
Compaction Temperature	319°F	
Rice Density (lbs/ft^3)	160.4	

Page 1 of 2

Washington State Department of Transportation - Materials Laboratory
PO Box 47365 Olympia / 1655 2nd Ave. Tumwater / WA 98504
BITUMINOUS SECTION MIX DESIGN VERIFICATION REPORT

TEST OF: AGGREGATE PROPERTIES FOR HMA CLASS: 1/2" — WORK ORDER NO: 007419
LAB ID NO: 0000225192 — MIX ID NO: G82068

-----CONTRACTOR'S DESIGN AGGREGATE STRUCTURE AND AGGREGATE TEST DATA-----

			Combined	Specifications	Tolerance
Material:	3/4'-#4	3/8"-0			
Source:	GT-318	GT-318			
Ratio:	27%	73%			
1 1/2" square					
1" square					
3/4" square	100.0	100.0	100	100	99 - 100
1/2" square	80.0	100.0	95	90 - 100	90 - 100
3/8" square	42.0	100.0	84	MAX 90	78 - 90
U.S. No. 4	2.0	75.0	55		50 - 60
U.S. No. 8	1.0	46.0	34	28 - 58	30 - 38
U.S. No. 16	1.0	30.0	22		
U.S. No. 30	1.0	20.0	15		
U.S. No. 50	1.0	15.0	11		
U.S. No. 100	1.0	11.0	8		
U.S. No. 200	1.0	8.2	6.3	2.0 - 7.0	4.3 - 7.0

Gsb Coarse	2.781	2.763			
Gsb Fine		2.746			
Gsb Blend	2.781	2.750	2.758		
Sand Equivalent			79	45 MIN.	
Uncompacted Voids (FAA)			49	44% MIN.	
Course Agg Frac					
U.S. No. 4			99	90% Double	Face Fracture

-----STATE MATERIALS LABORATORY AGGREGATE TEST DATA-----

Gsb Coarse	2.788	2.767			
Gsb Fine		2.737	2.737		
Gsb Blend	2.788	2.744	2.756		
Sand Equivalent		82	82	45 MIN.	
Uncompacted Voids (FAA)			49	44% MIN.	
Course Agg Frac					
U.S. No. 4	99	98	99	90% Double	Face Fracture

-----COMMENTS-----

Remarks:
Verification of Volumetric Properties determined by SGC internal angle.

Environmental & Engineering Programs:		T152 -	3	THOMAS E. BAKER P.E.
Construction Engineer	X	T153 -		Materials Engineer
Accounting Section	X	T166 -	3	By: Joseph R. DeVol
General File	X	T172 -		Bituminous Materials Engineer
Bituminous Materials Section	X	T175 -		(360) 709-5421
Region: NORTH CENTRAL		T178-	1	Date: 4 / 17 / 2008
Construction Office--42	X			
Materials Engineer---42	X			
P.E.: M. FLEMING	X(2)			

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Page 2 of 2

Appendix D

Mix Testing Results

Table 24. HMA mix testing results.

Test Property	Spec.	JMF	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9
3/4	99-100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/2	90-100	95.0	96.0	96.0	94.0	93.0	94.0	92.0	91.0	95.0	93.0
3/8	78-90	84.0	86.0	87.0	86.0	81.0	83.0	78.0	80.0	83.0	84.0
No. 4	51-61	56.0	56.0	59.0	57.0	55.0	54.0	51.0	51.0	52.0	52.0
No. 8	31-39	35.0	36.0	37.0	36.0	35.0	34.0	32.0	32.0	33.0	33.0
No. 16		22.0	23.0	24.0	23.0	23.0	21.0	21.0	21.0	22.0	21.0
No. 30		15.0	16.0	16.0	16.0	16.0	15.0	14.0	15.0	15.0	15.0
No. 50		11.0	12.0	12.0	12.0	12.0	11.0	10.0	11.0	12.0	11.0
No. 100		8.0	9.0	9.0	9.0	9.0	8.0	8.0	9.0	9.0	8.0
No. 200	4.3-7.0	6.3	6.6	6.6	6.2	6.5	6.3	5.7	6.6	6.9	5.8
% Binder	4.7-5.7	5.2	5.3	5.5	5.1	4.9	5.0	5.0	5.2	4.9	5.0
% Va	2.5-5.5	3.7	3.4	5.4	**5.7**	4.2	4.9	**5.7**	4.3	5.0	5.2
VMA	>12.5	14.9	14.0	15.9	15.2	14.3	14.7	15.3	14.3	14.5	14.9
VFA		75.0	75.7	66.0	**62.5**	70.6	66.7	**62.7**	69.9	65.5	65.1
D/A	0.6-1.6	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.6	**1.7**	1.4
Gmb		2.482	2.502	2.454	2.464	2.484	2.474	2.456	2.490	2.477	2.468
Gmm		2.577	2.591	2.594	2.613	2.592	2.601	2.604	2.602	2.608	2.603
Gsb		2.756	2.756	2.756	2.756	2.756	2.756	2.756	2.756	2.756	2.756
Gb		1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033

Table 25. WMA mix testing results.							
Test Property	**Spec.**	**JMF**	**Lot 1**	**Lot 2**	**Lot 3**	**Lot 4**	**Lot 5**
3/4	99-100	100.0	100.0	100.0	100.0	100.0	100.0
1/2	90-100	95.0	95.0	92.0	95.0	97.0	97.0
3/8	78-90	84.0	85.0	81.0	84.0	88.0	87.0
No. 4	51-61	56.0	56.0	52.0	54.0	58.0	56.0
No. 8	31-39	35.0	36.0	33.0	34.0	36.0	36.0
No. 16		22.0	23.0	21.0	22.0	23.0	23.0
No. 30		15.0	16.0	15.0	16.0	16.0	16.0
No. 50		11.0	12.0	11.0	12.0	12.0	13.0
No. 100		8.0	9.0	8.0	9.0	9.0	10.0
No. 200	4.3-7.0	6.3	6.9	6.2	6.9	6.7	6.8
% Binder	4.7-5.7	5.2	5.3	5.3	5.0	5.7	5.6
% Va	2.5-5.5	3.7	4.7	5.0	5.2	3.7	4.0
VMA	>12.5	14.9	14.8	15.1	14.9	14.7	14.2
VFA		75.0	68.2	66.9	65.1	74.8	71.8
D/A	0.6-1.6	1.4	1.6	1.5	**1.7**	1.5	1.6
Gmb		2.482	2.479	2.472	2.468	2.494	2.504
Gmm		2.577	2.602	2.601	2.603	2.590	2.608
Gsb		2.756	2.756	2.756	2.756	2.756	2.756
Gb		1.033	1.033	1.033	1.033	1.033	1.033

Appendix E

Density Test Results

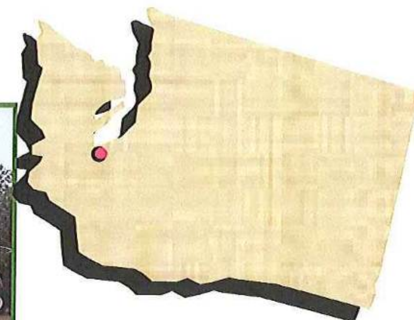
Table 26. HMA density test results.						
Lot Number	**Date Tested**	**Test #1**	**Test #2**	**Test #3**	**Test #4**	**Test #5**
1	6/9	92.0	93.5	95.6	93.3	97.4
2	6/9	94.6	94.8	96.2	92.8	94.4
3	6/11	92.8	95.2	92.6	92.0	92.7
4	6/11	96.0	93.6	95.6	94.7	93.2
5	6/11	94.8	92.2	93.1	94.8	93.4
6	6/11	95.3	95.3	94.5	90.4	94.7
7	6/11	94.6	95.7	94.3	91.7	94.1
8	6/11	94.1	92.2	94.2	93.4	92.8
9	6/11	94.6	90.5	92.8	95.4	93.0
10	6/11	94.3	96.4	94.1	92.8	92.8
11	6/12	92.4	92.1	92.8	95.2	94.5
12	6/12	94.2	93.8	92.0	94.3	92.0
13	6/12	92.7	94.0	92.0	93.1	91.9
14	6/12	95.3	93.9	94.3	93.6	93.0
15-C	6/12	96.3	92.1	91.6	90.7	91.8
16	6/12	92.8	90.9	94.7	91.0	95.2
17	6/16	92.0	90.9	93.6	93.2	96.1
18	6/16	91.2	96.5	96.0	93.8	93.6
19	6/13	92.9	93.0	96.7	92.7	90.7

Table 27. WMA density test results.						
Lot Number	**Date Tested**	**Test #1**	**Test #2**	**Test #3**	**Test #4**	**Test #5**
1	6/23	92.8	94.1	91.5	92.2	96.0
2	6/23	93.5	92.3	94.4	94.3	93.0
3	6/23	95.4	95.1	94.0	92.7	95.6
4	6/23	91.2	93.0	91.5	93.1	94.4
5	6/23	93.4	93.8	91.3	94.3	94.6
6	6/23	94.4	94.4	93.3	92.5	94.5
7	6/24	94.6	93.0	94.7	93.2	95.9
8	6/24	93.3	92.2	92.6	93.5	94.3
9	6/24	96.2	95.6	93.8	94.5	94.9
10	6/24	92.2	92.1	96.4	93.0	92.8
11	6/24	92.3	95.1	93.8	94.4	90.6

Appendix F

FHWA – Warm Mix Asphalt Testing Report

Federal Highway Administration
Office of Pavement Technology



Warm Mix Asphalt Testing Report

Interstate 90, near George, WA

WMA

Federal Highway Administration
Office of Pavement Technology
1200 New Jersey Ave., S.E.
Washington, D.C. 20590

Long Life Asphalt Pavements for the 21st Century

Mobile Asphalt Testing Laboratory

Prepared by the Program Manager
Matthew Corrigan (202) 366-1549

In conjunction with
Mr. Chuck Paugh
Mr. Satish Belagutti
And laboratory technicians;
Donald Petty, Bradford Tschetter, David Heidler, and Darnel Jackson

Federal Highway Administration, Office of Pavement Technology
1200 New Jersey Ave, SE, Washington, DC 20590

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Background

The Washington State DOT (WSDOT) requested the assistance of the FHWA, Office of Pavement Technology's mobile asphalt testing laboratory (MATL) program during construction of a pavement section on I-90 with Warm Mix Asphalt (WMA) technology. Jerry Roseburg, WSDOT, North Central Region Materials Engineer, provided samples of the control and warm asphalt mixtures taken during construction. Two mixes were tested and evaluated.

1. Hot Mix Asphalt control mix
    a. 12.5 mm mix produced with PG 76-28 binder and 20% RAP.
2. Warm Mix Asphalt
    a. 12.5 mm mix produced with PG 76-28 with 2% Sasobit and 20% RAP.

The laboratory mix designs for the HMA control and WMA mixes are in included in Appendix A.

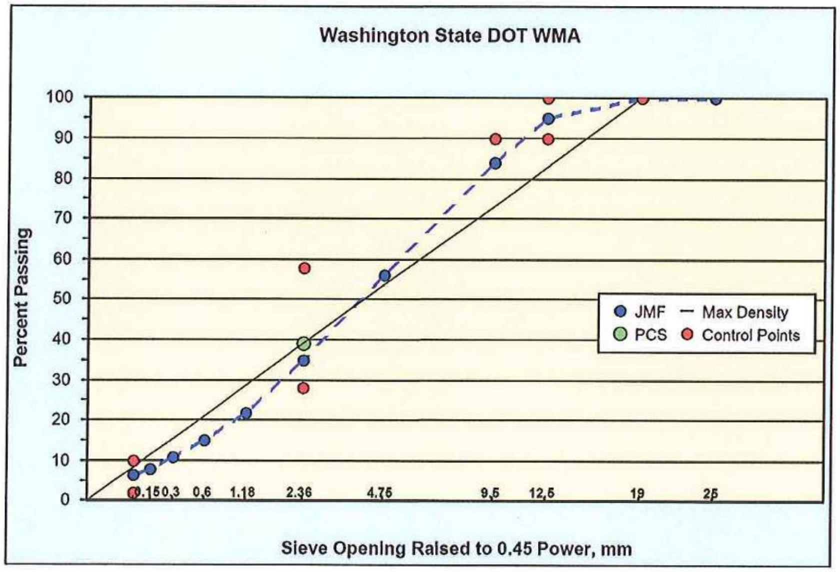


Figure 1: .45 power chart Warm Mix/Control JMF

Figure 1 plots the target mix design gradation for both the warm mix and control mix.

The Sasobit® WMA additive was the additive used on this project. Sasobit is a Fischer-Tropsch paraffin wax produced from either coal gasification or from processing natural gas.

- 1 -

Objective

The testing conducted by the MATL included the dynamic modulus, flow number, maximum theoretical specific gravity of un-compacted mixes, and bulk specific gravity of compacted mixes. The Hamburg wheel-track testing was conducted with equipment located at Turner-Fairbank Highway Research Center, McLean, VA by the MATL project lab staff.

Procedure

The loose un-compacted asphalt mixture samples were shipped to the MATL staff from the construction project in five gallon buckets, 10 buckets were received for each mix. Randomly selected buckets of each mix, both Control and Sasobit warm mix, were reheated to a temperature sufficient for the mixtures to be pliant enough to mix and split into test size specimens. The Superpave gyratory compactor (SGC) was used to compact specimens for the asphalt mix performance tests and the Hamburg wheel tracking tests. Hamburg test specimens were compacted to a height of 60 mm and target air voids (V_a) of 7%.

The asphalt mix performance test specimens were compacted to a target height of 185 mm and a target V_a of 8.5%, and then cored to a diameter of 100 mm by means of a conventional core drill. The cored specimen ends were then cut using a masonry table saw to provide final performance specimen dimensions of 150 mm by 100 mm diameter. The coring and sawing of the original SGC specimen is required to provide the correct height to diameter ratio and a uniform distribution throughout the performance test specimens. The resulting performance test specimen V_a is targeted at 7%.

- Test specimens were manufactured for :
    - Theoretical Maximum Specific Gravity (G_{mm}), AASHTO T 209
    - Performance test specimens at 7% air voids
        - Dynamic Modulus (|E*|); Flow Number (Fn)
    - Hamburg Wheel-Track testing, AASHTO T 324

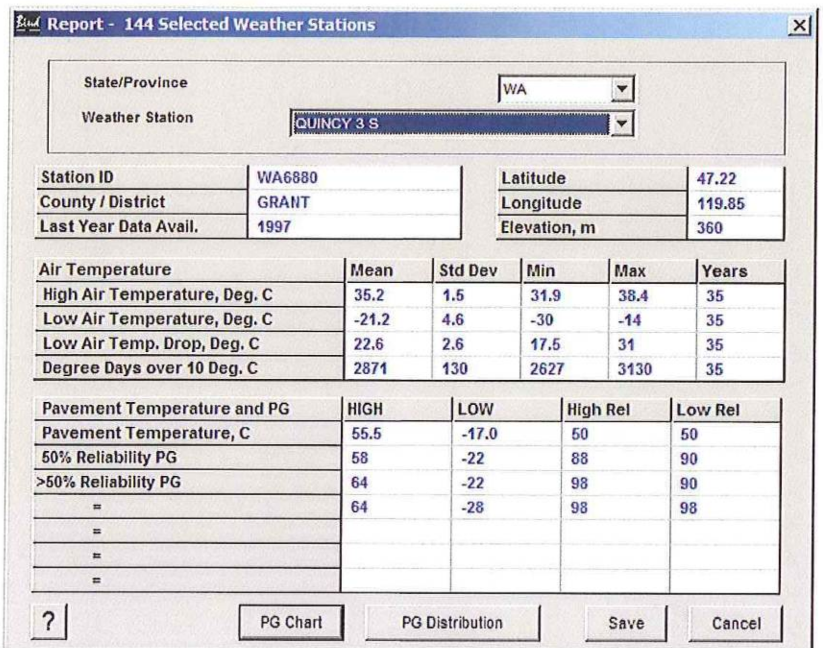
Table 1: Performance Test Matrix

	|E*| - Dynamic Modulus					Fn - Flow Number
	4.4° C	21.1° C	37.8° C	54.4° C	Frequencies	58° C
Control Mix test specimens	4 Specimens			4 Specimens	0.1, 0.5, 1, 5, 10, 25 Hz	4 Specimens
Sasobit Mix test specimens	4 Specimens			4 Specimens		4 Specimens

Dynamic Modulus testing was conducted using the IPC-Global Asphalt Mixture Performance Test (AMPT) device, formerly called the Simple Performance Test (SPT).

The test device applies cyclical loading to obtain a resulting target of 100 micro-strains for 10 cycles at various selected frequencies and temperatures. Each specimen was tested at the range of frequencies and temperatures listed in test matrix summarized in Table 1. These temperature and frequencies were selected based on the guidance provided by the National Cooperative Highway Research Program (NCHRP). These values can then be used as direct inputs into the Mechanistic Empirical Pavement Design Guide (MEPDG) and also used to develop mixture E* master curves to predict values for other temperatures.

The lab compacted specimen bulk specific gravities (G_{mb}) are provided in Appendix B. A duplicate set of four specimens were fabricated and tested at 54° C as a check to ensure that the dynamic modulus values are not influenced by any induced permanent strain which may develop (dependent on mixture behavior) from testing at 37.8° C.


Report - 144 Selected Weather Stations

State/Province: WA

Weather Station: QUINCY 3 S

Station ID	WA6880	Latitude	47.22
County / District	GRANT	Longitude	119.85
Last Year Data Avail.	1997	Elevation, m	360

Air Temperature	Mean	Std Dev	Min	Max	Years
High Air Temperature, Deg. C	35.2	1.5	31.9	38.4	35
Low Air Temperature, Deg. C	-21.2	4.6	-30	-14	35
Low Air Temp. Drop, Deg. C	22.6	2.6	17.5	31	35
Degree Days over 10 Deg. C	2871	130	2627	3130	35

Pavement Temperature and PG	HIGH	LOW	High Rel	Low Rel
Pavement Temperature, C	55.5	-17.0	50	50
50% Reliability PG	58	-22	88	90
>50% Reliability PG	64	-22	98	90
=	64	-28	98	98
=				
=				
=				

? PG Chart PG Distribution Save Cancel

Figure 2: Weather station data from LTPPBind, version 3.1.

The flow number test is a repeated load or dynamic creep test which is used as an indicator of rutting potential. A single load cycle applied includes loading for 0.1 seconds and then unloaded for a rest period of 0.9 seconds. A loading of 689 kPa (100 psi), and a confining stress of 69 kPa (10 psi) was used for testing until either 10,000 load cycles or 5% permanent strain is reached, whichever occurs first and the flow number is then determined. The flow number is defined in NCHRP Report 513, TRB (2003) as the number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated load test.

The test temperature was determined from the LTTPBind, version 3.1 software using the nearest weather station data available for the I-90 project in George, WA. The temperature selected was the 50% reliability pavement temperature of 58° C. Figure 2 displays the LTPPBind software results.

Results

Dynamic Modulus

The dynamic modulus testing results are summarized in Appendix C. Figure 3 compares the average dynamic modulus values for each mix at the selected test temperatures and frequencies applied to the test specimens.

As expected, the Sasobit WMA additive had a stiffening effect on the asphalt mixture compared to the HMA control mix. This stiffening effect by the Sasobit additive has been observed in other WMA project testing by MATL staff as well as other research.

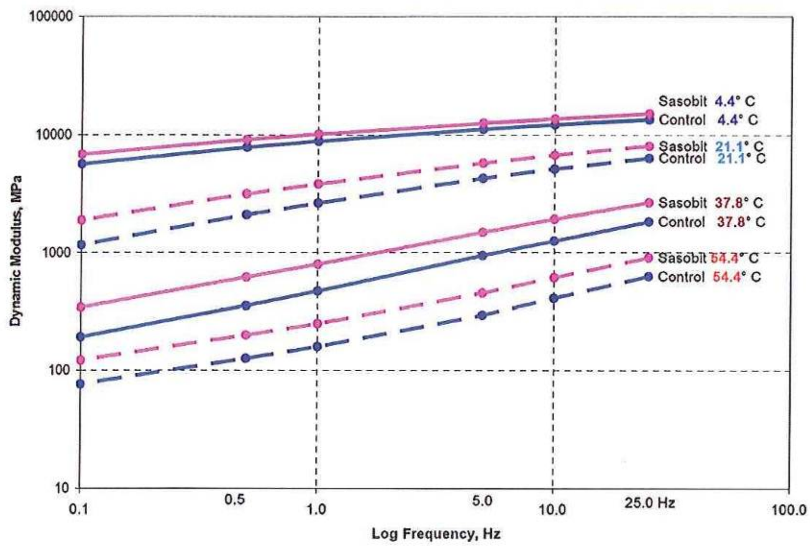


Figure 3: Dynamic Modulus, |E*|

Although the Sasobit effect on both the high and low temperature performance grade of the binder is highly dependent on each binder source. MATL experience generally shows a one grade increase in the high temperature binder performance grade when using the typically recommended rate of 1.5 percent by weight of binder. These project mixtures utilized a PG 76-xx base binder for the control, would be expected to stiffen to a PG 82-xx grade. Asphalt binder performance grading should be performed to verify the effect of the Sasobit additive on the specific binder used

Flow Number

The flow number tests indicated a trend similar to that evidenced in the dynamic modulus testing. The mixture with the Sasobit additive appears to be slightly stiffer than the control mix as indicated by the larger flow number values. Figure 4 depicts the flow number values for the control mix as well as the WMA, labeled as Sasobit. Additional data is plotted and labeled as Francken, which presents the data using a curve fitting model referred to as the Francken model[1]. This curve fitting appears to reduce variability of the flow number values compared to the current polynomial model fitting approach.

The IPC software allows the user to select the cycle sampling interval (1 - 20) used to determine the flow number value. The parameter controls the rate of sample processing and can assist in smoothing the strain rate curve. The initial portion of the strain rate curve typically represents specimen consolidation during testing and is represented by a negative slope. Continued load applications will result in a change from a negative slope to a positive slope as the specimen approaches tertiary flow conditions. At the minimum rate of change of the strain rate curve, the flow number is determined. Many factors can influence the strain rate, including aggregate fracture, which may provide a false Fn value and can be minimized by increasing the sampling interval.

Figure 4 plots the F_n for the control and the warm mix asphalt mixtures; the flow number for the control is smaller than the Sasobit warm mixture. The higher flow number value indicates that more load cycles were applied before permanent shear deformation begins to occur under constant volume.

The accumulated strain at the flow number is plotted for the mixtures in Figure 5.

The total cycles applied during flow number testing is plotted in Figure 6. The Sasobit warm asphalt mixture withstood slightly more load repetition cycles than the control mixture before accumulating 5% strain. The Sasobit mixture likely experienced an increase in binder stiffness due to the additive.

[1] Francken, L. (1977) Pavement Deformation Law of Bituminous Road Mixes in Repeated Load Triaxial Compression. Proceedings of the Fourth International conference on the Structural Design of Asphalt Pavements, Volume I, University of Michigan, Ann Arbor, Michigan.

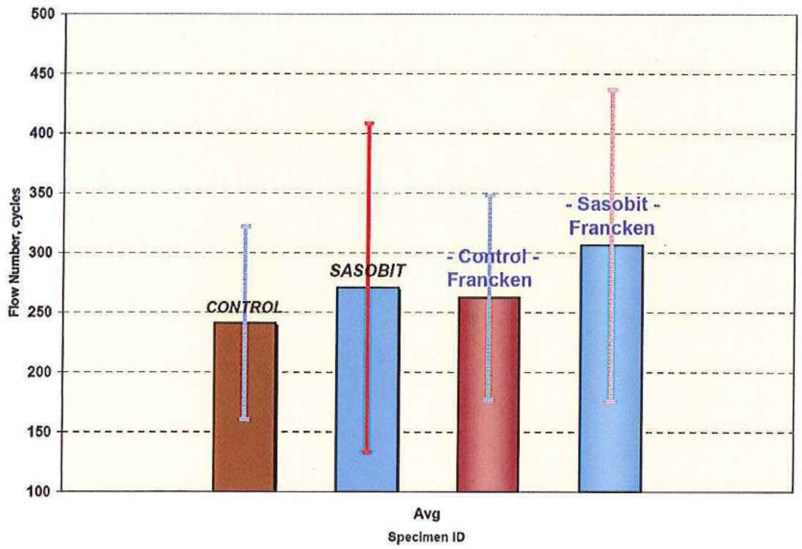


Figure 4: Flow Number, F_n

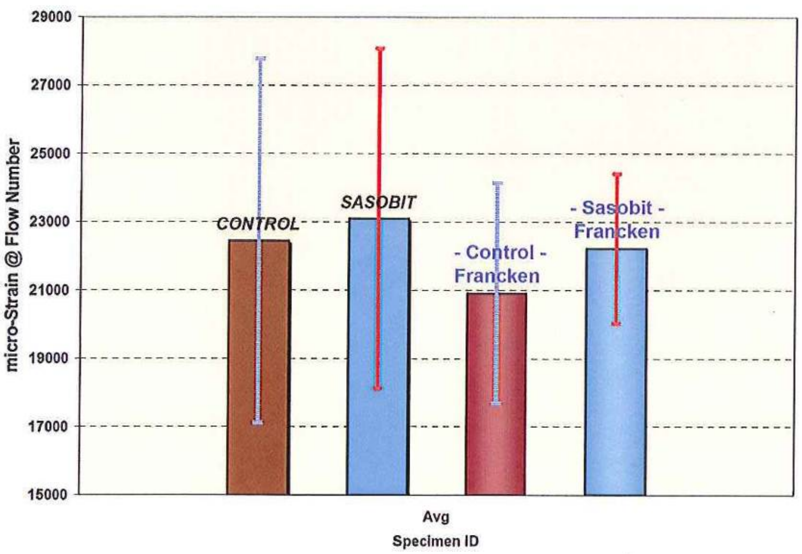


Figure 5: Accumulated Strain at Flow Number

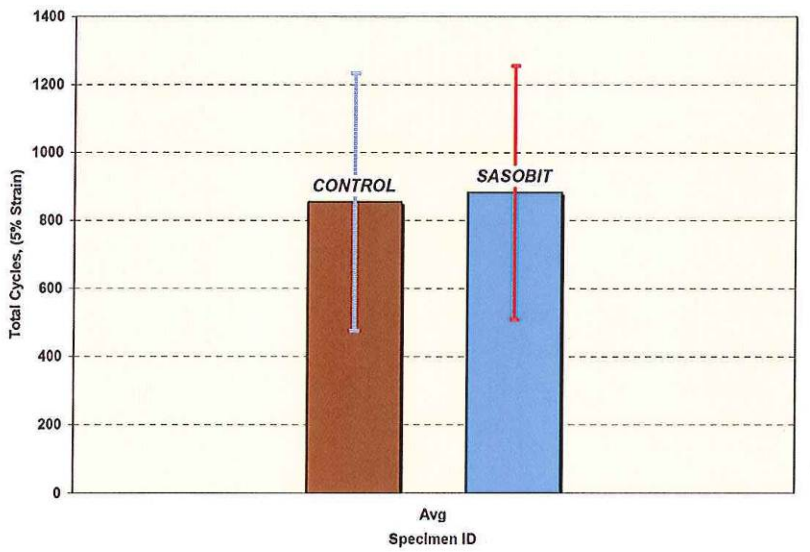


Figure 6: Total cycles at 5% Strain

Hamburg Wheel-Track Device Testing

The Hamburg wheel-track device (HWTD) has been used by the asphalt industry to determine the premature failure susceptibility of hot mix asphalt and is gaining popularity with both Agency and contractors to evaluate mixture performance. This test method is used to evaluate the effects of moisture damage and permanent deformation by applying constant cyclic loading while the samples are submerged in water at a constant temperature. The HWTD was used to evaluate the moisture susceptibility and rutting characteristics of the HMA control mixture and the WMA with Sasobit additive.

Purpose

The purpose of this evaluation is to determine the effects of moisture damage and permanent deformation of the WMA w/RAP mixes by using Hamburg Wheel-Track Device (HWTD).

Test Matrix

This study included two mixes namely the control hot mix and warm mix asphalt with Sasobit additive. The experiment included the following:

3. Hot Mix Asphalt control mix
    a. 12.5 mm mix produced with PG 76-28 binder and 20% RAP.
4. Warm mix
    a. 12.5 mm mix produced with PG 76-28 with 2% Sasobit and 20% RAP.
5. Test temperature: 50°C
6. Number of Passes: 30,000
7. Replicates: three

Hamburg Wheel Track Device (HWTD)

The Hamburg Wheel tracking device is shown in Figure 7. It is an electrically powered test device capable of moving a 203.2 mm (8 in.) diameter, 47-mm (1.85-in.) wide steel wheel back and forth across a test specimen. The load on the wheel is 705 ± 4.5 N (158 lbf ± 1.0 lbf). The wheel makes approximately 50 passes across the specimen per minute. The maximum speed of the wheel is approximately 0.305 m/s (1 ft/sec).

The HWTD has a water bath capable of controlling the temperature within ± 1.0°C (1.8°F) over a range of 25 to 70°C (77 to 158°F) and circulates the water to stabilize the temperature within the specimen tank. A gage capable of measuring the depth of the impression of the wheel within 0.01 mm (0.0004 in.), over a minimum range of 0 to 20 mm (0.8in.) is mounted on the HWTD to measure the depth at the midpoint of the wheel's path on the test specimen.

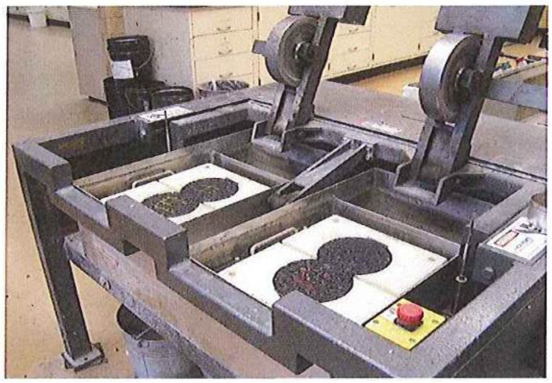
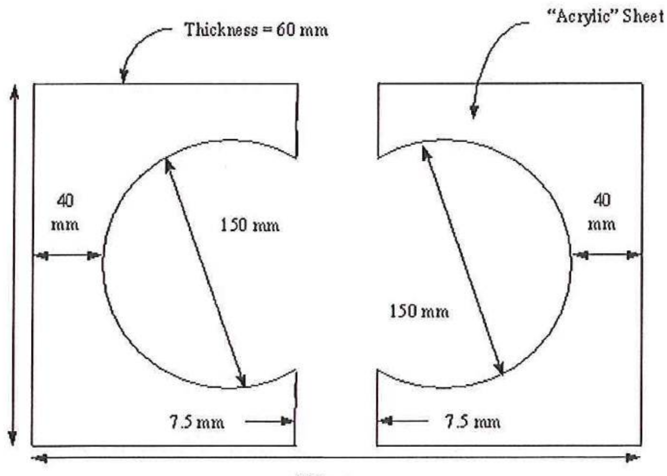


Figure 7: Hamburg Wheel Tracking Device

Sample Preparation

The test requires two SGC test specimens for each test. Six gyratory specimens were compacted in accordance with AASHTO T312 with the dimensions of 60 ± 2 mm height by 150 mm diameter for each of the control and WMA-Sasobit mixes with a 7 ± 0.5% target air void content. Volumetric properties of these specimens were measured. The test specimens were cut to the dimensions shown in Figure 8 in order to fit in the molds required for performing the wheel tracking test.



** Not drawn to scale

Figure 8: Test Specimen Configuration for the Hamburg Wheel-Tracking Device

Test Procedure

Test specimens were placed in the specimen molds and the specimen trays were mounted into the empty water bath. Then the test bath was filled with water and set at the desired test temperature. When the water bath reached the test temperature for 30 minutes, the steel wheels were lowered onto the specimens and the test was started. By default the wheel tracking device shuts off automatically when 20,000 cycles have occurred, however the maximum number of passes could be set to 40,000 passes. The device will also shutoff automatically if the average LVDT displacement is 40.9mm or greater. Three replicates tests were conducted with the control mix mounted on left side mold and Sasobit mix mounted on the right side mold of the HWTD. Each test took approximately 9 hours to complete.

Results

Figure 9 shows the Hamburg wheel tracking test results of Washington Control mix of three tests.

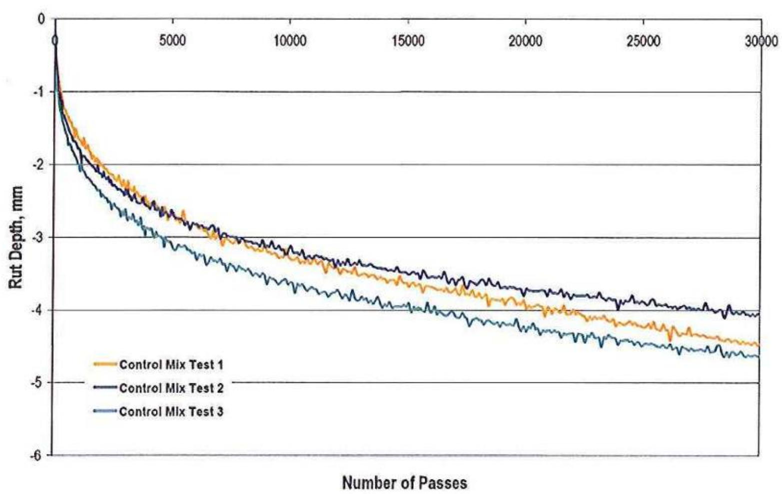


Figure 9: Hamburg Wheel Track Test Results of HMA Control Mix

Figure 10 shows the Hamburg wheel tracking test results of Washington WMA Sasobit mix of three tests. Table 2 shows the summary of Hamburg wheel track rut depths of

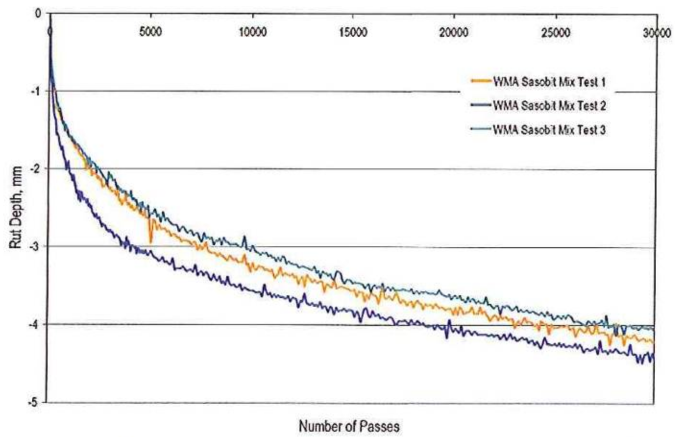


Figure 10: Hamburg Wheel Track Test Results of Washington WMA Sasobit Mix

Washington control and WMA Sasobit mixes. Rutting slopes were determined from the start of the steady-state portion of the curve and up to 20,000 passes. Hamburg Wheel Track test results of individual tests for both Control and Sasobit mixes are presented in Appendix E.

Table 2: Summary of Washington DOT Hamburg wheel track test results

	HMA Control Mix		WMA Sasobit Mix	
Replicate	Rut Depth, mm	Slope, mm/cycle	Rut Depth, mm	Slope, mm/cycle
1	4.48	-6.29E-05	4.22	-5.08E-05
2	4.05	-5.04E-05	4.44	-4.74E-05
3	4.64	-5.68E-05	4.06	-4.25E-05
Average	4.39	-5.67E-05	4.24	-4.69E-05
S.D.	0.305	0.00001	0.191	0.000004
CV	6.95	-11.02	4.50	-8.90

Both mixes exhibited similar rutting behavior. The control mix had an average rut depth of 4.39 mm with a creep slope of -5.67×10^{-05} mm/cycle and the WMA Sasobit mix had an average rut depth of 4.24 mm with a creep slope of -4.69×10^{-5} mm/cycle. The mixes did not show stripping based on the following three observations:

1. Both Control mix and WMA Sasobit displayed no visual stripping
2. Fines were not seen in the water bath after the test
3. Hamburg wheel track test results do not show inflection point leading to a stripping slope.

Figure 11 shows the comparison of Hamburg wheel tracking average test results of Washington control and WMA Sasobit mixes.

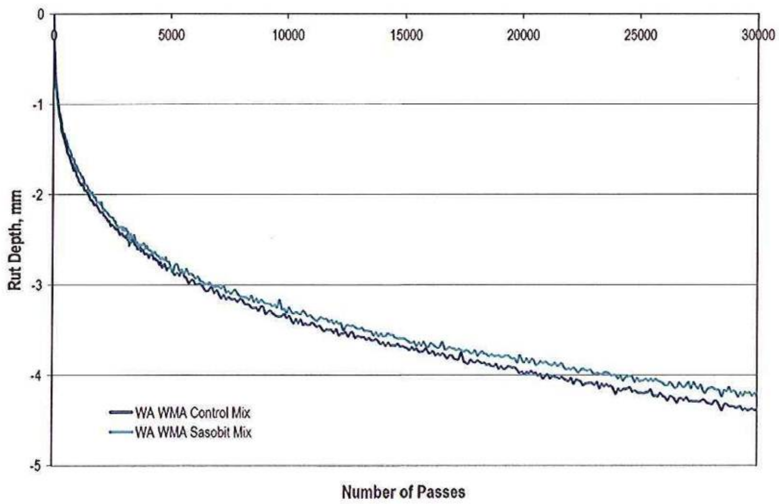


Figure 11: Comparison of Hamburg results of Control and WMA Sasobit Mixes

Findings

The average difference in rut depth of control and Sasobit mix was not significant compared to the standard deviation for both mixes. Typically a rut depth less than 10mm for a mix from Hamburg Wheel track testing is considered to have good resistance to permanent deformation. Based on the Hamburg WTD test results and visual observations both control and WMA Sasobit mixes showed very good resistance to permanent deformation. There were no stripping inflection points as the curves did not show two distinct steady-state portions for both mixes which indicates that both mixes have good resistance to stripping and moisture damage.

Appendix A
Control and Warm Mix Asphalt Designs

Washington State Department of Transportation - Materials Laboratory
PO Box 47365 Olympia / 1655 2nd Ave. Tumwater / WA 98504

BITUMINOUS SECTION MIX DESIGN VERIFICATION REPORT

HMA CLASS:	1/2"	WORK ORDER NO:	007419
DATE SAMPLED:	3/19/2008	LAB ID NO:	0000225192
DATE RECV'D:	3/24/2008	TRANSMITTAL NO:	512862
SR NO:	I-90	MIX ID NO:	G82068
SECTION:	WEST OF GEORGE PAVING	CONTRACTOR:	C.W.A.

VALID FOR 2008

CONTRACTOR'S MIX DESIGN TEST DATA

						Specifications
Pb		5.0	5.5	6.0		
% Gmm @ Nini:	8	84.3	85.5	87.1	≤	89.0
% Va @ Ndes:	100	5.8	4.2	2.4	Approximate	4.0
% VMA @ Ndes:	100	15.5	15.4	15.3	≥	14.0
% VFA @ Ndes:	100	63	73	85		65 - 75
% Gmm @ Nmax:	160		97.3		≤	98.0
D/A		1.5	1.3	1.2		0.6 - 1.6
Pbe		4.1	4.7	5.4		
Gmm		2.604	2.578	2.545		
Gmb		2.454	2.469	2.485		
Gb		1.033	1.033	1.033		
Gse		2.831	2.833	2.807		

CONTRACT 7419 ONLY

STATE MATERIALS LABORATORY VERIFICATION TEST DATA

						Specifications	Tolerance ± 0.5%
Pb		5.0	5.5	6.0			
% Gmm @ Nini:	8	85.2	86.4	87.8	≤	89.0	
% Va @ Ndes:	100	5.2	3.7	2.1	Approximate	4.0	2.5 - 5.5
% VMA @ Ndes:	100	15.0	14.9	14.7	≥	14.0	≥12.5
% VFA @ Ndes:	100	66	75	86		65 - 75	
% Gmm @ Nmax:	160		97.7		≤	98.0	
D/A		1.5	1.4	1.2		0.6 - 1.6	
Pbe		4.2	4.7	5.2			
Gmm		2.600	2.577	2.554			
Gmb		2.465	2.482	2.501			
Gb		1.033	1.033	1.033			
Gse		2.825	2.823	2.819			

VERIFIED

STRIPPING EVALUATION

% Anti-Strip:	0.0%	0.25%	0.50%	0.75%	1.0%
Visual Appearance:	NONE	NONE	NONE	NONE	NONE
% Retained Strength:	99	100	100	101	101

STATISTICAL

STATE MATERIALS LABORATORY RECOMMENDATIONS

		Remarks:
Asphalt Binder Supplier	SEM	
Asphalt Binder Grade	PG76-28	Verification of Volumetric Properites determined by SGC internal angle.
Percent Binder (Pb) (By Wt. Total Mix)	5.5	
% Anti-Strip (By Wt. Asphalt Binder)	0.00%	
Type of Anti-Strip		
Mix ID Number	G82068	
Sample Wt. (grams)	4885	(Informational Only)
Sample Height @ Ndes	115.0	(Informational Only)
Ignition Calibration Factor	0.53	(Informational Only)
Optimum Mixing Temperature	343°F	
Compaction Temperature	319°F	
Rice Density (lbs/ft^3)	160.4	

Page 1 of 2

Washington St. Department of Transportation - Mater. Laboratory
PO Box 47365 Olympia / 1655 2nd Ave. Tumwater / WA 98504
BITUMINOUS SECTION MIX DESIGN VERIFICATION REPORT

TEST OF: AGGREGATE PROPERTIES FOR HMA CLASS: 1/2" — WORK ORDER NO: 007419
LAB ID NO: 0000225192 — MIX ID NO: G82068

CONTRACTOR'S DESIGN AGGREGATE STRUCTURE AND AGGREGATE TEST DATA

			Combined	Specifications	Tolerance
Material:	3/4'-#4	3/8"-0			
Source:	GT-318	GT-318			
Ratio:	27%	73%			
1 1/2" square					
1" square					
3/4" square	100.0	100.0	100	100	99 - 100
1/2" square	80.0	100.0	95	90 - 100	90 - 100
3/8" square	42.0	100.0	84	MAX 90	78 - 90
U.S. No. 4	2.0	75.0	55		50 - 60
U.S. No. 8	1.0	46.0	34	28 - 58	30 - 38
U.S. No. 16	1.0	30.0	22		
U.S. No. 30	1.0	20.0	15		
U.S. No. 50	1.0	15.0	11		
U.S. No. 100	1.0	11.0	8		
U.S. No. 200	1.0	8.2	6.3	2.0 - 7.0	4.3 - 7.0
Gsb Coarse	2.781	2.763			
Gsb Fine		2.746			
Gsb Blend	2.781	2.750	2.758		
Sand Equivalent			79	45 MIN.	
Uncompacted Voids (FAA)			49	44% MIN.	
Course Agg Frac					
U.S. No. 4			99	90% Double	Face Fracture

STATE MATERIALS LABORATORY AGGREGATE TEST DATA

			Combined	Specifications	Tolerance
Gsb Coarse	2.788	2.767			
Gsb Fine		2.737	2.737		
Gsb Blend	2.788	2.744	2.756		
Sand Equivalent		82	82	45 MIN.	
Uncompacted Voids (FAA)			49	44% MIN.	
Course Agg Frac					
U.S. No. 4	99	98	99	90% Double	Face Fracture

COMMENTS

Remarks:
Verification of Volumetric Properties determined by SGC Internal angle.

Environmental & Engineering Programs:		T152 -	3	THOMAS E. BAKER P.E.
Construction Engineer	X	T153 -		Materials Engineer
Accounting Section	X	T166 -	3	By: Joseph R. DeVol
General File	X	T172 -		Bituminous Materials Engineer
Bituminous Materials Section	X	T175 -		(360) 709-5421
Region: NORTH CENTRAL		T178-	1	Date: 4 / 17 / 2008
Construction Office--42	X			
Materials Engineer---42	X			
P.E.: M. FLEMING	X(2)			

SENT TO REGION
APR 1 8 2008
FROM STATE MATERIALS LAB

Page 2 of 2

Washin[illegible] State Department of Transportation - Materials [illegible]oratory
PO [illegible] 7365 Olympia / 1655 S 2nd Ave. Tumwater / W[illegible] 504
BITUMINOUS SECTION TEST REPORT

TEST OF: A.C.P MIX DESIGN CLASS SUPERPAVE 1/2" WMA*
DATE SAMPLED: 3/19/2008
DATE RECVD HQS: 3/19/2008
SR NO: 90
Section: WEST OF GEORGE PAVING

WORK ORDER NO: 007419
LAB ID NO 0000225836
TRANSMITTAL NO: 522609
MIX ID NO: G82164

CONTRACTOR'S PROPOSAL

Mat'l:	3/4"-#4	3/8"-0	RAP	COMBINED	SPECIFICATION	TOLERANCE
Source:	GT-318	GT-318	STOCKPILE			
Ratio:	27%	53%	20%			
1 1/2"						
1"						
3/4"	100	100	98	100	100	99 – 100
1/2"	85	100	93	95	90 – 100	90 – 100
3/8"	50	100	86	84	MAX 90	78 – 90
No. 4	2	80	63	55		50 – 60
No. 8	1	48	45	34	28 – 58	30 – 38
No. 16	1	28	33	22		
No. 30	1	18	24	15		
No. 50	1	13	18	11		
No. 100	1	9	13	8		
No. 200	1.0	7.9	9.3	6.3	2.0 – 7.0	4.3 – 7.0

REMARKS

* WMA, Warm Mix Asphalt, Anti-Strip evaluation with 2% Sasobit by total weight of virgin binder ([illegible]) and [illegible] Recycled Asphalt Pavement, (RAP).

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JUN 23 2008

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LOTTMAN STRIPPING EVALUATION

% ANTI-STRIP	0.0%	1/4%	1/2%	3/4%	1.0%
Visual Appearance:	NONE	NONE	NONE	NONE	NONE
% Retained Strength:	97	109	103	114	116

RECOMMENDATIONS

SUPPLIER	SEM	
GRADE	PG76-28	
% ASPHALT (BY TOTAL MIX)	5.1	
% ANTI-STRIP (BY WT. ASPHALT)	0.00%	
TYPE OF ANTI-STRIP		
IGNITION CALIBRATION FACTOR	0.53	(INFORMATIONAL ONLY)
MIX ID NUMBER	G82164	
MIXING TEMPERATURE	293°F	
COMPACTION TEMPERATURE	269°F	

Headquarters: T152 -
Construction Engineer--------------X T153 -
Accounting Section ----------------X T166 -
General File-----------------------X T172 - 1
Bituminous Section----------------X T175 -
Region: North Central T178 -
Construction Office- 42 ---------X
Materials Eng------- 42 ---------X
P.E.: E. PIERSON --X(2)

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol
(360)709-5421
Date: 6 / 17 / 2008

APPENDIX B
Specimen Bulk Specific Gravities

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES
USING SATURATED SURFACE DRY SPECIMENS
AASHTO T166-93

Project WA DOT WMA
Date Aug-08
Technician

W.O.Name Control
Task Descript.

Compaction ServoPac

Binder, %
Gsb

Mix Design Lot No.	ID	Binder Cont. (%)	Cycles or D/H Limit	Sample In Air A	Sample In Water C	Surface Dry B	Volume of Specimen	Bulk SG Gmb	Water Abs.	Estim. Air voids	Measured Max. SG, Gmm	Air Voids	VMA	VFA	
				[g]	[g]	[g]	(B-C) [cm3]	A/(B-C)	(B-A)/(B-C)*100 [%]	[%]	(1-(Gmb/Gmm))*100 Test	[%]			
	T	Spec	60mm												
Hamburg	C	1		2429.1	1439.2	2445.6	1006.4	2.414	1.6		2.585	6.6			
	B	2		2429.9	1439.2	2444.6	1005.4	2.417	1.5		2.585	6.5			
	E	3		2430.0	1435.2	2442.7	1007.5	2.412	1.3		2.585	6.7			
	H	4		2426.1	1437.3	2444.0	1006.7	2.410	1.8		2.585	6.8			
	F	5		2427.7	1440.0	2447.7	1007.7	2.409	2.0		2.585	6.8			
	I	6		2427.7	1439.7	2448.3	1008.6	2.407	2.0		2.585	6.9			
	A	7		2428.4	1429.9	2441.1	1011.2	2.402	1.3		2.585	7.1			
	G	8		2427.9	1438.3	2449.3	1011.0	2.401	2.1		2.585	7.1			
	D			2430.1	1446.2	2452.9	1006.7	2.414	2.3		2.585	6.6			
Performance Test	T	Core	150mm												Avg Va
	1	7450.0		2832.7	1660.0	2836.8	1176.8	2.407	0.3		2.585	6.9	4.4 - 37.8		
	2			2810.0	1653.6	2820.2	1166.6	2.409	0.9		2.585	6.8			
	3			2786.5	1635.1	2795.6	1160.5	2.401	0.8		2.585	7.1			6.91
	4			2813.1	1656.8	2824.8	1168.0	2.408	1.0		2.585	6.8			
	5			2821.1	1662.0	2832.6	1170.6	2.410	1.0		2.585	6.8	54.4		
	6			2821.6	1656.5	2831.3	1174.8	2.402	0.8		2.585	7.1			6.74
	7			2841.2	1673.5	2851.7	1178.2	2.411	0.9		2.585	6.7			
	8			2855.9	1681.4	2864.0	1182.6	2.415	0.7		2.585	6.6			
	9			2819.3	1646.8	2812.1	1165.3	2.419	-0.6		2.585	6.4	54.4		
	10			2859.0	1678.8	2866.6	1187.8	2.407	0.6		2.585	6.9	Fn		
	11			2822.7	1656.8	2831.6	1174.8	2.403	0.8		2.585	7.1			6.87
	12			2832.1	1662.4	2840.7	1178.3	2.404	0.7		2.585	7.0			
	13			2807.3	1647.4	2819.5	1172.1	2.395	1.0		2.585	7.3			
	14			2792.6	1646.8	2812.1	1165.3	2.396	1.7		2.585	7.3			
	15			2841.5	1674.2	2850.0	1175.8	2.417	0.7		2.585	6.5	Fn		
	16			2795.2	1640.6	2807.0	1166.4	2.396	1.0		2.585	7.3			
	17			2789.5	1633.7	2799.8	1166.1	2.392	0.9		2.585	7.5			
	18			2791.3	1636.8	2804.5	1167.7	2.390	1.1		2.585	7.5			
	19			2811.2	1646.2	2820.8	1174.6	2.393	0.8		2.585	7.4			
							AVG	2.404	0.8			7.0	54.4	6.8	
							StDev	0.009							

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES
USING SATURATED SURFACE DRY SPECIMENS
AASHTO T166-93

Project WA DOT WMA
Date Aug-08
Technician

W.O.Name SASOBIT
Task Descript.

Compaction ServoPac

Binder, %
Gsb

Mix Design Lot No.	ID	Binder Cont. (%)	Cycles or D/H Limit	Sample In Air A	Sample In Water C	Surface Dry B	Volume of Specimen	Bulk SG Gmb	Water Abs.	Estim. Air voids	Measured Max. SG, Gmm	Air Voids	VMA	VFA
							(B-C)	A/(B-C)	(B-A)/(B-C)*100		(1-(Gmb/Gmm))*100			
				[g]	[g]	[g]	[cm3]		[%]	[%]	Test	[%]		
	T	Spec	60mm											
Hamburg	1			2430.3	1437.2	2449.0	1011.8	2.402	1.8		2.576	6.8		
	2			2440.3	1438.5	2457.1	1018.6	2.396	1.6		2.576	7.0		
	3			2429.3	1432.6	2447.0	1014.4	2.395	1.7		2.576	7.0		
	4			2430.8	1432.2	2447.0	1014.8	2.395	1.6		2.576	7.0		
	5			2429.5	1429.4	2447.2	1017.8	2.387	1.7		2.576	7.3		
	6			2430.8	1434.9	2450.2	1015.3	2.394	1.9		2.576	7.1		
	7			2431.1	1431.9	2447.0	1015.1	2.395	1.6		2.576	7.0		
											2.576			
											2.576			
	T	Core	150mm								2.576			Avg Va
Performance Test	1	7420		2793.5	1638.7	2804.7	1166.0	2.396	1.0		2.576	7.0		
	2			2834.7	1658.9	2841.0	1182.1	2.398	0.5		2.576	6.9		
	3			2820.3	1650.6	2828.8	1178.2	2.394	0.7		2.576	7.1	4.4 - 37.8	6.95
	4			2822.4	1651.3	2827.3	1176.0	2.400	0.4		2.576	6.8		
	5			2839.6	1661.6	2848.3	1186.7	2.393	0.7		2.576	7.1		
	6			2823.3	1661.1	2836.5	1175.4	2.402	1.1		2.576	6.8	54.4	7.01
	7			2811.6	1644.1	2819.6	1175.5	2.392	0.7		2.576	7.1		
	8			2794.7	1641.5	2808.6	1167.1	2.395	1.2		2.576	7.0		
	9			2816.8	1651.1	2828.5	1177.4	2.392	1.0		2.576	7.1		
	10			2814.8	1658.4	2831.9	1173.5	2.399	1.5		2.576	6.9	Fn	7.03
	11			2837.9	1664.5	2848.9	1184.4	2.396	0.9		2.576	7.0		
	12			2855.5	1667.0	2860.7	1193.7	2.392	0.4		2.576	7.1		
	13			2838.0	1664.2	2850.4	1186.2	2.393	1.0		2.576	7.1		
	14			2859.7	1673.3	2866.7	1193.4	2.396	0.6		2.576	7.0		
	15			2843.5	1663.0	2855.3	1192.3	2.385	1.0		2.576	7.4		
	16			2827.8	1659.0	2841.1	1182.1	2.392	1.1		2.576	7.1		
	17			2780.6	1622.9	2795.4	1172.5	2.372	1.3		2.576	7.9		
	18			2855.3	1670.5	2861.7	1191.2	2.397	0.5		2.576	6.9		
							AVG	2.393	0.9			7.1	54.4	7.0
							StDev	0.004						

APPENDIX C
Dynamic Modulus Results Summary

PROJECT **WA_WMA_08** Unconfined E* Test Results

*E * - Dynamic Modulus*

	MIXTURE	Specimens	4.4° C 25 Hz	4.4° C 10 Hz	4.4° C 5 Hz	4.4° C 1 Hz	4.4° C 0.5 Hz	4.4° C 0.1 Hz	21.1° C 25 Hz	21.1° C 10 Hz	21.1° C 5 Hz	21.1° C 1 Hz	21.1° C 0.5 Hz	21.1° C 0.1 Hz
Production Material	CONTROL	1	12535	11301	10314	7958	6997	4878	5784	4596	3769	2197	1709	901.3
		2	14586	13210	12138	9709	8664	6413	6899	5647	4766	3044	2465	1411
		3	14236	12897	11862	9463	8449	6215	6740	5541	4688	2991	2431	1399
		4	12643	11456	10472	8143	7201	5058	5884	4727	3904	2308	1807	948
		Avg	13500	12216	11197	8818	7828	5641	6327	5128	4282	2635	2103	1165
		s	1063	978	937	895	850	785	574	543	518	445	401	278
		COV	7.9%	8.0%	8.4%	10.2%	10.9%	13.9%	9.1%	10.6%	12.1%	16.9%	19.0%	23.9%
	SASOBIT	1	13314	12105	11151	8924	8027	5969	6995	5844	5014	3260	2672	1559
		2	16411	14840	13617	10923	9784	7329	8508	7055	6038	3997	3279	1964
		3	14912	13626	12618	10252	9255	7033	8320	6992	6033	4060	3367	2033
		4	15533	13991	12842	10313	9229	6897	8382	6958	5952	3963	3271	1985
		Avg	15043	13641	12557	10103	9074	6807	8051	6712	5759	3820	3147	1885
		s	1306	1143	1030	842	743	587	708	580	498	375	320	219
		COV	8.7%	8.4%	8.2%	8.3%	8.2%	8.6%	8.8%	8.6%	8.7%	9.8%	10.2%	11.6%

	MIXTURE	Specimens	37.8° C 25 Hz	37.8° C 10 Hz	37.8° C 5 Hz	37.8° C 1 Hz	37.8° C 0.5 Hz	37.8° C 0.1 Hz	Specimens	54.4° C 25 Hz	54.4° C 10 Hz	54.4° C 5 Hz	54.4° C 1 Hz	54.4° C 0.5 Hz	54.4° C 0.1 Hz
Production Material	CONTROL	1	1729.0	1152.0	848.5	406.8	300.2	154.7	5	847.5	576.2	419.0	217.2	167.4	92.9
		2	2018.0	1416.0	1077.0	554.0	421.9	231.5	6	619.8	413.7	298.8	167.8	135.5	83.3
		3	2014.0	1418.0	1082.0	557.0	423.6	232.1	7	530.8	338.6	241.3	135.6	110.2	69.9
		4	1596.0	1058.0	783.2	373.6	278.1	151.3	9	517.2	320.7	226.1	117.0	93.6	60.6
		Avg	1839	1261	948	473	356	192		629	412	296	159	127	77
		s	211	184	155	96	78	46		153	116	88	44	32	14
		COV	11.5%	14.6%	16.3%	20.4%	21.8%	23.7%		24.3%	28.2%	29.6%	27.5%	25.4%	18.6%
	SASOBIT	1	2345.0	1687.0	1294.0	666.2	512.2	279.9	5	985.2	679.6	505.4	272.7	215.4	133.2
		2	2861.0	2078.0	1606.0	858.0	667.9	374.6	6	848	571	420.1	235.3	188.8	116.8
		3	2598.0	1904.0	1483.0	795.0	619.9	345.5	7	746.7	499	368.1	206	169.1	104.2
		4	2806.0	2056.0	1609.0	870.6	681.6	377.2	8	1045	710	527.2	287.8	225.8	134.6
		Avg	2653	1931	1498	797	620	344		906	615	455	250	200	122
		s	234	180	148	94	77	45		135	98	74	37	26	14
		COV	8.8%	9.3%	9.9%	11.7%	12.4%	13.1%		14.9%	15.9%	16.3%	14.8%	12.9%	11.8%

APPENDIX D
Flow Number Results Summary

Flow Number Test @ 58° C; 69 kPa (10 psi) Confinement SAMPLE INTERVAL 20 CYCLE version 1.26

Flow Number Data as per NCHRP 9-29 protocols

Specimens	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
10	251	18090	00:17:39	50031	1059		151.1	144.3		
11	171	30191	0:06:37	50101	397		149.8	143.2		
12	191	21244	0:11:49	50010	709		151.9	143.1		
15	351	20239	0:20:51	50030	1251		149.5	142.8		
Avg	241	22441	0	50043	854					
	81	5332	0	40	378					
	33.5%	23.8%	55.0%	0.1%	44.3%					
9	471	24862	0:23:12	50030	1392		150.2	143.4		
10	191	21557	0:11:09	50010	669		149.8	143.1		
11	251	28858	0:09:09	50036	549		150.7	143.9		
12	171	17128	0:15:18	50044	918		151.9	145.1		
Avg	271	23101	0	50030	882					
	138	4977	0	15	373					
	50.8%	21.5%	42.3%	0.0%	42.3%					

Flow Number Data - Francken Fitting Model - IPC version 1.37

	Specimens	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles
CONTROL	10	294	18043	00:17:39	50031	1059
	11	168	25496	0:06:37	50101	397
	12	223	20537	0:11:49	50010	709
	15	365	19541	0:20:51	50030	1251
	Avg	262.5	20904	0	50043	854
		86	3228	0	40	378
		32.6%	15.4%	55.0%	0.1%	44.3%
SASOBIT	9	494	24491	0:23:12	50030	1392
	10	213	20219	0:11:09	50010	669
	11	221	23695	0:09:09	50036	549
	12	298	20461	0:15:18	50044	918
	Avg	306.5	22217	0	50030	882
		131	2193	0	15	373
		42.7%	9.9%	42.3%	0.0%	42.3%

Flow Number Test @ 58° C; 69 kPa (10 psi) Confinement SAMPLE INTERVAL 20 CYCLE version 1.37

Flow Number Data as per NCHRP 9-29 protocols

Specimens	Flow Point, cycles	µStrain @ Flow	Test Duration (time)	Total Accumulated Strain	Total Cycles	% loss of height (microstrains)	Initial height of specimen (measured)	Height of specimen after FN test (measured)	% deformation based on msrd heights (calc'd)	Measured deformation during Flow Test (mm)
10	239	17728	00:17:39	50031	1059		151.1	144.3		
11	176	30652	0:06:37	50101	397		149.8	143.2		
12	188	21097	0:11:49	50010	709		151.9	143.1		
15	355.00	20322	0:20:51	50030	1251		149.5	142.8		
Avg	240	22450	0	50043	854					
	82	5655	0	40	378					
	34.1%	25.2%	55.0%	0.1%	44.3%					
9	466	24754	0:23:12	50030	1392		150.2	143.4		
10	176	20743	0:11:09	50010	669		149.8	143.1		
11	249	28728	0:09:09	50036	549		150.7	143.9		
12	164	16828	0:15:18	50044	918		151.9	145.1		
Avg	264	22763	0	50030	882					
	140	5127	0	15	373					
	53.1%	22.5%	42.3%	0.0%	42.3%					

APPENDIX E
Hamburg Wheel Tracking Test Results

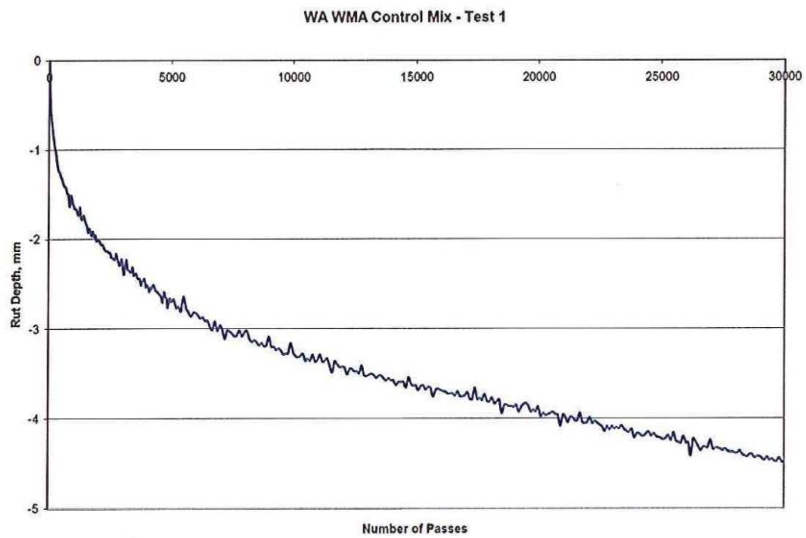

Figure A1: Hamburg Wheel Track Test Results of Washington WMA Control Mix Test 1

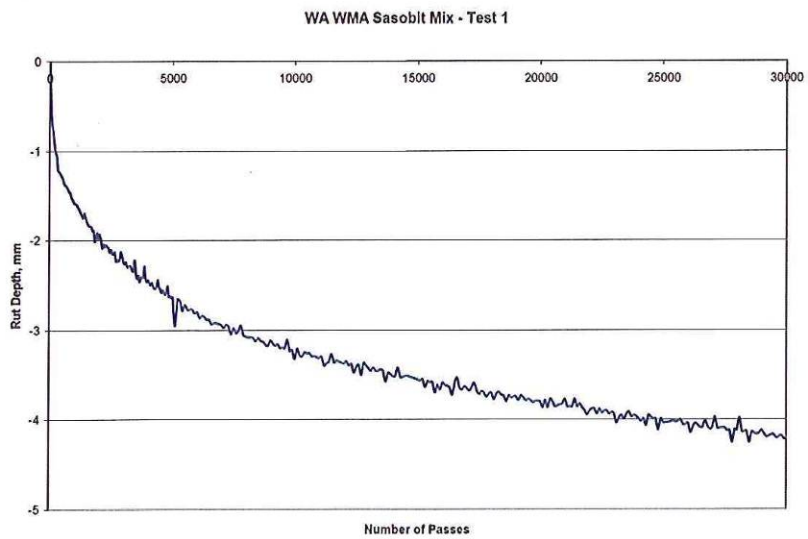

Figure A2: Hamburg Wheel Track Test Results of Washington WMA Sasobit Mix Test 1

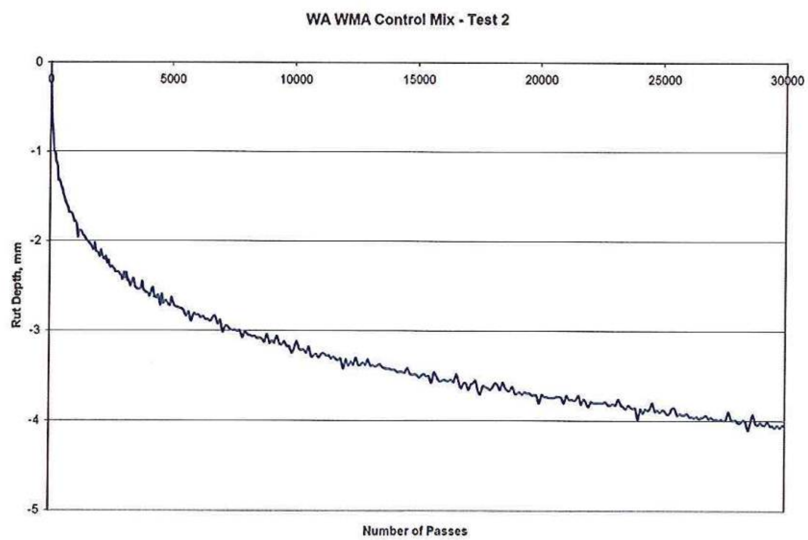

Figure A3: Hamburg Wheel Track Test Results of Washington WMA Control Mix Test 2

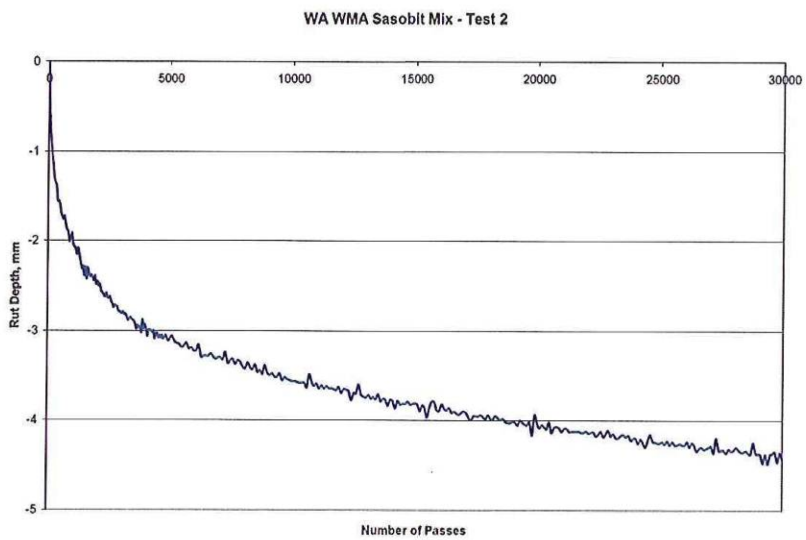

Figure A4: Hamburg Wheel Track Test Results of Washington WMA Sasobit Mix Test 2

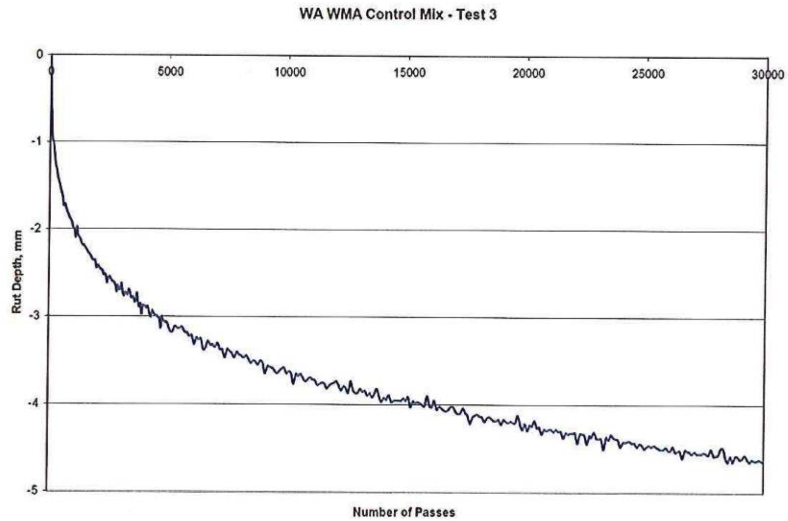

Figure A5: Hamburg Wheel Track Test Results of Washington WMA Control Mix Test 3

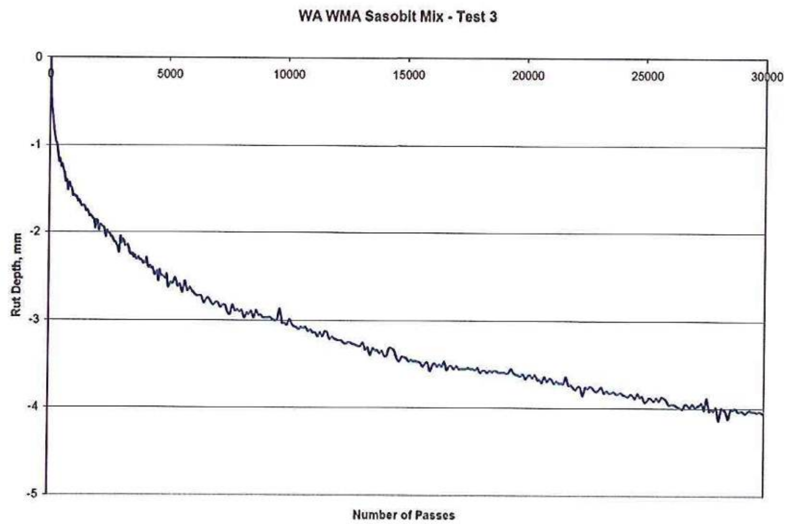

Figure A6: Hamburg Wheel Track Test Results of Washington WMA Sasobit Mix Test 3