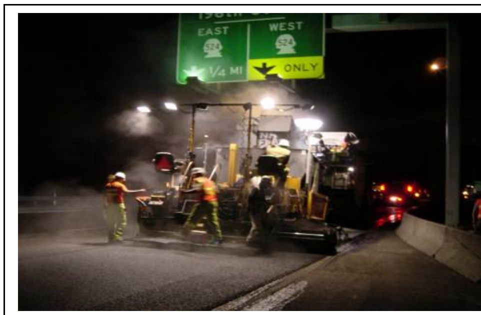
Experimental Feature Report

Post Construction & Performance Report
Experimental Feature WA 05-06

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses

Contract 7134
I-5
52nd Avenue West to SR-526 – Southbound
MP 180.10 to MP 189.30





Washington State
Department of Transportation

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 683.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses	March 2008
	6. PERFORMING ORGANIZATION CODE WA 05-06
7. AUTHOR(S) Keith W. Anderson, Linda M. Pierce, Jeff S. Uhlmeyer, and Jim Weston	8. PERFORMING ORGANIZATION REPORT NO.
. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Department of Transportation Materials Laboratory, MS-47365 Olympia, WA 98504-7365	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Project Manager: Kim Willoughby, 360-705-7978	13. TYPE OF REPORT AND PERIOD COVERED Post-Construction and Performance Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This experimental project is being conducted as a part of WSDOT's effort to produce pavements that reduce the noise generated at the tire/pavement interface. Experimental sections of open-graded friction courses (OGFC) were built using asphalt rubber (AR) and styrene-butadiene-styrene (SBS) polymer modified asphalt binders. A section of conventional Class ½ inch hot mix asphalt (HMA) serves as the control section for the two experimental sections.

Sound intensity measurements were conducted using the On Board Sound Intensity (OBSI) method immediately after construction and monthly, weather permitting, for a year following construction.

OBSI readings immediately after construction indicated that the OGFC-AR and OGFC-SBS sections were 2.8 to 3.8 decibels, respectively, quieter than the Class ½ inch HMA control section. Data from one year later showed that the AR and SBS modified sections were 1.5 to 3.3 decibels quieter, respectively, than the control section. Sound intensity readings taken between wheel paths are at levels similar to the initial readings after the sections were constructed indicating that studded tire wear is having a negative effect on the sound absorbing qualities of the open-graded mixes.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
quieter pavements, rubber asphalt, open-graded friction courses, on board sound intensity measurements, polymer asphalt, styrene-butadiene-styrene	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	98	

DISCLAIMER

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Introduction

This experimental feature documents the construction of two quieter pavements: (1) an open-graded friction course (OGFC) modified with an asphalt rubber binder, hereafter referred to as OGFC-AR and (2) an OGFC with a styrene-butadiene-styrene (SBS) polymer asphalt binder, hereafter referred to as OGFC-SBS. OGFC, with a higher volume of surface voids (a minimum of 15 percent air voids), absorb some of the noise generated at the tire/pavement interface and are thus "quieter" than densely-graded pavements with fewer voids (around 4-8 percent).

Open-graded pavements are not new to the state of Washington or the Washington State Department of Transportation (WSDOT). OGFC's were used extensively in the state in the early to middle 1980's. Their use was discontinued due to problems with excessive rutting caused by studded tire wear. The renewed interest in open-graded pavements is prompted by successful use of this type of pavement in other states, principally Arizona. The use of rubberized open-graded pavements as one solution to making pavements quieter has been promoted in numerous road industry publications. This aggressive proclamations regarding rubberized open-graded pavement as the answer to making pavements quieter has reached even to the public sector who are now asking for this type of pavement to be used on the highways that bisect their neighborhoods.

Background

There are downsides with the use of open-graded pavements. Open-graded pavements are very susceptible to excessive wear from studded tires. This excessive wear produces ruts in the pavements that fill with water during rainy periods and pose the additional hazard of hydroplaning. The other downside is pavement life. The life of open-graded pavements is cut short by the studded tire wear mentioned previously. Pavement lives of less than 10 years, and as short as three to four years were experienced with these types of pavement in the 1980's in Washington. States where the use of OGFC has been successful (Florida, Texas, Arizona and California) do not experience extensive studded tire usage. Similarly, these states are southern, warm weather states; a clear advantage when placing a product like OGFC with asphalt-rubber. Arizona DOT, for example, requires the existing pavement to have an 85°F surface temperature at the time of placement. Washington State urban pavements, placed at night to avoid traffic impacts, rarely reach this temperature during the available nighttime hours for paving (10:00 p.m. to 5:00 a.m.), even in summer. Other pavements and bridge decks reach such temperatures at night only on rare occasions, making successful placement of this type of pavement a challenge.

Open-graded pavements also have benefits other than reducing the noise level. Drivers have improved visibility during rain storms on open-graded pavements due to the open void structure that drains away excess water. The quick drainage of water away from the surface of the pavement also improves the wet weather friction resistance of the roadway and decreases the potential for hydroplaning. At night the drainage capability of the pavement helps to improve visibility by reducing the glare associated with standing water on the pavement. Painted traffic markings are also more visible at night because of less water standing on the roadway.

Project Description

The site selected for the experimental use of the OGFC is located on I-5 near the town of Lynnwood, Washington (Figure 1). The project, Contract 7134, 52nd Ave. West to SR 526 SB Paving and Safety, consisted of paving the southbound lanes from Milepost (MP) 180.10 to (MP) 188.65. Wilder Construction Company from Everett, Washington was the low bidder on the project. The project called for 0.06 feet of open-graded mix to be placed directly on top of the existing pavement on all three general purpose lanes and the HOV lane with the exception of the second lane. The second lane, which was extensively cracked and rutted, was to be milled to a depth of 0.15 feet and inlaid with an equal depth of PG 64-22 Class ½ inch HMA prior to placement of the 0.06 foot OGFC overlay. The average daily traffic (ADT) on this section of I-5 is 79,800 with 7.3% trucks.

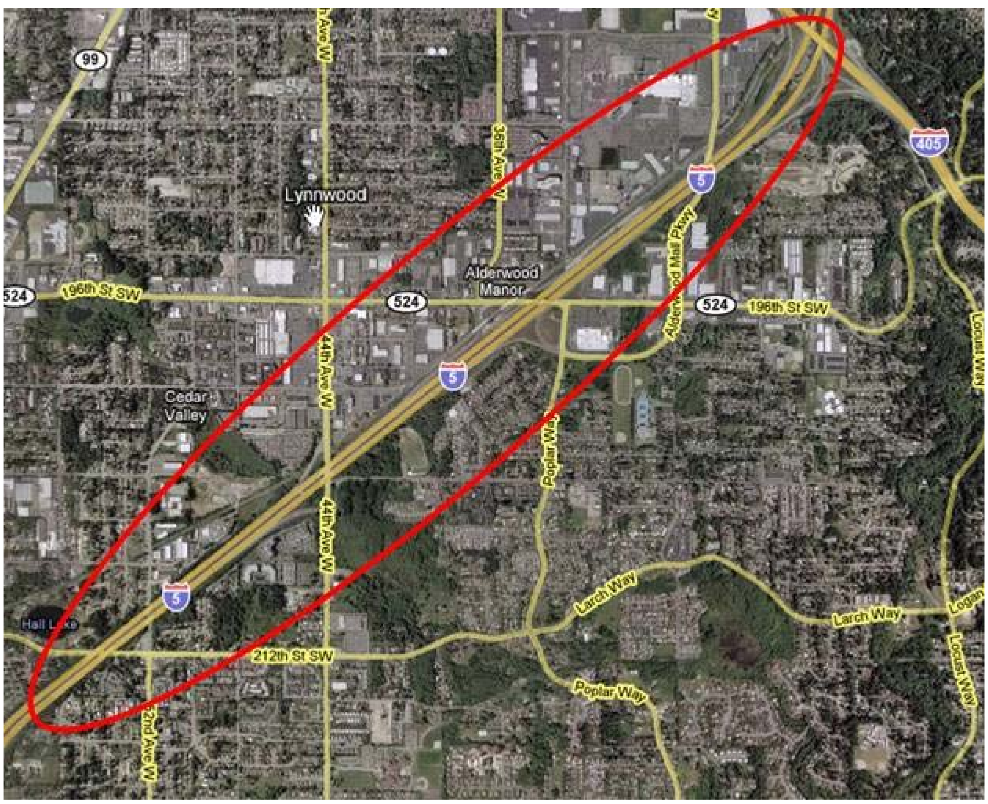


Figure 1. Location of Contract 7134 near Lynnwood, Washington.

The OGFC-SBS was placed in all four lanes from MP 180.75 to 181.82, a distance of 1.07 miles (Figure 2). The OGFC-AR was placed in all four southbound lanes from MP 181.82 to 182.58, a distance of 0.76 miles. The remainder of the project received a 0.15 foot mill and fill with Class ½ inch HMA. The section of Class ½ inch HMA from the beginning of the project at MP 180.10 to the OGFC-SBS section at MP 180.75 was selected to be the control section.

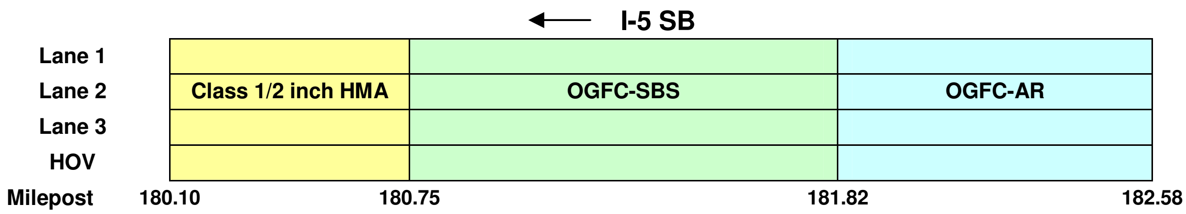


Figure 2. Plan map of section layout.

Mix Design Process

Special mix design processes were required for both of the open-graded pavements. The asphalt rubber mix design was the design developed and used by the Arizona Department of Transportation (ADOT). The polymer mix design was developed in-house and based on discussions from the National Center for Asphalt Technology and it used a slightly modified version of the ADOT aggregate gradation for open-graded friction courses. The mix designs can be found in Appendix A.

OGFC-AR

ADOT was called upon for help in the development of the mix design for the OGFC-AR. Their expertise with the design and use of asphalt-rubber goes back many years. Granite Construction, the parent company of the project's Contractor, Wilder Construction, hired the firm of MACTEC Engineering and Consulting, Inc., located in Phoenix, AZ to develop the binder design which combined the binder with the crumb rubber. The binder design was provided to ADOT, along with the aggregate gradation, who then verified the mix design. The lab reports from both ADOT and MACTEC are found in Appendix A. The design called for a fine mix with 55-70 percent in the #4 to 3/8 inch size and 22-37 percent in the #8 to #4 size. The design binder content was 9.2 percent with 0.50 percent anti-strip additive and the amount of crumb rubber added was set at 22 percent by weight of the asphalt binder. Three stockpiles were used from pit site B-335, 3/8 inch chips, #4 to #8 sand, and #4 to 0 sand blended at the ratios of 72, 20 and 8 percent, respectively. Tesoro Corporation, Anacortes, Washington was the source of the PG64-22 asphalt binder and Crumb Rubber Manufacturers, Rancho Domingo, California, provided the crumb rubber for the project. Important features of the design are summarized in Table 1.

Table 1. Mix design for the OGFC-AR.			
Sieve Size	**Gradation**	**Specifications**	**Source/Supplier**
3/8"	100	100	B-335
#4	34	30-45	B-335
#8	8	4-8	B-335
#200	1.5	0–2.5	B-335
Binder Grade	**Percent Asphalt**		**Source/Supplier**
PG64-22	9.2		Tesoro, Anacortes, WA
Anti-Strip	**Percent**		
ARR-MAZ 6500	0.50		Arr-Maz Custom Chemicals, Mulberry, FL
Crumb Rubber	**Percent by Wt. of AC**		**Source/Supplier**
CRM	22		Crumb Rubber Manufacturers, Rancho Domingo, CA

OGFC-SBS

The mix design for the OGFC-SBS was performed in the WSDOT Headquarters Materials Laboratory. The starting point for the percent of asphalt was determined by an asphalt retention process which suggested using 6.8 percent. Samples were mixed at 6.3, 6.8 and 7.3 percent asphalt and evaluated using the FHWA pie plate drain down test. The results of the pie plate drain down test suggested using more asphalt than the initial target of 6.8 percent. However, before additional tests could be conducted, a recommendation was needed for the mix design that was to be used for the construction of the test section at the asphalt plant site in Everett. Therefore, a preliminary design calling for 7.8 percent was issued for the test section construction. Additional samples were then mixed using 7.3, 8.3, and 8.8 percent asphalt and evaluated using the pie plate drain down test. All of the samples were in specification for volumetric properties, but the pie plate drain down test suggested that 8.3 percent was optimum; therefore, the asphalt content for the mainline paving was set at this level. The gyration level used for the mix design was 50 based on a recommendation from the ADOT.

Aggregate for the OGFC-SBS came from the same pit site, B-335, and the same three stockpiles were used, but the blend differed from the OGFC-AR having 66 percent from the 3/8 inch chips stockpile, 21 percent from the #4 to #8 stockpile, and 13 percent #4 to 0 stockpile.

Fiber produced from recycled paper was used as a stabilizing additive to thicken the asphalt binder and prevent drain down. The SBS modified PG70-22 binder was provided by US Oil, Tacoma, Washington and the fibers were obtained from Hi-Tech Asphalt Solutions, Mechanicsville, Virginia. Details of the mix design are listed in Table 2.

Table 2. Mix design for the OGFC-SBS.

Sieve Size	Gradation	Specifications	Source/Supplier
3/8”	100	100	B-335
#4	37	35-55	B-335
#8	10	9-14	B-335
#200	2.1	0–2.5	B-335
Binder Grade	**Percent Asphalt**		**Source/Supplier**
PG70-22	8.3		US Oil, Tacoma, WA
Anti-Strip	**Percent**		**Source/Supplier**
ARR-MAZ 6500	0.25		Arr-Maz Custom Chemicals, Mulberry, FL
Stabilizing Additive	**Percent**		**Source/Supplier**
Processed recycled paper	0.30		Hi-Tech Asphalt Solutions

Construction

The Special Provisions for the contract contains several items pertaining to the construction of the two special OGFC pavements. A brief description of these items is included in this section of the report as a guide to understanding the circumstances under which the sections were constructed. The Special Provisions are included in Appendix B.

OGFC-AR Special Provisions

The Special Provisions required that the asphalt binder for the OGFC-AR would be a PG58-22 or PG64-22. The crumb rubber must conform to the gradation requirements shown in Table 3. The crumb rubber will have a specific gravity of 1.15 ± 0.05 and will be free of wire or other contaminating materials, except that the rubber will not contain more than 0.5 percent fabric. Calcium carbonate could be added to prevent the particles from sticking together. The minimum amount of crumb rubber required in the mix was 20 percent by weight of the asphalt binder.

Table 3. Gradation requirement for crumb rubber.

Sieve Size	Percent Passing
No. 8	100
No. 10	100
No. 16	65 – 100
No. 30	20 – 100
No. 50	0 – 45
No. 200	0 – 5

The temperature of the asphalt binder at the time of the addition of the crumb rubber should be between 350 and 400°F. A one-hour reaction period was required after the mixing of the rubber with the binder. At the end of the reaction period the rubber particles must be thoroughly "wetted" without any rubber floating on the surface or agglomerations of rubber particles observable. The temperature of the asphalt-rubber immediately after mixing will be between 325 and 375°F.

The mixed asphalt-rubber must be kept thoroughly agitated during the period of use to prevent the settling of the rubber particles. In no case can the asphalt-rubber be held at a temperature of 325°F or above for more than 10 hours. Asphalt-rubber held for more than 10 hours must be allowed to cool and gradually reheated to the prescribed temperature. A batch of asphalt-rubber can only be cooled and reheated in this manner once.

OGFC-SBS Special Provisions

The asphalt binder for the OGFC-SBS will be a PG70-22 produced by adding SBS modifier to a non air blown or oxidized PG58-22 or PG64-22. The fibers required in the mixture can be cellulose fibers, cellulose pellets, or mineral fibers. If the mix was produced in a dryer-drum plant, fibers were required to be added to the aggregate and uniformly dispersed prior to the injection of the asphalt binder. Storage time for the OGFC-SBS was not to exceed four hours.

Asphalt Plant

The asphalt plant was a dryer-drum type plant located at Wilder Construction's Smith Island facility. Granite Construction provided the additional equipment for the production of the asphalt-rubber binder. The photos shown in Figures 2 through 5 depict the process used to load the crumb rubber into a shear mixer prior to its storage in heated and agitated tanks. Once the asphalt and rubber mixture was blended the process for producing the HMA was no different than conventional dryer-drum plant production.

Modifications to the plant were also necessary for the production of the OGFC-SBS. Figure 6 shows the fiber mixing and distribution machine which introduced a controlled amount of fiber into the dryer drum. Figure 7 shows the supply line hose and hose fitting on the dryer drum.

Figure 3. Lifting bags of crumb rubber.

Figure 4. Loading of crumb rubber into double bin supply hopper.

Figure 5. Double bin crumb rubber weigh hopper.

Figure 6. Shear mixer used to combine the crumb rubber with the asphalt binder.

Figure 7. Fiber supply machine.

Figure 8. Fiber supply hose and hose fitting in dryer drum plant.

Paving Operations

Paving began on August 17, 2006 with the construction of test sections of both OGFC-AR and OGFC-SBS. The test sections were located on Ross Avenue near the site of the Wilder Construction Company asphalt plant. Following successful completion of the test sections, the mainline paving began on August 19. The paving of the OGFC test sections was completed in two consecutive weekend closures, August 19 and 20 and August 25 and 26. A summary of the paving operation from the Inspector's Daily Reports is listed in Table 4. One additional paving day was needed to replace a section of the OGFC-SBS that had a rough ride and was showing excessive raveling immediately after construction. Additional information can be found on this problem under the section on Construction Problems.

Table 4. Paving history for OGFC-AR and OGFC-SBS.

Date	Lane	Milepost Limits	Pavement Type	Comments
August 19	Collector	181.83 – 182.27	OGFC-AR	Collector lane between I-405 and SR-524.
August 19	1	181.83 – 182.59	OGFC-AR	Mix temperatures from 285 to 317°F.
August 19	2	181.83 – 182.59	OGFC-AR	
August 20	3 & 4	181.83 – 182.59	OGFC-AR	
August 20	2	181.73 – 181.83	OGFC-SBS	
August 25	3 & 4	180.76 - 181.83	OGFC-SBS	Mix temperatures from 268 to 310°F. Air temperatures from 67-73°F.
August 26	1	180.76 – 181.83	OGFC-SBS	Mix temperatures from 260 to 305°F. Air temperatures from 68-74°F.
August 26	2	180.76 – 181.52	OGFC-SBS	Shuttle Buggy not used from Sta. 9584+00 to 9544+00.
September 23	2	180.76 – 181.52	OGFC-SBS	Sta. 9584+00 to 9544+00 replaced using Shuttle Buggy

The paving of the mainline was done at night; therefore, most of the photos of the paving operation shown below are from the paving of the test sections. The first two, Figures 9 and 10, show the streaky application of the CRS-2P tack coat at the beginning of each pass of the distributor truck on both the test section and mainline paving.

Figure 9. Tack coat application on test section.

Figure 10. Globs of excess tack on the roadway.

The second set of two photos, Figures 11 and 12, show the Ingersoll Rand PF 5510 Blaw-Knox paver paving the OGFC-AR test section.

Figure 11. Paving the OGFC-AR test section.

Figure 12. Another view of the OGFC-AR test section paving.

The third set of two photos, Figures 13 and 14, show the Ingersoll Rand DD-130 rollers that were used in the required static mode to compact the open-graded mix. Three rollers were used during the mainline paving with a fourth, an Ingersoll Rand DD-110, added on occasion. Liquid soap was added to the water in the rollers (1 gallon of dish soap to 300 gallons of water) to prevent the rollers from sticking to the hot-mix.

Figure 13. Aggressive rolling of OGFC-AR test section.

Figure 14. The soap bubbles on the pavement are from the soap added to the water to prevent sticking.

The fourth set of photos, Figures 15 and 16, show the OGFC-AR mix prior to the screed and a close-up of the mix during the compaction process.

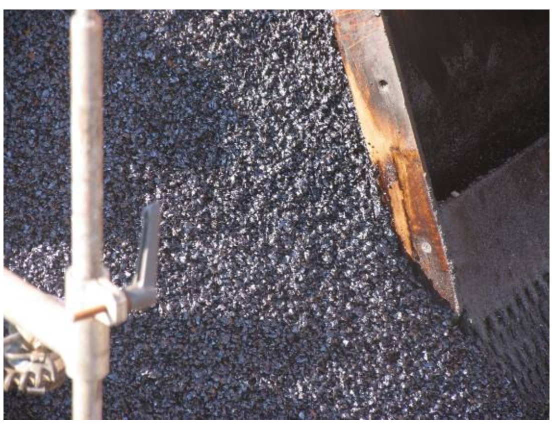


Figure 15. OGFC-AR mix behind the material management kit prior to the screed.

Figure 16. Close-up of OGFC-AR mix during the compaction process.

The fifth set of photos, Figures 17 and 18, show the OGFC-SBS mix prior to rolling and after compaction.

Figure 17. OGFC-SBS prior to rolling. Blemishes are footprints.

Figure 18. OGFC-SBS after compaction.

The final two photos from the construction process, Figures 19 and 20, show the Roadtec Shuttle Buggy material transfer vehicle use to remix the OGFC-AR and OGFC-SBS prior to passing it through the paving machine, and a long-distance view of the paving train. Both photos were taken from the actual mainline paving.

Figure 19. Roadtec Shuttle Buggy materials transfer vehicle.

Figure 20. Paving train consisting of dump trucks, Shuttle Buggy, paver and rollers.

Cost

The bid prices for the three types of HMA used on Contract 7134 ranged from a low of $62.50 per ton for the Class 1/2 inch HMA to a high of $130.00 per ton for the OGFC-AR. The OGFC-SBS price was in the middle at $90.00 per ton. The estimated quantities and total cost for each type of pavement are shown in Table 5 along with the low bid price.

Table 5. Cost comparison information.

Bid Item	Estimated Quantity (tons)	Low Bid (per ton)	Total Cost
Class 1/2" HMA	28,853	$62.50	$1,803,313
OGFC-AR	1,686	$130.00	$219,180
OGFC-SBS	2,441	$90.00	$219,690

Recycled Tire Usage

One ton of OGFC-AR contains 33.2 lbs of crumb rubber. It takes approximately 300 tons of asphalt to pave one lane mile of pavement at a depth of 0.06 feet. Assuming that the weight of usable rubber in an average passenger tire is 18 pounds, there would be 550 tires consumed to produce one lane mile of OGFC-AR on this project. The total length of OGFC-AR paving including the four mainline lanes and ramps was 5.55 miles. This project, therefore, recycled approximately 3,050 tires.

Construction Problems

The only problem encountered during the placement of the open-graded sections was a breakdown of the Shuttle Buggy on the final day of paving of the OGFC-SBS section. The Contractor elected to continue to complete the section without the use of a transfer device, which proved problematic, as the pavement had a rough riding surface and began to ravel almost immediately. As a result, the Contractor removed and replaced this section.

Construction Testing

The construction process was monitored for specification compliance by the Project Engineers staff and for temperature differentials by personnel from the Headquarters' Materials Laboratory Pavements Section.

Specification Compliance Testing

The gradation, percent asphalt and percent rubber for the paving of the test section and the two days of production paving are listed in Table 6. The Special Provisions called for acceptance to be based on meeting the gradation requirements because conventional asphalt content testing methods do not work with rubber-asphalt binders. The data for the percent of asphalt and rubber was from worksheets supplied by Granite Construction that listed the tons of binder, rubber and hot mix produced for each days paving. The production results show the gradations to be within specification limits, the asphalt content low on one day, high on the next day, on target for the third day, and the rubber percentage on target for all three days.

Table 6. Gradation, percent asphalt and percent rubber results for OGFC-AR.

Sieve	Target	Date					Specification
		8/17	8/19	8/19	8/20	8/20	
3/8	100	99	100	100	100	100	**100**
#4	34	36	33	33	32	36	**30-38**
#8	8	8	8	7	7	8	**4-8**
#200	1.5	1.6	1.6	1.6	1.5	1.8	**0-2.5**
%AC	9.2	9.01	9.64		9.20		**9.2**
%CRM	22.0	22.0	22.0		22.0		**22.0**

The information for the OGFC-SBS, Table 7, is similar in that data is only available for the gradations which all met the specification limits. The contract did not require that a percent of asphalt be measured for the production paving due to the addition of SBS which also, just as in the case of the rubber, negates normal asphalt content testing, however, one value was calculated based on the tons of mix and binder used on August 26 and it met the mix design recommendation.

Table 7. Gradation and percent asphalt results for OGFC-SBS.						
Sieve	Target	Date				Specification
		8/17	8/25	8/26	9/22	
3/8	100	99	100	100	100	**100**
#4	37	35	37	40	41	**35-55**
#8	10	8	11	11	12	**9-14**
#200	2.1	0.8	2.3	2.5	2.0	**0-2.5**
%AC	8.3	8.2	-	8.3	-	**8.3**

In summary, both the OGFC-AR and OGFC-SBS pavements were constructed in compliance with the mix design recommendations for aggregate gradation, asphalt content, and, in the case of the OGFC-AR, crumb rubber content.

Temperature Monitoring

An infrared camera was used throughout the paving operation to monitor the temperature of the mix as delivered in the dump trucks and as it passed through the paver and was placed on the roadway. Temperature differences of as much as 160°F were noted between the crust of hot mix that forms on top of the delivery trucks (140°F) and the hot mix under the crust (300°F). Based on past experience, temperature differences of this magnitude would normally lead to significant portions of the mat having density problems because the significantly cooler material from the crust cannot be compacted. However, the Special Provisions required the use of a Roadtec Shuttle Buggy to mitigate this problem by remixing the material prior to placement. Figure 21 shows the typical temperature differences noted in the delivery vehicles. Spot 2 is the crust and Spot 1 is the material under the crust that is being exposed as the bed of the truck is raised.

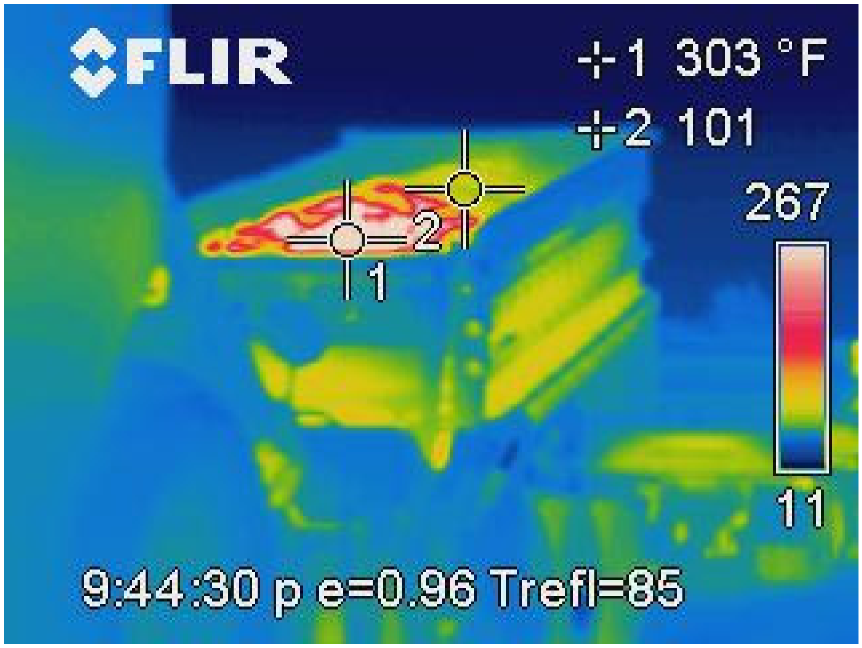


Figure 21. Temperature differentials in a delivery truck.

Figure 22 is an infrared photo of the mix as comes out of the paver after having been remixed by the Shuttle Buggy. The even red color across the width and length of the mat illustrates the positive effects that remixing has on the uniformity of the temperatures across the mat. The aforementioned was the typical image captured throughout the project when the Shuttle Buggy was in use. As noted previously, a portion of the project was completed without the use of the Shuttle Buggy and although this portion of the paving was not documented with infrared images, past experience with end dumping directly into the paver would indicate that significant temperature differentials resulted that led to the early raveling problems.

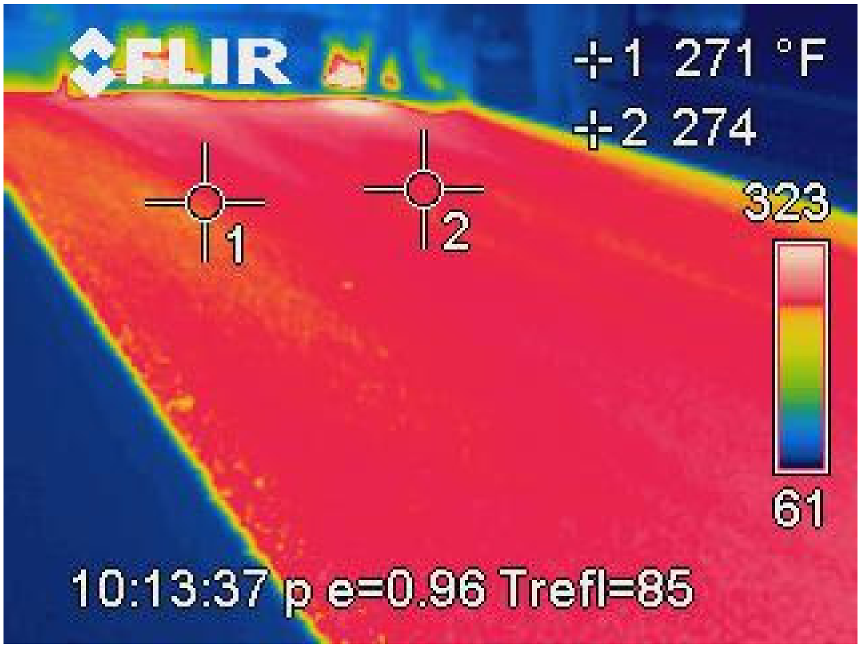


Figure 22. Infrared photo of the mat behind the paver showing uniform temperatures.

Temperature monitoring is important on all hot mix projects, but especially critical on overlays that are as thin as the OGFC used on this project. Documentation of the construction operation is included as Appendix C.

Post-Construction Testing

Friction

Post-construction evaluation of the two test sections of open graded pavement and the control section of Class ½ inch HMA included measurements of friction, smoothness, rutting/wear and noise. Table 8 contains the friction number results for the three pavement types. Tests were performed with a ribbed tire using a locked-wheel friction tester meeting ASTM E-274 requirements. The results indicate very good friction numbers with the values for the control section being slightly higher than the open-graded sections, which are almost equivalent in friction resistance. The values are all well above the required levels for adequate friction resistance.

Table 8. October 2007 FN results.

Pavement Type	Lane	FN
OGFC-AR	1	48.1
OGFC-AR	2	45.3
OGFC-AR	3	44.5
OGFC-AR	HOV	45.5
OGFC-AR Average		**45.9**
OGFC-SBS	1	46.8
OGFC-SBS	2	45.2
OGFC-SBS	3	44.0
OGFC-SBS	HOV	45.1
OGFC-SBS Average		**45.3**
Class ½ inch HMA	1	50.2
Class ½ inch HMA	2	48.2
Class ½ inch HMA	3	47.2
Class ½ inch HMA	HOV	46.9
Class ½ inch HMA Average		**48.1**

Ride

Ride and transverse profile measurements were made shortly after construction on September 29, 2006 and then again on April 5, 2007 and August 6, 2007 using the WSDOT Pathway Pavement Condition Collection Van. Table 9 lists the ride measurements in International Roughness Index (IRI) (inches/mile) for each lane. Figure 23 shows a graph comparing the four values. All of the lanes of all of the sections are showing a slight increase in roughness with time

Table 9. IRI measurements.

Pavement Type	Lane	IRI (in/mile)			
		Sept. 2006	Apr. 2007	Aug. 2007	Oct. 2007
OGFC-AR	1	48	51	53	58
OGFC-AR	2	36	40	40	44
OGFC-AR	3	39	42	42	47
OGFC-AR	HOV	39	40	43	45
OGFC-SBS	1	43	45	52	55
OGFC-SBS	2	48	49	57	59
OGFC-SBS	3	43	44	48	51
OGFC-SBS	HOV	48	50	57	62
½ Inch HMA	1		64	53	71
½ Inch HMA	2		64	46	66
½ Inch HMA	3		58	51	65
½ Inch HMA	HOV		71	60	72

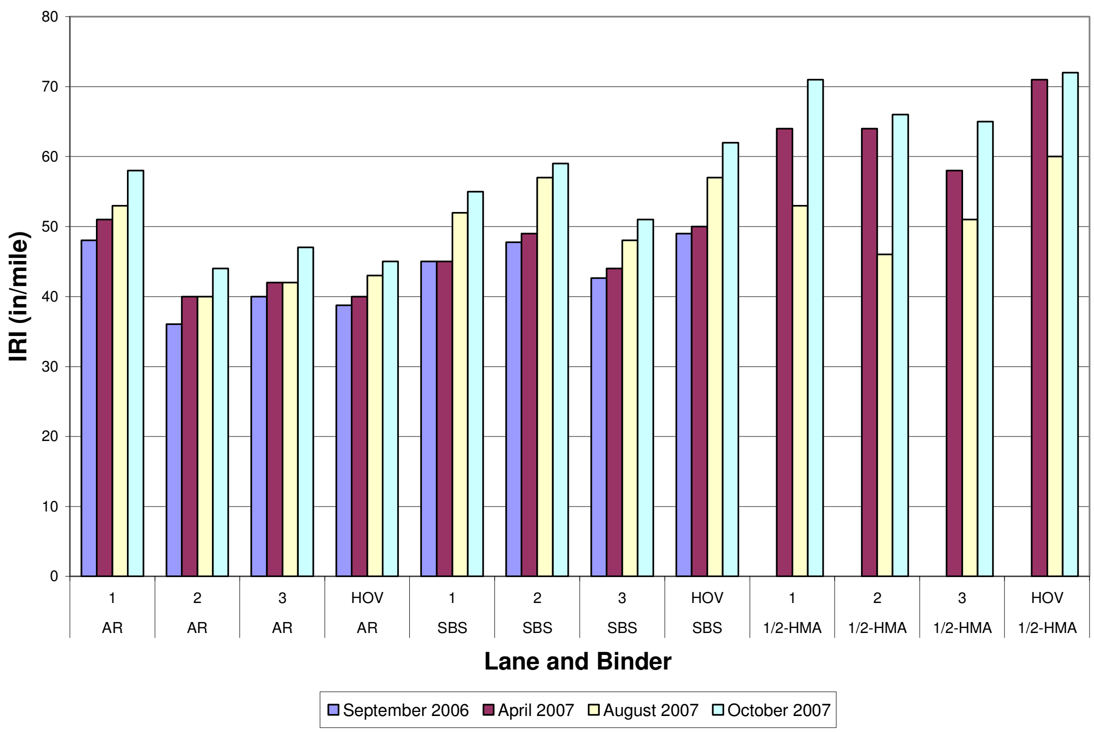


Figure 23. IRI measurements.

Wear/Rutting

The transverse profile measurements, which indicate the wear or rutting in the wheel paths, is listed in Table 10 and shown graphically in Figure 24. The wear/rutting measurement show a gradual increase over time for the SBS and control section, but the AR section follows a different pattern. After an increase in the April readings the measurements show a gradual decrease in wear or rutting with time.

Table 10. Wear/rutting measurements.					
Pavement Type	**Lane**	**Wear/Rutting (mm)**			
		Sept. 2006	**Apr. 2007**	**Aug. 2007**	**Oct. 2007**
OGFC-AR	1	1.7	2.6	2.4	2.6
OGFC-AR	2	1.9	2.5	2.2	2.3
OGFC-AR	3	1.5	2.1	1.7	2.0
OGFC-AR	HOV	1.3	1.9	1.4	1.5
OGFC-SBS	1	1.9	2.2	2.2	2.4
OGFC-SBS	2	1.7	2.4	2.8	3.0
OGFC-SBS	3	2.0	2.4	2.0	2.3
OGFC-SBS	HOV	1.8	2.0	1.9	2.0
½ Inch HMA	1		1.9	1.7	2.2
½ Inch HMA	2		2.4	2.1	2.8
½ Inch HMA	3		2.2	1.9	2.6
½ Inch HMA	HOV		1.8	1.4	1.9

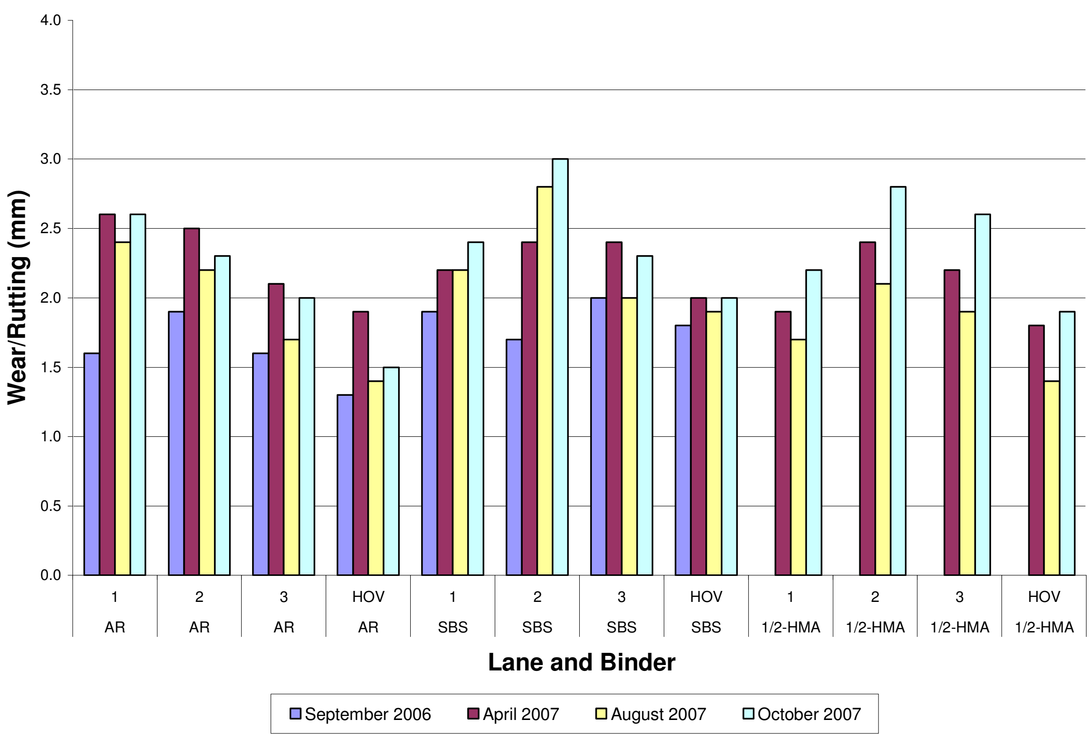


Figure 24. Wear/rutting measurements for all three pavement types.

Noise Measurement

Noise measurement is a new concept to the paving community. Therefore, the following information on the measurement of noise is included to briefly introduce the subject. Information provided is from an FHWA presentation by Judith L. Rochat, U.S. DOT/Volpe National Transportation Systems Center at the Quiet Asphalt 2005 A Tire/Pavement Noise Symposium held on November 1-3, 2005 at Purdue University, Lafayette, Indiana.

There are three types of sound measurements currently used to characterize highway noise as noted below:

1. Source measurement: measures the effect of pavement on tire/pavement interaction source level.
2. Sound absorption measurement: measures the effect of pavement on sound absorption.
3. Wayside measurement: measures the effect of pavement on communities.

There are various ways to measure each of the three types as will be described in the following sections.

Source Measurement

There are three types of source measurements; (1) the Close-Proximity Method (CPX), (2) the On-Board Sound Intensity (OBSI), and the laboratory drum method (DR). The Close-Proximity Method uses microphones near the tire to measure sound pressure. The tire is mounted on a separate vehicle, usually a special trailer with enclosures around the tire to minimize contamination. This is the type of measurement used by the National Center for Asphalt Technology (NCAT), ADOT, and throughout most of Europe. The On-Board Sound Intensity method uses two adjacent microphones mounted near the tire to measure sound intensity levels. The microphones are mounted on a vehicle, usually a rear tire, but no enclosure is used to reduce noise from outside sources. This method was developed by General Motors and has been used by the California Department of Transportation (Caltrans) and ADOT and is the method that was used in this study. The final method, the laboratory drum method, is used only in the laboratory. A pavement-lined drum rotates against a tire mounted external to the drum. Microphones near the tire measure sound pressure levels similar to the Close-Proximity Method. It is currently used only at a facility located at Purdue University.

Sound Absorption Measurement

There are also three types of sound absorption measurements; (1) impedance tube, (2) impulse response, and (3) ground impedance using effective flow resistivity. The impedance tube methods takes measurement in the laboratory on core samples from the pavement. A sound source (loudspeaker) is mounted at one end of an impedance tube and a sample of the pavement is placed at the other end. The loudspeaker generates broadband, stationary random sound waves that are reflected back from the sample. Sound pressure readings are taken at two points in the tube and from these the sound absorption coefficient can be determined.

The impulse response method can be used in the laboratory or in-situ. A source of sound is used to produce a response from the pavement surface which is then measured. It is similar to the impedance tube method except the measurement is taken in an essentially free field, that is, there is no confinement of the sound by a tube. There is only one microphone used and it measures both the intensity of the source and the amount of absorption by the pavement.

The ground impedance method uses point source, two-microphone configuration set up on a pavement surface in the field. Data is captured for multiple frequencies to characterize the pavement.

The impedance tube method is used strictly in the laboratory. The impulse response and ground impedance methods are used in the field but require a closure of a lane to make the measurements.

Wayside Measurement

There are four types of wayside measurements; (1) Statistical Pass-By Method (SPB), (2) Controlled Pass-By Method (CPB), (3) Coast-By Method (CB) and (4) Time-Averaging Method. All four methods use a microphone set at a prescribed distance away from and height above the roadway. The Statistical Pass-By Method measures the sparse highway traffic with a single sound level representing a minimum of 180 single vehicle pass-bys. Traffic (counts, categorizations, speeds) and meteorological data must be captured. SPB has been used by Caltrans and Oregon Department of Transportation for noise studies.

The Controlled Pass-By Method is similar to the SPB except that a limited number of controlled vehicles are used to generate the noise. It has been used in both Caltrans and ADOT studies and in several European studies. The Coast-By Method is identical to the CPB except the engine of the control vehicle is switched off during the pass-by.

The Time-Averaging Method measures the existing traffic over a prescribed time period. Traffic (counts, categorization, and speeds) and meteorological data must be captured. The method has been used by Caltrans, ADOT and ODOT for studies.

Noise Measurement Equipment

The On Board Sound Intensity method was the one chosen by WSDOT because the noise produced by the tire/pavement is the only one that can be controlled by changes in the pavement characteristics. Two adjacent microphones are mounted vertically near a tire to measure the sound intensity levels, Figure 25. Data from the microphones is sent to the computer shown in Figure 26. The computer collects the sound information as 11 separate data points corresponding to frequencies from 500 to 5,000 Hz. The tire used on the vehicle is a Uniroyal Tiger Paw AWP (P225/60R16) which is equivalent to the Goodyear Aquatred III (P205/70R15) which is the Standard Reference Test Tire (SRTT).

Figure 25. Twin microphones mounted near the rear tire of a vehicle. Note Uniroyal Tiger Paw tire.

Figure 26. Computer used for data collection.

Results

Initial measurements were made on the existing HMA pavement prior to the overlay to serve as a base line. This section ranged in age from eight to twenty years with an average of approximately twelve years. The sound intensity readings ranged between 103.8 and 105.3 with an average of 104.6 dBA. After completion of the open-graded overlays, sound intensity measurements were conducted on a monthly basis, weather permitting (noise measurements cannot be made when the pavement is wet) on all lanes of the three sections, OGFC-AR, OGFC-SBS and Class ½ inch HMA.

Table 11 summarizes the sound intensity measurements for the OGFC-AR section. The same information is plotted in Figure 27.

Table 11. Sound intensity measurements for OGFC-AR.

Date	Lane 1	Lane 2	Lane 3	HOV	Average
8/23/2006	94.7	95.0	94.9	95.7	95.1
9/7/2006	94.3	95.6	94.6	95.5	95.0
9/28/2006	96.0	95.6	96.0	96.2	96.0
10/17/ 2006	97.9	97.7	101.1	96.9	98.4
12/4/2006	98.1	97.8	96.6	95.2	96.9
12/28/2006	101.8	98.2	97.9	-	99.3
1/25/2007	100.4	98.7	-	-	99.6
3/6/2007	98.9	101.1	99.3	98.8	99.5
3/21/2007	103.3	103.4	100.9	99.0	101.7
4/23/2007	100.5	101.4	99.2	97.9	99.7
5/29/2007	101.2	101.7	98.4	98.3	99.9
6/26/2007	100.5	101.5	99.0	97.1	99.5
7/26/2007	99.6	101.3	98.6	96.9	99.1
9/6/2007	100.4	101.6	98.7	96.8	99.4
9/26/2007	100.6	101.8	99.5	97.6	99.9
10/31/2007	102.4	103.6	101.1	98.8	101.5
12/6/2007	103.2	104.1	101.7	100.0	102.2

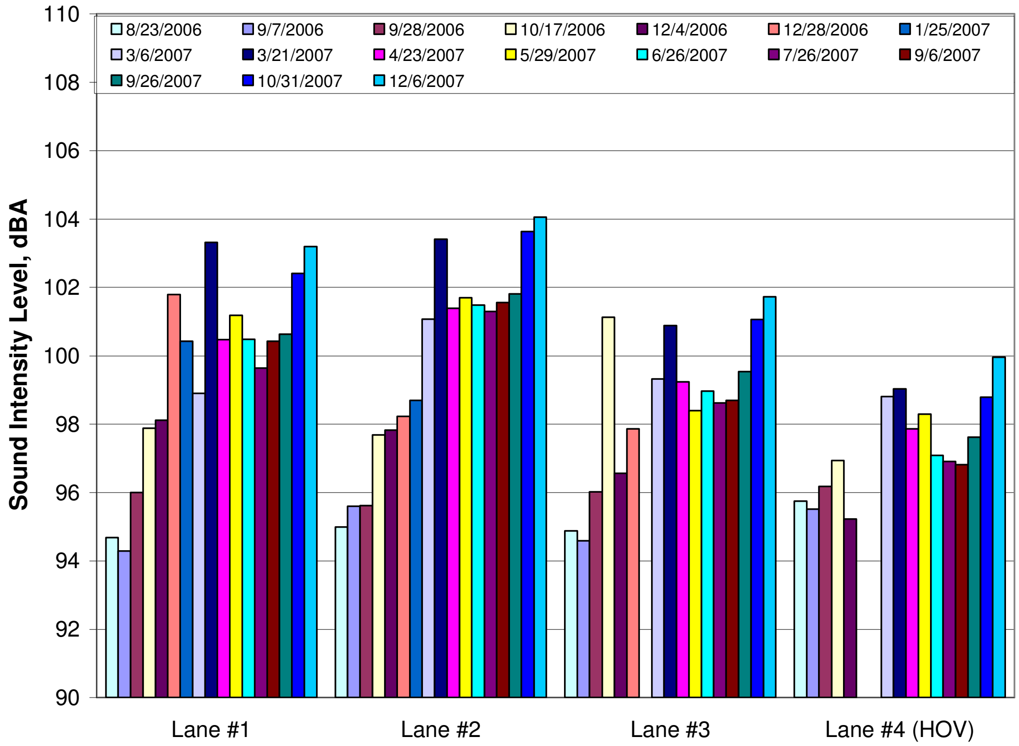


Figure 27. Sound intensity measurements for OGFC-AR.

All of the lanes of the OGFC-AR have increased in sound intensity level since opening to traffic with Lane 2 showing the greatest increase and the HOV lane the least increase. All of the lanes recorded their peak sound intensity reading during the winter of 2006-07 and appear to be repeating that pattern based on the most recent reading on December 6.

Table 12 summarizes the measurements for the OGFC-SBS section and Figure 28 plots those same results.

Table 12. Sound intensity measurements for OGFC-SBS					
Date	Lane 1	Lane 2	Lane 3	HOV	Average
9/7/2006	96.3	95.8	96.1	95.7	96.0
9/28/2006	96.6	96.4	96.3	95.8	96.3
10/17/2006	100.1	96.9	97.0	98.1	98.0
12/4/2006	98.1	97.1	97.3	96.7	97.3
12/28/2006	101.8	101.3	98.9	96.9	99.7
1/25/2007	98.1	100.1	-	-	99.1
3/6/2007	97.2	98.6	98.8	98.0	98.2
3/21/2007	102.0	101.7	99.5	98.9	100.5
4/23/2007	100.0	100.2	98.4	98.8	99.4
5/29/2007	100.2	100.1	98.2	98.3	99.2
6/26/2007	99.8	99.8	97.4	97.6	98.7
7/26/2007	99.2	98.8	96.7	97.1	96.0
9/6/2007	97.9	98.6	96.6	97.4	97.6
9/26/2007	100.3	99.0	97.0	97.5	98.5
10/31/2007	100.8	99.6	98.1	98.4	99.2
12/6/2007	101.6	100.7	97.9	99.0	99.8

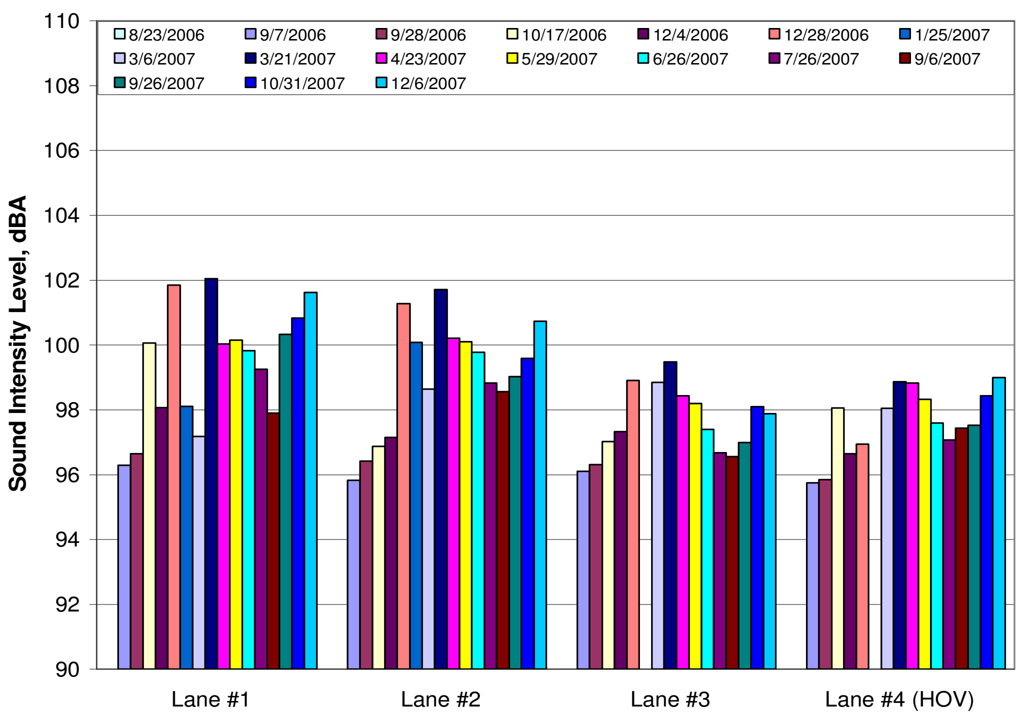


Figure 28. Sound intensity measurements for OGFC-SBS.

The pattern of the sound intensity measurements on the OGFC-SBS section was similar to the OGFC-AR section with all lanes showing an increase throughout the winter months and a decrease during the spring and summer and then another increase through the fall and winter. The December and March measurements were the highest sound intensity readings for the 2006-07 winter for all of the lanes except the HOV which had peaks in October and March.

The measurements on the Class ½ inch HMA used on the remainder of the project are shown in Table 13 and in Figure 29.

Table 13. Sound intensity measurements for Class 1/2 inch HMA.

Date	Lane 1	Lane 2	Lane 3	HOV	Average
8/23/2006	99.5	100.0	99.0	99.2	99.4
9/7/2006	97.8	99.5	99.2	98.8	98.8
9/28/2006	97.7	99.1	99.1	99.8	98.9
10/17/2006	100.4	100.0	100.2	100.6	100.3
12/4/2006	100.1	100.7	99.8	100.8	100.3
12/28/2006	102.1	102.0	101.5	101.6	101.8
1/25/2007	101.3	101.7	101.3	100.9	101.3
3/6/2007	100.6	101.5	101.4	102.5	101.5
3/21/2007	102.1	102.9	102.4	101.8	102.3
4/23/2007	101.7	102.2	101.5	100.5	101.5
5/29/2007	102.5	102.3	101.8	100.5	101.8
6/26/2007	100.8	101.2	100.4	99.8	100.6
7/26/2007	101.6	101.5	101.6	100.4	101.3
9/6/2007	101.7	102.0	100.2	99.8	100.9
9/26/2007	101.8	102.2	101.6	100.6	101.6
10/31/2007	103.2	103.4	102.6	101.7	102.7
12/6/2007	103.4	103.3	102.1	101.6	102.6

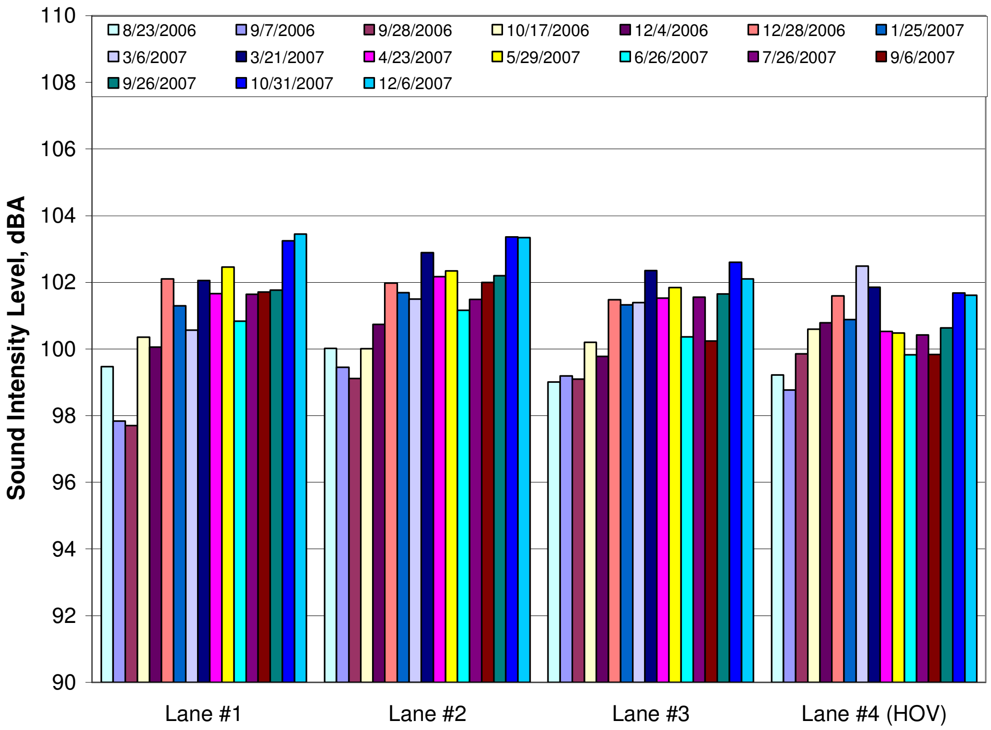


Figure 29. Sound intensity measurements for Class ½ inch HMA.

The ½ inch HMA showed the same trend as the OGFC-AR and OGFC-SBS with an increase over the winter months and a decrease during the spring and summer of 2007 and then back up during the fall to the present reading on December 6, 2007. The level of increase during the winter was of a lesser magnitude than either the OGFC-AR or OGFC-SBS sections and the overall variation throughout the year did not fluctuate as widely as either of the open-graded mixes.

The sound intensity levels for all three pavement types show erratic results through the winter months and then show a dip through the spring and summer before increasing again in the fall and winter. There could be several explanations for this phenomena; (1) temperature may affect either the pavement or the measuring equipment, (2) the voids in the pavement surface are being filled with fine material during the winter sanding season and then flushed out in the spring and summer, and (3) the use of studded tires from October 1 through March 31 may be producing additional small aggregate particles that are filling the voids along with the sand mentioned previously. The Class ½ inch HMA section does not show as much of the up and down pattern as the two open-graded mixes which may give strong support to the theory that the void structure is being filled in the open-graded pavements and causing the rise in sound intensity levels. The HMA also does not show the wide variations in readings that were noted in the first winter for the AR and SBS sections, but does show the dip in levels through the warmer spring and summer months. Therefore, there could be two causes operating simultaneously, void filling and temperature. Additional data collection is necessary before a definite conclusion can be drawn.

Noise Measurement Analysis

A comparison of the sound intensity readings for the new HMA, the OGFC-AR and the OGFC-SBS is shown in Table 14. The September 2006 and September 2007 measurements were chosen for the comparison in an attempt to minimize the affects of either temperature or void filling on the readings. The average sound intensity level for all lanes of the asphalt rubber section increased from 95.0 dBA to 99.9 dBA, an increase of 4.9 dBA. In contrast the average for the OGFC-SBS and Class ½ inch HMA control section only increased 2.5 and 2.8 dBA, respectively. The increase for individual lanes for the OGFC-AR ranged between 2.1 dBA and 6.3 dBA and between 0.9 and 4.0 dBA for the OGFC-SBS section. The range of increase for the Class ½ inch HMA control section was 1.8 to 4.0 dBA.

Table 14. Change in sound intensity level (dBA) from September 2006 to September 2007.

Section	Lane 1	Lane 2	Lane 3	HOV	All Lanes
Asphalt Rubber	6.3	6.2	4.9	2.1	4.9
SBS	4.0	3.2	0.9	1.8	2.5
Class½ inch HMA	4.0	2.7	2.4	1.8	2.8

The average sound intensity level for the OGFC-AR lanes was 99.9 dBA in September of 2007. Comparing this to the average sound intensity level of the control section of Class ½ inch HMA lanes, which is a 101.6 dBA, there is a difference of only 1.7 dBA. The same comparison between the OGFC-SBS lanes and the control section result in a difference of 3.1 dBA (101.6-98.5). The literature indicates that a change of 1 to 3 dBA is "just perceptible" to the human ear and it is only at a level of 5 dBA that a change is "noticeable" (Quiet Asphalt 2005).

Additional sound intensity measurements were made on September 6, 2007 to determine if the pavement that has not experienced as much concentrated traffic (i.e. the center of the lane) has the same or different sound intensity levels as the wheel path. Two runs were made for each pavement type and each position in Lane 2 only. Figure 30 shows the results from the runs and the initial readings taken after construction. The OGFC-SBS and Class ½ inch HMA are almost the same as the initial readings right after construction. In contrast, the OGFC-AR reading in the center of the lane is 1.1 dBA higher than the initial post-construction measurement. A comparison of the readings between those made in the wheel paths and those made in the center of the lane reveals that the noise levels in the wheel paths for the OGFC-SBS and Class ½ inch HMA are about 2.6 and 2.4 dBA higher, respectively, than in the center of the lane. The OGFC-AR is 4.9 dBA higher in the wheel path than in the center of the lane, indicating the likelihood that more damage from studded tires is occurring.

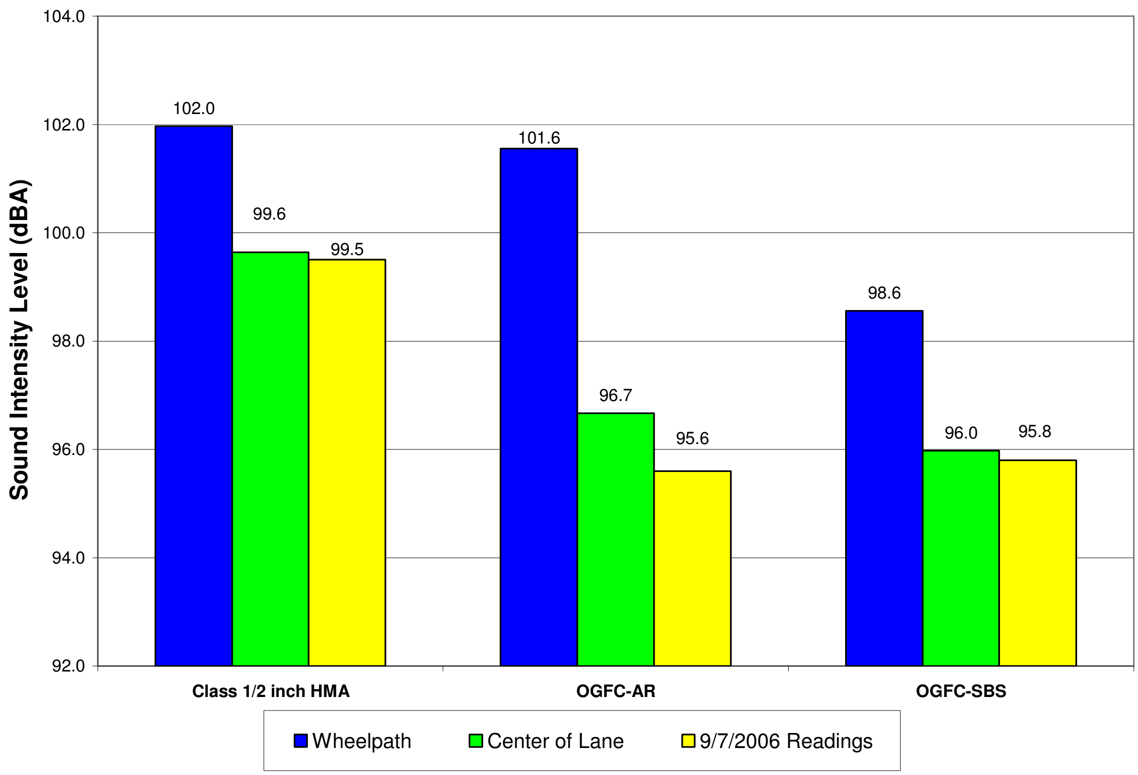


Figure 30. Sound intensity level variation with position in the lane and in comparison to the initial post-construction readings.

Splash and Spray

One of the attributes of open-graded pavements is its ability to reduce the splash and spray from vehicles during periods of rain. The interconnected void structure of the pavement allows the rain to infiltrate into the pavement and make its way to the shoulder through these interconnected passages. The result is almost no splash and spray. This attribute, however, does not always last the life of the pavement. The void structure of the pavement is susceptible to filling with sand sized particles deposited from vehicles or as a result of sanding during snowy winter periods. This clogging of the voids occurred in as little as three years on the open-graded pavements built in the early 1980's.

The only method of measuring a pavements ability to reduce splash and spray is visual observation. A telephone call to NW Region Maintenance Superintendent, Jim Danninger, confirmed that the two sections of open-graded pavement do have less splash and spray than the surrounding dense-graded pavements as of the summer of 2007.

Long-Term Performance

The long-term performance of both the OGFC-AR and OGFC-SBS are of special interest to WSDOT given its past history with open-graded pavements. Appendix D contains an in-house report from September of 1995 on the performance of past-generation open-graded pavements which are also called Class D mixes. WSDOT first started using these types of pavements in the late 1970's. The use of these pavements was short lived, however, due to rutting and raveling problems that caused many to not reach their targeted eight year life. Sections of open-graded mix built on heavily traveled urban interstates lasted as few as four years with the most common life being seven to eight years. Open-graded pavements placed on roadways with less traffic performed much better as can be seen in Figure 31 which plots the time to a 1/2 inch rut against average daily traffic (ADT) per lane. The data plotted is from 56 sections of open-graded pavement built between early 1978 and 1997 (a complete listing of all 56 sections is found in Appendix E). The ½ inch rut depth was the trigger for scheduling rehabilitation because of the safety issue with respect to the potential for hydroplaning and their minimal thickness of 3/4 to 1 inch.

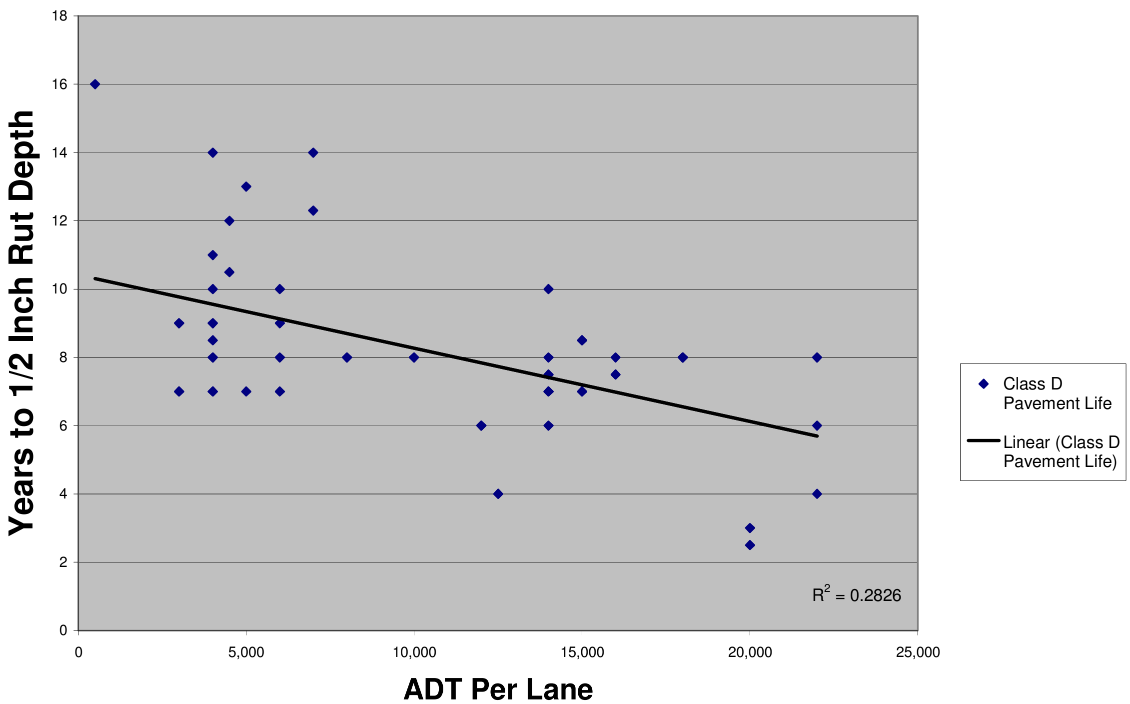


Figure 31. OGFC pavement life for various amounts of traffic.

The life of open-graded pavements was not only dependent on traffic, but also on the number of vehicles using studded tires. The Eastern Region has one of the highest percentages of vehicles with studded tires and as a result has a history of problems with pavement wear. A few sections reached an age of eight years, but in general the life span was in the four to six year range, which is not acceptable. As a result, all of the 147 lane miles of open-graded pavements in the Region were resurfaced with dense graded mixes by 1995.

The Southwest Region's experience was similar to that of the Eastern Region. Excessive wear of most of their sections occurred between the seventh and eighth year, sometimes earlier. Studded tires are not as big an issue in the Southwest Region; however, there are some indications that wear from the use of tire chains may have also contributed to the excessive wear. The other factor that contributed to the shortened life of the open-graded pavements was the heavy concentration of traffic, since most of the sections were on I-5 in the Vancouver urban area.

The South Central Region has one of the best performance histories for these types of pavements, probably due to lower traffic volumes, less studded tire use and more favorable climatic conditions. The favorable climatic conditions are warm, dry summers and winters without much snow.

The short service life coupled with the higher cost of this type of pavement (Eastern Region documented that the Class D mixes were 1.73 times more expensive than Class B dense graded mix) resulted in WSDOT's discontinued use of this mix type in September of 1995.

Conclusions

The special test sections of OGFC-AR and OGFC-SBS were constructed, from all indications, according to the specifications. The use of an MTV insured that the mix going into the paving machine was uniform in temperature and as a result no significant temperature differentials were observed in the mat behind the paver. Post-construction testing also confirmed that the pavement placed was up to standards and suitable for the long-term evaluation of the benefits of open-graded pavements with respect to friction resistance, ride, rutting, splash and spray and tire/pavement noise mitigation.

The conclusions that can be drawn from the data currently available are:

- The OGFC-SBS pavement is performing better than the asphalt rubber binder pavement with respect to tire/pavement noise mitigation.
- The difference in sound intensity levels between the control section of Class ½ inch HMA and the OGFC-SBS section is at the "just perceptible" level to the human ear.
- The differences between the sound intensity levels of the OGFC-AR section and the control section or OGFC-SBS section are not perceptible to the human ear.
- Studded tire wear is having a significant negative impact on the sound intensity measurements on all sections with the OGFC-AR section showing the greatest increase in dBA level since construction.

Future Research

This project will be monitored for a period of at least five years with data collected on friction, ride, wear, splash and spray and noise. Annual reports will be issued that summarize the changes in each of the variables mentioned previously. A final report will be written at the conclusion of the evaluation period. Details of the evaluation plan can be found in Appendix F.

References

Quiet Asphalt 2005: *A Tire/Pavement Noise Symposium*, November 1-3, 2005, Lafayette, Indiana. Asphalt Pavement Alliance, Institute for Safe, Quiet and Durable Highways, North Central Superpave Center, and Purdue University, 2005.

Appendix A

Mix Designs

ARIZONA DEPARTMENT OF TRANSPORTATION
MATERIALS GROUP

414 AR ACFC Mix Design | Lab # 2006-09050 | Date: 07/17/2006

This design meets ADOT Specifications

Tracs # XM12201X | Project # XM12201X | Project Name: WSDOT C-7134
Resident Engineer: | Contractor: WILDER CONSTRUCTION COMPANY

General Design Information

lab# 2006-16133 CRA Grade CRA-2	CRA Source	CRA Specific Gravity 1.041
lab# 2006-16132 PG Grade PG64-22	PG source	PG Specific Gravity 1.017
lab# 2006-00364 Rubber Type B	Rubber Source CRM	% by wt of asphalt cement 22.0
Admixture Type NONE Design% 0.0	Admix Source	Admix Specific Gravity
		Total number of stockpiles: 3

Aggregate

	lab#	Description	Pit#	Design %
1.	2006-00353	3/8" Chips	B335	72
2.	2006-00352	#4-8 Sand	B335	20
3.	2006-00351	#4-0	B335	8
4.				
5.				
6.				
7.				
			Total	100%

Composite Gradation

Sieve #	Specification band % passing min	Specification band % passing max	Gradation w/o admix % passing	Gradation w/admix % passing	Field Target Band % passing min	Field Target Band % passing max
1 ½"			100			
1"			100			
¾"			100			
½"			100			
3/8"	100		100			
¼"			64			
#4	30	45	34			
#8	4	8	8			
#10			7			
#16			5			
#30			4			
#40			3			
#50			2			
#100			1			
#200	0.0	2.5	1.5			

Composite Aggregate Properties

Property	Test Value	min	max
L.A. Abrasion % at 100 revolutions (AASHTO T96)	3		9
L.A. Abrasion % at 500 revolutions (AASHTO T96)	13		40
Sand Equivalent (AZ 242)	58	45	
Two Fractured Faces, % (AZ 212)	95	85	
Flakiness Index, % (AZ 238)	14		25
Carbonates, % (AZ 238)	0.9		30
Combined O.D. Specific Gravity (AZ 210)	2.679	2.35	2.85
Corrected Combined O.D. Specific gravity (with admix)	2.679		
Combined Water Absorption, % (AZ 814)	1.31		2.50

Calculated Mix Properties Results		
Description	Design Values	Specification Limits
Design Binder Content	9.2	
Bulk Density pcf	119.9	
Asphalt Absorption	0.26	< 1.0

Stockpile Gradations			
	2006-00354 3/8" Chips	2006-00352 #4-8 Sand	2006-00351 #4-0
Sieve #			
1 ½"	100	100	100
1"	100	100	100
¾"	100	100	100
½"	100	100	100
3/8"	100	100	100
¼"	51	98	99
#4	15	77	95
#8	2	4	70
#10	2	2	64
#16	1	1	50
#30	1	0	36
#40	1	0	30
#50	0	0	25
#100	0	0	18
#200	0.4	0.1	13.7

Laboratory Aggregate Specific Gravity Test Results				
Type	O.D. Sp. Gr.	SSD Sp. Gr.	Water Absorption %	Tested On
Fine (AZ 211)	2.503	2.585	3.26	-#8
Coarse (AZ 210)	2.695	2.726	1.11	-#8

Laboratory Rice Data (AZ 806)			
% Asphalt	Maximum Specific Gravity	Maximum Density – pcg	Effective Specific Gravity
4.0	2.536	158.0	2.697

This design has been prepared and submitted under the direction of:

Lab Supervisor: Hu, Changming   Bituminous Engineer: Simpson, Don

Remarks: The design is acceptable on the condition that the 3/8" chips are scalped to remove material retained on the 3/8" sieve.

Design approved by: ________________________________

MACTEC

engineering and constructing a better tomorrow

July 7, 2006

Mr. Nathan Huschka
Granite Construction
38000 Monroe Street
Indio, California 92203

Subject: **Asphalt-Rubber Binder Testing**
Washington Department of Transportation
WaDOT Project Name: I-5, 52nd Avenue to SR 526, SB Paving and Safety
WaDOT Project Number: 05A045
MACTEC Lab No. 68943
MACTEC Project No. 4975-06-0060

Dear Mr. Huschka:

As authorized by Granite Construction, MACTEC Engineering and Consulting, Inc. (MACTEC) has completed a series of tests on asphalt cement and crumb rubber for the subject asphalt-rubber (A-R) binder. The materials used for this A-R binder design are presented below and were submitted to our Phoenix laboratory by supplier representatives. A summary of the tests performed and MACTEC's results are presented in this report.

Materials

Material	Source/Supplier	Phoenix, Arizona
PG 64-22 Asphalt Cement	Tesoro Corporation	Anacortes, Washington
AD-here LOF 65-00 Liquid Anti-Strip	Arr Maz Custom Chemicals	Mulberry, Florida
Scrap Tire (WaDOT) Crumb Rubber Modifier	Crumb Rubber Manufacturers	Rancho Domingo, California

Asphalt Cement Grade Confirmation

Test	Result	Specified Limits
Dynamic Shear Rheometer, 64°C, G*/sinδ (T315)	1.20	1.00 minimum

CRM Physical Analysis

Test	Result	Specified Limits
Metal Content, %	None	None
Fiber Content, %	Trace	0.5 Maximum
Specific Gravity (D1817)	1.157	1.1-1.2

CRM Gradation, Percent Passing (AASHTO T 11/27)

Sieve Size	Result	Specified Limits
2.00 mm/No. 10	100.0	100
1.18 mm/No. 16	70.6	65 - 100
600 µm/No. 30	30.3	20 - 100
300 µm/No. 50	9.0	0 - 45
150 µm/No. 100	1.8	
75 µm/No. 200	0.2	0 - 5

MACTEC Engineering and Consulting, Inc.
3630 East Wier Avenue • Phoenix, AZ 85040 • Phone: 602.437.0250 • Fax: 602.437.3675
www.mactec.com

Washington DOT, I-5, 52nd Ave to SR 526
Granite Construction
MACTEC Project No. 4975-06-0060 (68943)

July 7, 2006
Asphalt-Rubber Binder Testing

As specified by Wilder Construction and directed by Granite Construction, 0.5% liquid anti-strip by weight of asphalt cement was added to the PG 64-22 asphalt cement. It should be noted that use of liquid anti-strip in A-R binders is not typical ADOT practice and MACTEC does not have any documentation as to its effectiveness in open-graded asphalt-rubber concrete mixes. Mineral admixture, usually hydrated lime, is typically included to enhance resistance to moisture damage and there is a considerable body of experience with its effectiveness in such mixes. Hydrated lime provides some additional benefits in its interaction with the A-R binder that enhance binder stiffness and curing of the resulting hot mix when it is newly placed and most vulnerable to damage by traffic. MACTEC does not know if substitution of liquid anti-strip for mineral admixture will have any adverse impacts on long term pavement performance.

The asphalt-rubber binder testing was performed in our laboratory by heating a known quantity of the blended asphalt cement and liquid anti-strip to 204°C (400°F). The CRM, (proportioned by total binder weight) was slowly added to the hot asphalt cement and liquid anti-strip. The asphalt rubber blend was tested for viscosity at 177°C (350°F) using a Haake style Viscotester Model VT-04 with Rotor 1, resilience (ASTM D5329), softening point (ASTM D36), and needle penetration (ASTM D5). The gradation of the CRM was determined in accordance with AASHTO T 11/27. Results of testing are presented in this report.

A variety of interaction periods were conducted to evaluate stability and retention of properties of the asphalt-rubber binder. The interaction periods cover a time range to identify properties after completion of field mixing (60 minutes after addition of the CRM), and possible job delay (4 to 6 hours). Tests at 24 hours (with exposure from 6 to 22 hours at a lower temperature to simulate overnight-unheated storage) were also performed to evaluate the stability of the asphalt rubber blend. Results of this testing indicate properties remain satisfactory throughout the 24 hour reaction period.

The proportions of Crumb Rubber Modifier (CRM) and PG 64-22 Asphalt Cement with 0.5% AD-here LOF 65-00 presented in this A-R binder design are as follows:

PHYSICAL PROPERTIES OF ASPHALT-RUBBER BINDER

18.0% Crumb Rubber (Crumb Rubber Manufacturers)
82.0% Asphalt Cement with 0.5% Anti-Strip (Tesoro PG 64-22/Arr Maz AD-here LOF 65-00)

Test Performed	Minutes of Reaction					Specified Limits
	60	90	240	360	1,440	
Rotational Viscosity at 350°F, Pa's, (10^{-3}), or cP	2100	2400	2700	2700	2200	1500 - 4000
Resilience at 77°F, % Rebound (D5329)	40		39		38	25 Minimum
Ring & Ball Softening Point, °F (D36)	148	150	149	149	147	130 Minimum
Penetration at 39.2°F, 200g, 60 sec., 1/10 mm (D5)	22		21		24	15 Minimum

Washington DOT, I-5, 52nd Ave to SR 526
Granite Construction
MACTEC Project No. 4975-06-0060 (68943)

July 7, 2006
Asphalt-Rubber Binder Testing

If you have any questions regarding this information or if we may be of further assistance in any way, please do not hesitate to contact us.

Sincerely,

MACTEC ENGINEERING AND CONSULTING, INC.

Sam W. Huddleston
Principal Scientist

Anne Stonex
Senior Engineer

SWH:AS:adm

(projects\4975\4975-06-0060\deliverables\68943arb)

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

TEST OF: OPEN GRADED FRICTION COARSE (OGFC) — WORK ORDER NO: 007134
DATE SAMPLED: 6/28/2006 — LAB ID NO 0000230062
DATE RECVD HQS: 7/6/2006 — TRANSMITTAL NO: 230062
SR NO: 5 — MIX ID NO: G61681
SECTION: 52nd AVENUE WEST TO SR 526, SB PAVING AND SAFETY

CONTRACTOR'S PROPOSAL

Mat'l:	3/8" CHIPS	#4-0	#4 - #8 SAND	COMBINED	SPECIFICATIONS
Source:	B-335	B-335	B-335		
Ratio:	66%	13%	21%		
3/8"	99.8	100.0	100.0	100	100
No. 4	12.3	93.9	78.4	37	35 – 55
No. 8	1.2	63.2	4.3	10	9 – 14
No. 200	0.7	12.0	0.5	2.1	0 – 2.5

LABORATORY ANALYSIS — SPECIFICATIONS

				SPECIFICATIONS
ASPH% BY TOTAL WT OF MIX:	**7.8**	**8.3**	**8.8**	
% VOIDS @ Ndes: 50	18.8	18.3	19.4	15.0 Min.
% VMA @ Ndes: 50	31.1	31.4	33.3	24.0 Min.
% Gmm @ Ndes: 50	81.3	81.7	80.7	82.0 Max.
Draindown @ 339°F	0.0	0.0	0.1	0.3 Max.
Stabilizing Additive	0.3	0.3	0.3	0.2 – 0.5
Gmm – MAX S. G. FROM RICE	2.427	2.417	2.392	
Gmb – BULK S. G. OF MIX	1.972	1.976	1.929	
Gsb – OF AGGREGATE BLEND	2.638	2.638	2.638	
Gsb – OF FINE AGGREGATE	2.551	2.551	2.551	
Gb – SPECIFIC GRAVITY OF BINDER	1.025	1.025	1.025	

LOTTMAN STRIPPING EVALUATION

% ANTI-STRIP	0.0%	1/4 %	1/2 %	3/4 %	1.0%
Visual Appearance:	SLIGHT	NONE	NONE	NONE	NONE
% Retained Strength:	84	107	115	113	139

RECOMMENDATIONS

SUPPLIER	U.S. OIL
GRADE	PG70-22
% ASPHALT (BY TOTAL MIX)	8.3
% ANTI-STRIP (BY WT. ASPHALT)	0.25
TYPE OF ANTI-STRIP	ARR-MAZ 6500
MIX ID NUMBER	G61681
MIXING TEMPERATURE	346°F
COMPACTION TEMPERATURE	316°F

Headquarters:
Construction Engineer----------------X
Materials File--------------------------X
General File----------------------------X
Bituminous Section------------------ X
Region: Northwest
Construction Office- 41 ----------X
Materials Eng------- 41 ----------X
P.E.: M. LENSSEN --X(2)

T152 - 3
T153 -
T166 - 3
T172 -
T175 -
T178 - 1

REMARKS: **Revised report to reflect adjusted asphalt content and completed mix design test data, 8/24/06.**

THOMAS E. BAKER, P.E.
Materials Engineer
By: Dennis M. Duffy P.E. ____________________
(360)709-5420
Date: 8 / 24 / 2006

Appendix B

Special Provisions

Description

The first paragraph of Section 5-04.1 is supplemented with the following:

(******)
This work shall consist of providing and placing Quieter Pavement overlays consisting of Open Graded Friction Course (OGFC) and Open Graded Friction Course Asphalt-Rubber (OGFC-AR) on the existing roadway in accordance with these Specifications and lines, grades, thicknesses, and typical cross-sections shown in the Plans and shall meet the requirements for hot-mix asphalt as modified herein.

OGFC shall consist of a mixture of asphalt, mineral aggregate, mineral filler, and other additives properly proportioned, mixed and applied on a paved surface.

OGFC-AR shall consist of a mixture of rubberized asphalt, mineral aggregate, mineral filler and other additives properly proportioned, mixed and applied on a paved surface.

Materials

The first paragraph of Section 5-04.2 is supplemented with the following:

(******)
Portland Cement, Type II9-02.1(1)
Hydrated Lime ASTM C 1097

The third paragraph of Section 5-04.2 is supplemented with the following:

(******)
The use of RAP shall not be used in the OGFC or OGFC-AR.

The fourth paragraph of Section 5-04.2 is supplemented with the following:

(******)
Asphalt binder material for the OGFC shall be PG 70-22. SBS modifier shall be added to the neat asphalt to produce a binder that complies with the requirements for PG 70-22.

Asphalt binder material for the OGFC-AR shall be asphalt-rubber conforming to the requirements of Asphalt Rubber (A). The crumb rubber gradation shall conform to the requirements of Asphalt-Rubber (B).

In no case shall the asphalt-rubber be diluted with extender oil, kerosene, or other solvents. Any asphalt-rubber so contaminated shall be rejected.

Asphalt-Rubber

(A) Asphalt Binder

Asphalt binder shall be PG 58-22 or PG 64-22 conforming to the requirements of 9-02, Bituminous Materials.

(B) Crumb Rubber

Rubber shall meet the following gradation requirements when tested in accordance with AASHTO T 11/27.

Sieve Size	Percent Passing
No. 8	100
No. 10	100
No. 16	65 – 100
No. 30	20 – 100
No. 50	0 – 45
No. 200	0 – 5

The rubber shall have a specific gravity of 1.15 ± 0.05 and shall be free of wire or other contaminating materials, except that the rubber shall contain not more than 0.5 percent fabric. Calcium carbonate, up to four percent by weight of the granulated rubber, may be added to prevent the particles from sticking together.

Certificates of Compliance conforming to 1-06.3 shall be submitted. In addition, the certificates shall confirm that the rubber is a crumb rubber, derived from processing whole scrap tires or shredded tire materials; and the tires from which the crumb rubber is produced are taken from automobiles, trucks, or other equipment owned and operated in the United States. The certificates shall also verify that the processing does not produce, as a waste product, casings or other round tire material that can hold water when stored or disposed of above ground.

Asphalt-Rubber Proportions

The asphalt-rubber shall contain a minimum of 20 percent ground rubber by the weight of the asphalt binder.

Asphalt-Rubber Properties

Certificate of Compliance conforming to 1-06.3 shall be submitted to the Engineer showing that the asphalt-rubber conforms to the following:

Property	Requirement
Rotational Viscosity*: 350 ^{o}F; pascal seconds	1.5 - 4.0
Penetration: 39.2 ^{o}F, 200 g, 60 sec. (ASTM D 5); minimum	15
Softening Point: (ASTM D 36); ^{o}F, minimum	130
Resilience: 77 ^{o}F (ASTM D 5329); %, minimum	25

* The viscotester used must be correlated to a Rion (formerly Haake) Model VT-04 viscotester using the No. 1 Rotor. The Rion viscotester rotor, while in the off position, shall be completely immersed in the binder at a temperature from 350 to 355 F for a minimum heat equilibrium period of 60 seconds, and the average viscosity determined from three separate constant readings (± 0.5 pascal seconds) taken within a 30 second time frame with the viscotester level during testing and turned off between readings. Continuous rotation of the rotor may cause thinning of the material immediately in contact with the rotor, resulting in erroneous results.

Asphalt-Rubber Binder Design

At least two weeks prior to the use of asphalt-rubber, the Contractor shall submit an asphalt-rubber binder design prepared by one of the following laboratories who have experience in asphalt-rubber binder design:

MACTEC Engineering and Consulting, Inc.
Contact: Anne Stonex
Address: 3630 East Wier Avenue
Phoenix, Arizona 85040
Phone: (602) 437-0250

Western Technologies, Inc.
Contact: John Hahle
Address: 2400 East Huntington Drive
Flagstaff, Arizona 86004
Phone: (928) 774-8700

Such design shall meet the requirements specified herein. The design shall show the values obtained from the required tests, along with the following information: percent, grade and source of the asphalt binder used; and percent, gradation and source(s) of rubber used.

Construction Requirements

Section 5-04.3 shall be supplemented with the following:

(******)

During production of asphalt-rubber, the Contractor shall combine materials in conformance with the asphalt-rubber design unless otherwise approved by the Engineer.

Direct transfer of the OGFC and OGFC-AR from the hauling equipment to the paving machine will not be allowed. A Shuttle Buggy will be required to deliver the OGFC and OGFC-AR from the hauling equipment to the paving machine.

Mixing of Asphalt-Rubber

The temperature of the asphalt binder shall be between 350 and 400°F at the time of addition of the ground rubber. No agglomerations of rubber particles in excess of two inches in the least dimension shall be allowed in the mixing chamber. The ground rubber and asphalt binder shall be accurately proportioned in accordance with the design and thoroughly mixed prior to the beginning of the one-hour reaction period. The Contractor shall document that the proportions are accurate and that the rubber has been uniformly incorporated into the mixture. Additionally, the Contractor shall demonstrate that the rubber particles have been thoroughly mixed such that they have been “wetted.” The occurrence of rubber floating on the surface or agglomerations of rubber particles shall be evidence of insufficient mixing. The temperature of the asphalt-rubber immediately after mixing shall be between 325 and 375°F. The asphalt-rubber shall be maintained at such temperature for one hour before being used.

Prior to use, the viscosity of the asphalt-rubber shall be tested and conform to the asphalt-rubber properties, which is to be furnished by the Contractor or supplier.

Handling of Asphalt-Rubber

Once the asphalt-rubber has been mixed, it shall be kept thoroughly agitated during periods of use to prevent settling of the rubber particles. During the production of asphaltic concrete the temperature of the asphalt-rubber shall be maintained between 325 and 375°F. However, in no case shall the asphalt-rubber be held at a temperature of 325°F or above for more than 10 hours. Asphalt-rubber held for more than 10 hours shall be allowed to cool and gradually reheated to a temperature between 325 and 375°F before use. The cooling and reheating shall not be allowed more than one time. Asphalt-rubber shall not be held at temperatures above 250°F for more than four days.

For each load or batch of asphalt-rubber, the contractor shall provide the Engineer with the following documentation:

1. The source, grade, amount and temperature of the asphalt binder prior to the addition of rubber.
2. The source and amount of rubber and the rubber content expressed as percent by the weight of the asphalt binder.
3. Times and dates of the rubber additions and resultant viscosity test.
4. A record of the temperature, with time and date reference for each load or batch. The record shall begin at the time of the addition of rubber and continue until the load or batch is completely used. Readings and recordings shall be made

at every temperature change in excess of 20°F, and as needed to document other events which are significant to batch use and quality.

HMA Mixing Plant

Section 5-04.3(1) ~~shall be~~ is supplemented with the following:

(******)
Fiber Supply System
When fiber stabilizing additives are required for OGFC, a separate feed system that meets the following will be required:

1) Accurately proportions by weight the required quantity into the mixture in such a manner that uniform distribution will be obtained.
2) Provides interlock with the aggregate feed or weigh systems so as to maintain the correct proportions for all rates of production and batch sizes.
   a) Controls dosage rate accurately to within plus or minus 10 percent of the amount of fibers required.
   b) Automatically adjusts the feed rate to maintain the material within the 10 percent tolerance at all times.
   c) Provides flow indicators or sensing devices for the fiber system that are interlocked with plant controls so that mixture production will be interrupted if introduction of the fiber fails or if the output rate is not within the tolerances given above.
3) Provides in-process monitoring, consisting of either a digital display of output or a printout of feed rate, in pounds per minute to verify the feed rate.

When a batch type plant is used, the fiber shall be added to the aggregate in the weigh hopper or as approved by the Engineer. The batch dry mixing time shall be increased by 8 to 12 seconds, or as directed by the Engineer, from the time the aggregate is completely emptied into the mixer. The fibers are to be uniformly distributed prior to the injection of the asphalt binder into the mixer.

When a continuous or drier-drum type plant is used, the fiber shall be added to the aggregate and uniformly dispersed prior to the injection of asphalt binder. The fiber shall be added in such a manner that it will not become entrained in the exhaust system of the dryer or plant.

Surge and Storage Systems
The storage time for OGFC mixtures not hauled immediately to the project shall be no more than 4 hours.

Hot Mix Asphalt Pavers

Section 5-04.3(3) is supplemented with the following:

(******)
For OGFC and OGFC-AR the direct transfer of these materials from the hauling equipment to the paving machine will not be allowed. A Shuttle Buggy shall be used to deliver the OGFC and OGFC-AR from the hauling equipment to the paving machine.

The Shuttle Buggy shall mix the OGFC and OGFC-AR after delivery by the hauling equipment but prior to laydown by the paving machine. Mixing of the OGFC and OGFC-AR shall be sufficient to obtain a uniform temperature throughout the mixture.

Rollers
Section 5-04.3(4) is supplemented with the following:

(******)
The wheels of the rollers used for Quieter Pavement shall be wetted with water, or if necessary soapy water, or a product approved by the Engineer to prevent the OGFC or OGFC-AR from sticking to the steel wheels during rolling.

A minimum of three static steel wheel rollers, weighing no less than eight tons, shall be provided. The drums shall be of sufficient width that when staggered, two rollers can cover the entire lane width.

Vibratory rollers must be used in the static mode only.

A pass shall be defined as one movement of a roller in either direction. Coverage shall be the number of passes as are necessary to cover the entire width being paved.

Two rollers shall be used for initial breakdown and be maintained no more than 300 feet behind the paving machine. The roller(s) for final compaction shall follow as closely behind the initial breakdown as possible. As many passes as is possible shall be made with the rollers before the temperature of the OGFC or OGFC-AR falls below 220 °F.

Preparation Of Existing Surfaces
Section 5-04.3(5)A is supplemented with the following:

(******)
For OGFC and OGFC-AR, a tack coat of CRS-2 or CRS-2P shall be applied to the existing surface at a rate of 0.12 to 0.20 (0.08 to 0.12 residual) gallons per square yard or as otherwise directed by the Engineer.

(NWR February 9, 2004)
The Contractor shall limit the amount of tack coat placed to that amount that will be fully covered by the asphalt overlay at the end of each work shift.

In accordance with Section 1-07.15(1) **Spill Prevention, Control and Countermeasures Plan** (SPCC), as part of the SPCC the Contractor shall address the mitigating measures to be taken in the event that the paving operation is suspended or terminated prior to the asphalt for tack coat being fully covered.

Mix Design
Section 5-04.3(7)A is supplemented with the following:

(******)

4. **Mix Design (OGFC-AR)** Approximately 500 pounds of produced mineral aggregate, in proportion to the anticipated percent usage, shall be obtained that are representative of the mineral aggregate to be utilized in the OGFC-AR production.

   The Contractor shall also furnish representative samples of the following materials: a five-pound sample of the crumb rubber proposed for use, one gallon of asphalt binder from the intended supplier, five gallons of the proposed mixture of binder and rubber, and a one-gallon can of the mineral admixture to be used in the OGFC-AR.

   Along with the samples furnished for mix design testing, the contractor shall submit a letter explaining in detail its methods of producing mineral aggregate including wasting, washing, blending, proportioning, etc., and any special or limiting conditions it may propose. The Contractor's letter shall also state the source(s) of mineral aggregate, the source of asphalt binder and crumb rubber, the asphalt-rubber supplier, and the source and type of mineral admixture.

   The above materials and letter shall be shipped to the Arizona DOT Central Laboratory at 1221 North 21st Avenue, Phoenix, AZ 85009 (Attention – Julie Nodes), with companion materials and letter sent to the WSDOT State Materials Laboratory in Tumwater. Within 10 working days of receipt of all samples and the Contractor's letter in the Arizona DOT Central Laboratory, the Arizona DOT will provide the Contractor with the percentage of asphalt-rubber to be used in the mix, the percentage to be used from each of the stockpiles of mineral aggregate, the composite mineral aggregate gradation, the composite mineral aggregate and mineral admixture gradation, and any special or limiting conditions for the use of the mix.

   Mix Design (OGFC) Mixtures shall be compacted with 50 gyrations of a Superpave Gyratory Compactor and the draindown at the mix production temperature (AASHTO T 305) shall be 0.3 max.

5. **Mix Design Revisions.** The Contractor shall not change its methods of crushing, screening, washing, or stockpiling from those used during production of material used for mix design purposes without approval of the Engineer, or without requesting a new mix design.

   During production of OGFC and OGFC-AR, the Contractor, on the basis of field test results, may request a change to the approved mix design. The Engineer will evaluate the proposed changes and notify the contractor of the Engineer's decision within two working days of the receipt of the request.

   If, at any time, unapproved changes are made in the source of bituminous material, source(s) of mineral aggregate, production methods, or proportional changes in violation of approved mix design stipulations, production shall cease until a new mix design is developed, or the Contractor complies with the approved mix design.

At any time after the mix design has been approved, the Contractor may request a new mix design.

The costs associated with the testing of materials in the developing of mix designs after a mix design acceptable to the Department has been developed shall be borne by the Contractor.

If, during production, the Engineer on the basis of testing determines that a change in the mix design is necessary, the Engineer will issue a revised mix design. Should these changes require revisions to the Contractor's operations which result in additional cost to the Contractor, it will be reimbursed for these costs.

6. **Fiber Stabilizing Additives.** If needed, fiber stabilizing additives shall consist of either cellulose fibers, cellulose pellets or mineral fibers and meet the properties described below. Dosage rates given are typical ranges but the actual dosage rate used shall be approved by the Engineer.

A. Cellulose Fibers: Cellulose fibers shall be added at a dosage rate between 0.2% and 0.5% by weight of the total mix as approved by the Engineer. Fiber properties shall be as follows:

1.	Fiber length:	0.25 inch (6 mm) max.
2.	Sieve Analysis	
	a. Alpine Sieve Method Passing No. 100 sieve:	60-80%
	b. Ro-Tap Sieve Method Passing No. 20 sieve: Passing No. 40 sieve: Passing No. 100 sieve:	 80-95% 45-85% 5-40%
3.	Ash Content:	18% non-volatiles (±5%)
4.	pH:	7.5 (±1.0)
5.	Oil Absorption: (times fiber weight)	5.0 (±1.0)
6.	Moisture Content:	5.0% max.

B. Cellulose Pellets: Cellulose pellets shall consist of cellulose fiber and may be blended with up to 20% asphalt cement. If no asphalt cement is used, the fiber pellet shall be added at a dosage rate between 0.2% and 0.5% by weight of the total mix. If asphalt cement is blended with the fiber, the pellets shall be added at a dosage rate between 0.4% and 0.8% by weight of the total mix.

1.	Pellet size:	1/4 in³ (6 mm³) max.
2.	Asphalt:	25 - 80 pen.

C. Mineral Fibers: Mineral fibers shall be made from virgin basalt, diabase, or slag and shall be treated with a cationic sizing agent to enhance disbursement of the fiber as well as increase adhesion of the fiber surface to the bitumen. The fiber shall be added at a dosage rate between 0.2% and 0.5% by weight of the total mix.

1.	Size Analysis:	
	Average Fiber length:	0.25 in. (6 mm) max.
	Average Fiber thickness:	0.0002 in. (0.005mm) max.
2.	Shot content (ASTM C1335)	
	Passing No. 60 sieve (250 µm):	90 - 100%
	Passing No. 230 sieve (63 µm):	65 - 100%

Acceptance Sampling and Testing – HMA Mixture

Section 5-04.3(8)A is revised as follows:

Item 3 is supplemented with the following:

(******)

Sampling - OGFC and OGFC-AR

OGFC and OGFC-AR will be evaluated for quality of gradation based on samples taken from the cold feed bin.

Item 5 is supplemented with the following:

(******)

Test Results - OGFC and OGFC-AR

Mineral Aggregate Gradation - OGFC

For the OGFC, a sample shall be taken in accordance with WSDOT T-2 on a random basis just prior to the addition of mineral admixture and bituminous materials. At least one sample shall be taken during the production of the OGFC. Samples will be tested for conformance with the mix design gradation. The gradation of the mineral aggregate shall be considered to be acceptable, unless average of any three consecutive tests or the result of any single test varies from the mix design gradation percentages as follows:

Passing Sieve	Mixture Control Tolerance
⅜ Inch	± 5.7
No. 4	± 5.5
No. 8	± 4.5
No. 200	± 2.0

(******)
Mineral Aggregate Gradation - OGFC-AR
For each approximate 300 tons of OGFC-AR, at least one sample of mineral aggregate shall be taken. Samples shall be taken in accordance with WSDOT T-2 on a random basis just prior to the addition of mineral admixture and bituminous materials. Samples will be tested for conformance with the mix design gradation. The gradation of the mineral aggregate shall be considered acceptable, unless the average of any three consecutive tests or the result of any single test varies from the mix design gradation percentages as follows:

Passing Sieve	Number of Tests	
	3 Consecutive	One
No. 4	± 4	± 4
No. 8	± 3	± 4
No. 200	± 1.0	± 1.5

(January 3, 2006)
The first paragraph of item 5 is revised to read:

The Engineer will furnish the Contractor with a copy of the results of all acceptance testing performed in the field within either 24 hours of sampling or four hours after the beginning of the next paving shift, whichever is later. The Engineer will also provide the Composite Pay Factor (CPF) of the completed sublots after three sublots have been produced. The CPF will be provided by the midpoint of the next paving shift after sampling results are completed.

The first sentence in the second paragraph of item 5 is revised to read:

Sublot sample test results (gradation, asphalt binder content, VMA and Va) may be challenged by the Contractor.

The third paragraph of item 5 is revised to read:

The results of the challenge sample will be compared to the original results of the acceptance sample test and evaluated according to the following criteria:

	Deviation
U.S. No. 4 sieve and larger	Percent passing ±4.0
U.S. No. 8 sieve	Percent passing ±2.0
U.S. No. 200 sieve	Percent passing ±0.4
Asphalt binder %	Percent binder content ±0.3
VMA %	Percent VMA ±1.5
Va %	Percent Va ±0.7

The last sentence of item ~~7~~5 is revised to read:

The calculation of the CPF in a test section with a mix design that did not verify will include gradation, asphalt binder content, VMA and Va.

Item 7 is supplemented with the following:

(******)
Test Section - OGFC
A mixture test section shall be constructed off-site prior to production paving of the OGFC. The test section shall be used to determine if the mix meets the requirements of mineral aggregate gradation and recommended asphalt binder content.

For the test section to be acceptable the mineral aggregate gradation shall be within the limits as shown in 5-04.3(8)A as supplemented and the asphalt content varies by no more than ±0.5 percent.

Test Section - OGFC-AR
A mixture test section shall be constructed off-site prior to production paving of the OGFC-AR. The test section shall be used to determine if the mix meets the requirements of mineral aggregate gradation and recommended asphalt-rubber binder content.

For the test section to be acceptable the mineral aggregate gradation shall be within the limits as shown in 5-04.3(8)A as supplemented and the asphalt-rubber content varies by no more than ±0.5 percent.

Compaction

(NWR March 1, 2004)
Control
The first sentence of item 1 in Section 5-04.3(10)B is revised to read:

HMA used in traffic lanes, including lanes for ramps, truck climbing, weaving, speed change, and shoulders, and having a specified compacted course thickness greater than 0.10 foot, shall be compacted to a specified level of relative density.

Joints

Section 5-04.3(12) is supplemented with the following:

(NWR May 9, 2005)
Transverse Joint Seal
The Contractor shall construct contraction joints at the bridge ends/bents as shown in the Plans. The joints shall be sawed to the dimensions shown in the Plans and filled with joint sealant filler meeting the requirement of Section 9-04.2(1).

Joints shall be thoroughly clean and dry at the time of sealing. Care shall be taken to avoid air pockets. The compound shall be applied in two or more layers, if necessary.

Planing Bituminous Pavement

Section 5-04.3(14) is supplemented with the following:

(January 5, 2004)
The Contractor shall perform the planing operations no more than *** five *** calendar days ahead of the time the planed area is to be paved with HMA, unless otherwise allowed by the Engineer in writing.

(January 5, 2004)
At the start of the planing operation the Contractor shall plane a 500 foot test section to be evaluated by the Engineer for compliance with the surface tolerance requirements. The test section shall have a minimum width of 10 feet. If the planing is in accordance with the surface tolerance requirements, the Contractor may begin production planing. If the planing is not in conformance with the surface tolerance requirements, the Contractor shall make adjustments to the planing operation and then plane another test section.

If at any time during the planing operation the Engineer determines the required surface tolerance is not being achieved, the Contractor shall stop planing. Planing shall not resume until the Engineer is satisfied that specification planing can be produced or until successful completion of another test section. The forward speed during production planing shall not exceed the speed used for the test section.

The completed surface after planing and prior to paving shall not vary more than 1/4 inch from the lower edge of a 10-foot straightedge placed on the surface parallel or transverse to the centerline. The planed surface shall have a matted texture and the difference between the high and low of the matted surface shall not exceed 1/8 inch.

Pavement repair operations, when required, shall be accomplished prior to planing.

(January 3, 2006)
Transverse Joints
The full depth end of each lane of planing shall be squared off to form a uniform transverse joint. The Contractor shall construct and maintain a temporary HMA wedge in accordance with Section 5-04.3(11) across the entire width of the transverse edge when traffic is allowed on the planed surface prior to paving. The wedge shall be

constructed before opening the lane to traffic. The Contractor shall remove the wedge immediately prior to paving.

(NWR May 9, 2005)
Transverse Joint Seal
The Contractor shall construct contraction joints at the bridge ends/bents as shown in the Plans. The joints shall be sawed to the dimensions shown in the Plans and filled with joint sealant filler meeting the requirement of Section 9-04.2(1).

Joints shall be thoroughly clean and dry at the time of sealing. Care shall be taken to avoid air pockets. The compound shall be applied in two or more layers, if necessary.

Weather Limitations

Section 5-04.3(16) is supplemented with the following:

(******)
The mixing and placing of OGFC and OGFC-AR shall not be performed when the existing pavement is wet or frozen. OGFC and OGFC-AR shall not be placed when the air temperature is less than 55°F.

Measurement

Section 5-04.4 is supplemented with the following:

(******)
Open-Graded Friction Course and Open-Graded Friction Course Asphalt Rubber will be measured by the ton in accordance with Section 1-09.2, with no deduction being made for the weight of asphalt binder, blending sand, mineral filler or any other component of the mixture.

(NWR May 9, 2005)
Transverse joint seal will be measured by the linear foot of joint sealed.

Payment

Section 5-04.5 is supplemented with the following:

(******)
"Open Graded Friction Course", per ton.
"Open Graded Friction Course" - Asphalt Rubber", per ton.

The unit contract price per ton for "Open-Graded Friction Course" and "Open-Graded Friction Course Asphalt Rubber" shall be full compensation for all costs incurred to carry out the requirements of Section 5-04 except for those costs included in other items which are included in this sub-section and which are included in the proposal.

(NWR May 9, 2005)
"Transverse Joint Seal", per linear foot.
The unit contract price for "Transverse Joint Seal" shall be full pay to complete the work as specified.

Price Adjustment for Quality of HMA

The first paragraph of Section 5-04.5(1)A is revised to read:

> Statistical analysis of quality of gradation, asphalt content and volumetric properties will be performed based on Section 1-06.2 using the following price adjustment factors:

Table of Price Adjustment Factors

Constituent	**Factor "f"**
VMA (Voids in mineral aggregate)	30
Va (Air Voids)	30
All aggregate passing 1/2"	2
All aggregate passing 3/8"	2
All aggregate passing U.S. No. 4	2
All aggregate passing U.S. No. 8	15
All aggregate passing U.S. No. 200	15
Asphalt Binder Content	30

The first two sentences of the second paragraph are revised to read:

> A pay factor will be calculated for sieves listed as a control point for the class of HMA, for the asphalt binder and volumetric properties (VMA and Va).

Appendix C

Comments on Construction of Open-Graded Pavements

Lynnwood Quite Pavements
I-5, 52^{nd} Avenue to SR-526
Construction Comments

The comments within this document are only those of Jim Weston, Pavement Implementation Engineer, and are not necessarily the views of the WSDOT.

TACK APPLICATION

The tack coat for both the OGFC test sections was applied by an Etnyre tack truck. The application of the CRS-2P tack was sporadic at the start of each application but generally very uniform after 500 feet of application. However, there were areas where high application rate caused problems. In these locations, the excess tack coat was picked up by the Shuttle Buggy tires and then deposited on the existing pavement surface as a mound of material. These mounds of cool tack coat would show up in the OGFC-SBS overlay as a cold spot or globule. This did not happen with the OGFC-AR. Tracking of the tack coat by the Shuttle Buggy and delivery trucks was observed in the wheelpaths. The amount of tracking was minimal in areas of good coverage but was somewhat substantial in areas that received light coverage (startup locations).

Figure 32. Image of typical tack application with some pickup visible in the wheelpaths.

DELIVERY VEHICLES

The use of tarps on the HMA delivery trucks and trailers was very sporadic throughout the paving operations. Thermal camera readings of the hot mix in the trucks showed that a cool crust of material had developed that was at a temperature as low as 101ºF whereas the internal temperatures of the mix were at, or above, 300ºF. This project was fortunate to have warmer paving temperatures than are typically seen on night pavers in Western Washington.

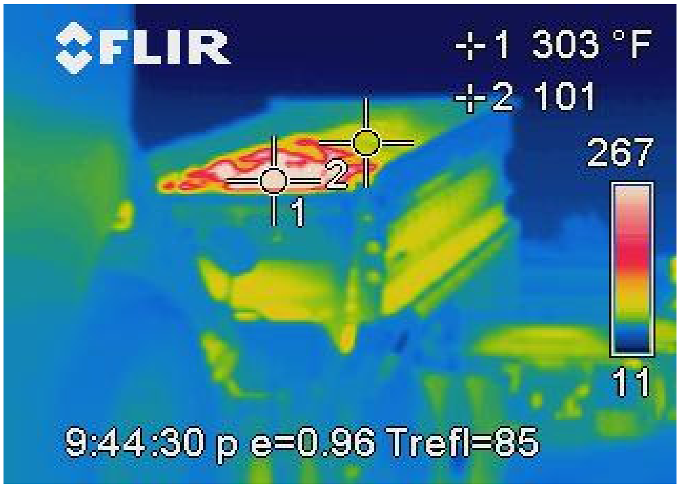


Figure 33. Thermal image of trailer showing cool crust on the HMA at 101° F and internal temperature of 303° F.

MATERIAL TRANSFER VEHICLE

A ROADTEC Shuttle Buggy (SB) material transfer vehicle was used throughout this project. The remixing and storage capabilities of this vehicle made it a smart choice for this project because of the thinness (1/2 inch) of the overlay and the fact that all paving was to be done at night when temperatures are generally cooler. Temperatures from the SB into the paver hopper were typically around 300ºF. The insulating and remixing capability of this device allowed for the pavement to have consistent temperatures across the mat and behind the screed. On the last night of paving and last lane paved, the SB encountered mechanical problems. A decision was made to continue without the SB in order to complete the project that night. This proved to be a poor decision as this section of pavement began to ravel shortly after placement due to the inconsistencies in the density of the mat caused by thermal differentials. The raveling problems resulted in the Contractor having to remove and replace the defective pavement.

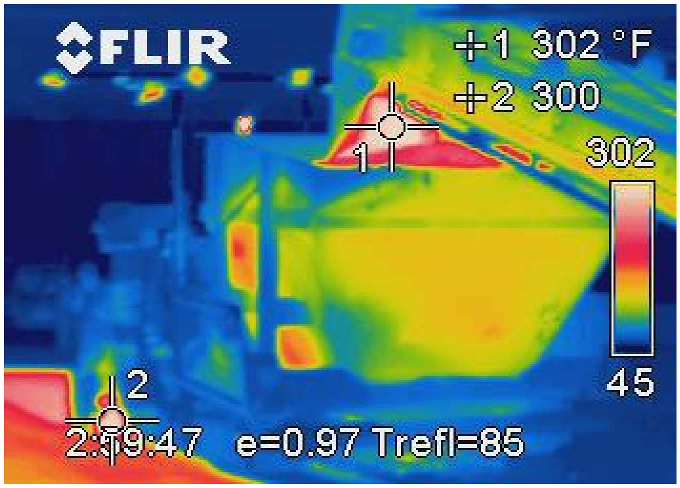


Figure 34. Thermal image of the mix as it leaves the Shuttle Buggy and enters the paver hopper at 302° F and exits the screed at 300° F.

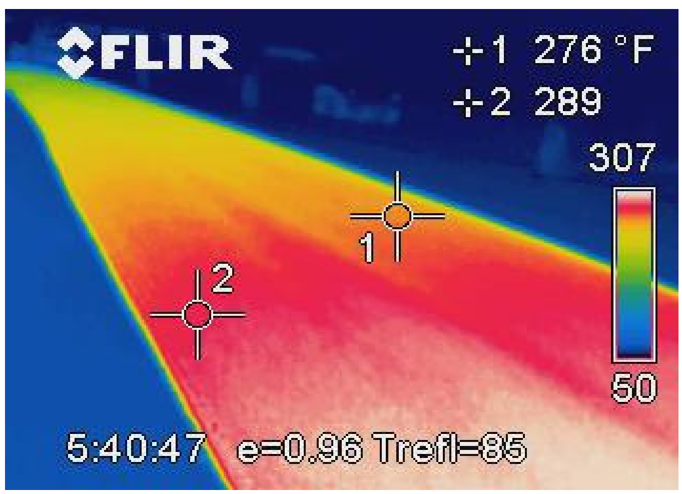


Figure 35. Image from back of screed looking towards the rollers (not shown).

PAVER

A Blaw-Knox PF-5510 paver equipped with what looked like was a 12-ton paver hopper box and a UltiMat screed. This paver was also outfitted with a retrofit kit that kept the screed from being starved at the gearbox. The only paver related problems had to do with the screed. When the screed was extended a cool area of mix would form on the outside edge of the extension. This cool mix would work its way to the front of the screed and then show up in the mat behind the screed.

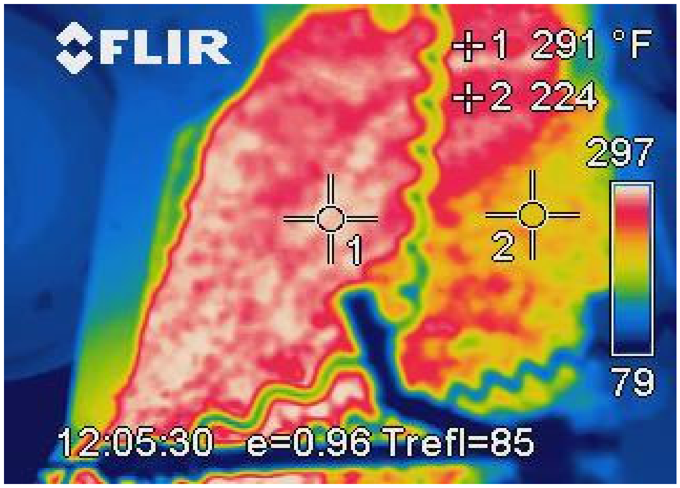


Figure 36. Thermal image looking at augers where spot 1 is typical temperature and spot 2 is where the mix would cool and slowly work to the front of the extended screed.

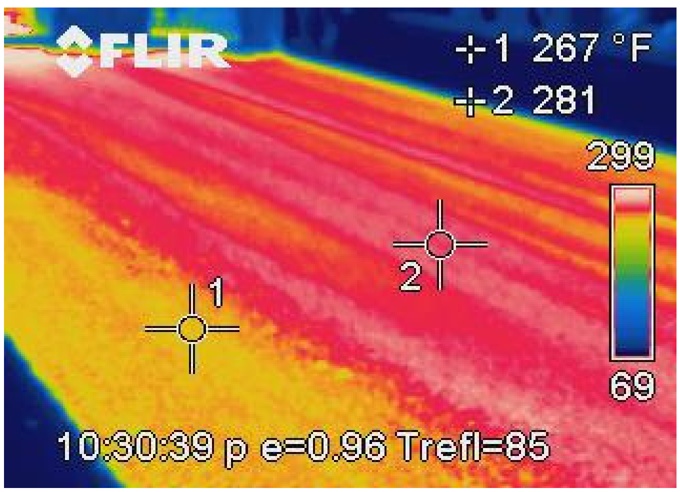


Figure 37. Lower temperature mix behind the screed extension (spot 1) and the higher temperature mix at the middle of the paver (spot 2).

A remedy for the problem of cool mix from the extended screed is probably an auger extension which was not practical for this project that only used the extension for shoulder paving.

The other item, also discussed in *Rollers* was that of the longitudinal joint. It is important to know that the screed should only allow for the material to be approximately ½ inch above the existing joint. Of course this may change slightly depending on the mix design but an OGFC will generally compact in the same manner.

ROLLERS
Three rollers were typically used for the paving of the OGFC-AR and OGFC-SBS. The first three rollers were Ingersoll-Rand DD-130's and a fourth roller (used on one occasion as a finish roller) was an Ingersoll-Rand DD-110. All rollers operated solely in static mode as specified in the contract Special Provisions. The first two rollers worked in tandem so that complete coverage of the lane width could be achieved in one pass. Generally, the only time that the rollers did not meet the requirement to be within 300 feet of the paver was at the beginning of a new lane. This was because while the rollers were addressing the construction at the end of the previous lane the paver would move down the mat, leaving the rollers behind. The only other time that roller operations did not meet specifications were on the first night of production paving (Ramp, Lane 1 and Lane 2) where roller operations began slowly but became more aggressive as the night progressed.

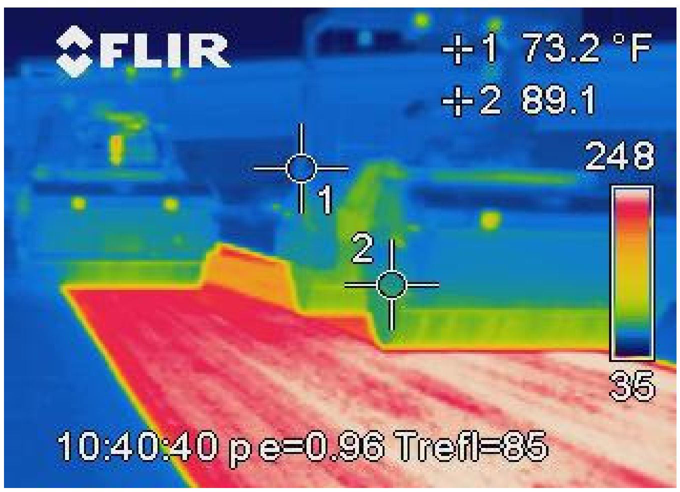


Figure 38. Image of breakdown rollers working in tandem with each other.

The longitudinal joints constructed on the first night of paving were visible, due to the thinness of the pavement and an aggregate structure that resisted compaction. The joints were constructed with nearly ¼ inch height difference between lanes after compaction. This issue appeared to have had two contributing factors; (1) a screed being too high resulting in an excess of mix, and (2) improper roller operation. The longitudinal joint was generally rolled from the cold-side with a four to six inch overlap onto the hot-side. It has been found that rolling from the hot-side with four to six inch overlap to the cold-side results in a better joint[1].

[1] *Longitudinal Joint Construction Technote,* WSDOT, February 2003 - http://www.wsdot.wa.gov/biz/mats/pavement/

Figure 39. Image of the mismatch at the longitudinal joint.

The only way that roller operations could have adhered to the 300-foot specification would be if the paver slowed down at the beginning of the new lane. This would require coordination with the plant and the timing of the delivery trucks so that all of the operations slowed down at the same time. As it was on this project trucks were lined up waiting to transfer their loads to the SB. The result was that the mix cooled in the trucks and thus the start of the next lane had some cooler pavement temperatures.

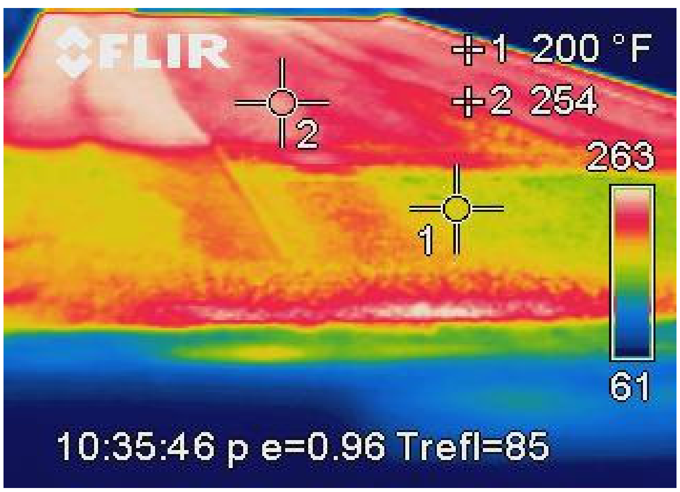


Figure 40. Thermal image of construction joint at startup.

OGFC-AR

OGFC-AR was sticky and adhered to the paving equipment (i.e.: rakes, truck beds, SB tires, etc.). It was difficult to work with this material around utilities, catch basins, and other objects and create a good appearing mat. The sticky nature of the mix resulted in the liberal use of release agents on all of the equipment including the tires of the Shuttle Buggy because it had begun to lift the CRS-2P that was now sticking to the tires. It was thought that this action might affect the long-term performance of the OGFC-AR because it would not have proper adhesion to the existing pavement surface.

Temperatures recorded direction behind the paver where generally between 280 ºF to 290ºF. These temperatures were consistent with those measured in Arizona when paving with the same mix.

OGFC-SBS
The OGFC-SBS was even stickier then the OGFC-AR. It also appeared to be more influenced by the CRS-2P tack coat. As the paver passed over a globule of CRS-2P, it would appear as a cold spot in the mat which, if not removed, became a CRS-2P in the pavement. It is not known to what degree this will affect pavement performance, if at all. This also occurred during the paving of the test section.

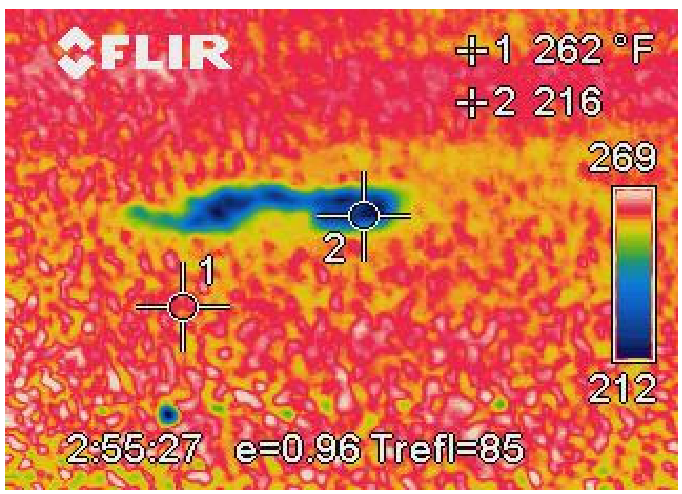


Figure 41. Thermal image of a cool glob of CRS-2P in the newly place OGFC-SBS surface.

OTHER ISSUES
Other issues that were present but not necessarily related to either OGFC-AR or OGFC-SBS was that of mix on the roadway. On two different instances, one OGFC-AR and the other OGFC-SBS, a substantial amount of material was accidentally dumped on the roadway prior to the SB.

For the OGFC-AR, when this happened the mix was picked up using the end-loader of a backhoe. The residual material was approximately ¼ - ½ inch thick and the paver paved over the top of this. This left a cooler spot in the mat where this was paved. In addition, the tires of the SB also tracked through the material that was loaded into the paver hopper. Results of this caused globs of cooler mix to reflect through the new pavement surface which ended up causing fat spots.

One other problem that occurred during the paving was spillage of mix from the paver hopper onto the existing roadway prior to the paving operation. When this happed the clean-up of this spilled mix was not as good as it should have been with the result that some residual material remained. The Shuttle Buggy would track through this material and picking it up on the tires and depositing it as globs of cooler mix to be paved over. The result for the OGFC-AR mix was fat spots in the final mat.

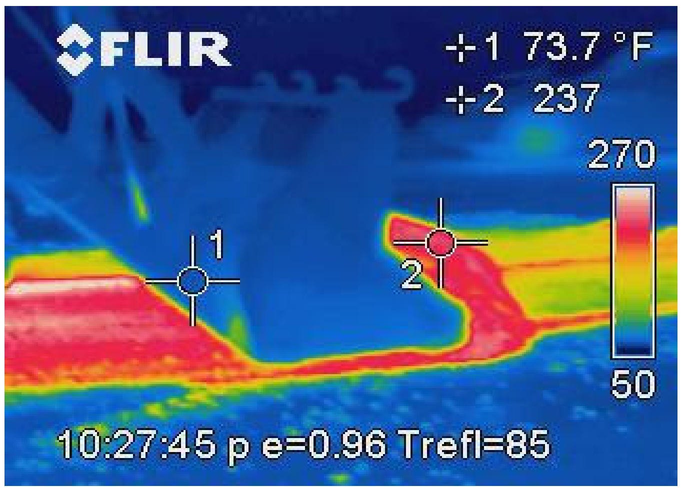


Figure 42. Thermal image of backhoe scooping dumped OGFC-AR from roadway.

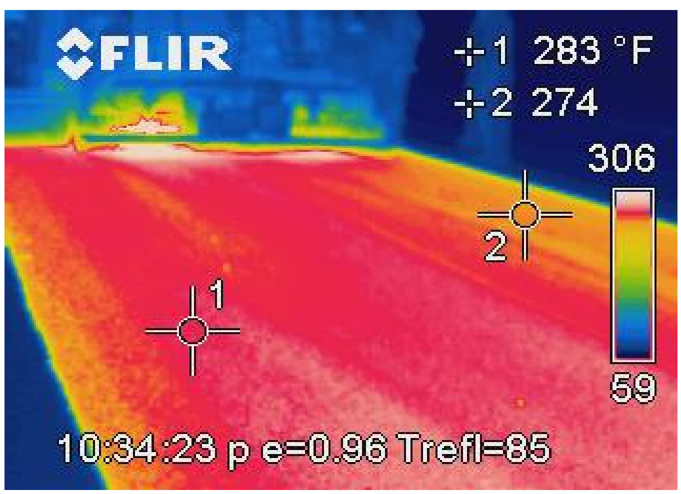


Figure 43. Thermal image where paver paved over remaining material that was picked up.

For the OGFC-SBS, the material lost was not as substantial as that of the OGFC-AR. The spilled mix was picked up using shovels (but more mix was left on the roadway), and the paver continued to pave over the mix. Because there was more mix on the roadway prior to the paver, a slight hump was created where the spilled mix remained. In addition, a significant amount of globs of mix were dropped on the roadway prior to the paver that reflected through. This ended up causing a considerable amount of remedial work to be done. Most of this work was involved in either removing a glob from the pavement, or placing material in a location that had material missing (this was typically caused from a glob that would drag under the paver until coming loose).

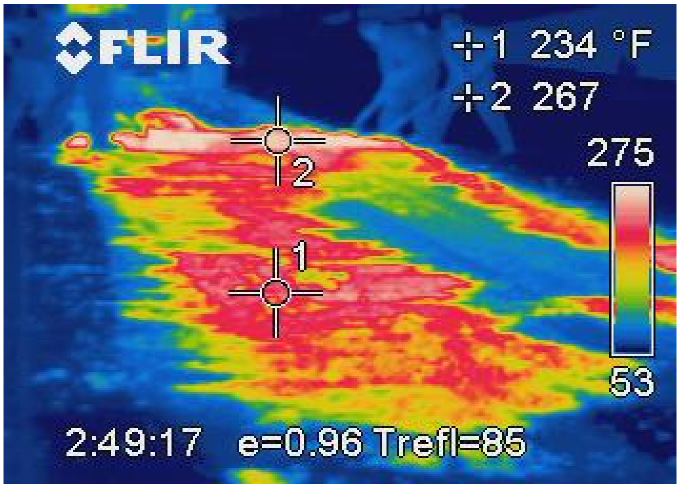


Figure 44. Thermal image of dumped material being shoveled.

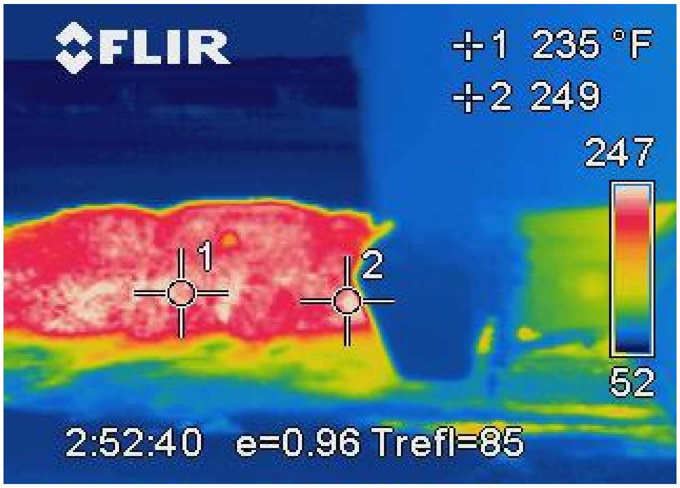


Figure 45. Thermal image of paver paving over remaining material on roadway.

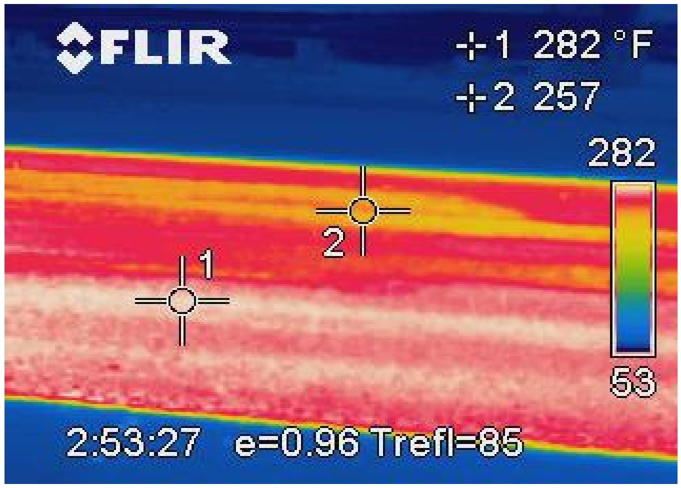


Figure 46. Image of cool spot where paver paved over remaining mix on roadway.

RECOMMENDATIONS

- It may be of benefit on future projects that use CRS-2P as a tack coat to modify the tack specifications to ensure an even application of the material. This might include a test of the tack coat truck prior to beginning paving to ensure that all of the snivies are clean and operating properly.
- Specify that tarps be used on all trucks and trailers to ensure maximum heat retention in the mix between the plant and the paving operation.
- Specify a material transfer vehicle be used on all thin lift open-graded friction course projects.
- Specify that the retrofit kit be used on all applicable paver models.
- Specify that auger extensions be used when the screed is extended a certain specified distance.

COMMENTS

- Proper procedures need to be adhered to when matching the pavement thicknesses at the longitudinal joint and proper rolling techniques need to be employed in order to ensure a tight, flush joint.
- The temperature of the screed should be at the same temperature as the mix prior to starting the paving operation.
- All of the paving operations need to be coordinated in order to adhere to keep the rollers within 300 feet of paver.
  - Slow down production at the plant at the end of the completion of one lane so that the material does not build up when the paver is being moved.
  - Don't load too many trucks prior to working at a construction joint.
  - Allow the rollers time to work effectively at the construction joint.
  - Keep the pavers moving consistently at a slow speed.

  - Ensure the paver doesn't begin paving out until rollers have completed the work at a construction joint.
- Minimize handwork as much as possible.
- Keep delivery trucks and MTV tires as clean as possible to avoid bringing debris into work area.
- Keep work area as clean as possible at all times. If material gets dumped onto the roadway, or build-up on tires becomes excessive, clean thoroughly. Remember that this is a thin surface and defects will reflect through.

Appendix D

In-House Report on Class D HMA Performance

ASSESSMENT OF ASPHALT CONCRETE PAVEMENT - CLASS D

September 1995

OVERVIEW

Rehabilitation of Washington State highways does not always require additional pavement structure but merely some type of surface treatment. For roadways with small average daily traffic (ADT), low speeds and adequate structure, a bituminous surface treatment (BST) will provide the desired surface. On higher ADT routes a BST (or chip seal) is not a practical option, as the roadway may have to be restricted or closed during construction. In addition, flying rock caused by higher vehicle speeds causes headlight and windshield damage.

To allow a surface treatment, similar to a BST, on heavily trafficked routes Class D asphalt is used. Class D asphalt overlays are used primarily to seal and maintain aged, but otherwise structurally sound pavements. Class D asphalt pavement (known previously as "open-graded asphalt seal coat") is commonly referred to as "open-graded asphalt pavement", and is basically a chip seal aggregate mixed hot in a plant with a relatively high percentage of asphalt cement. Class D overlays are placed with an asphalt paver at a compacted depth of 0.06 ft.

Class D asphalt differs from WSDOT's "standard" paving mix such as Class A or B in that the compacted mix appears as a honeycombed matrix. This matrix is caused by the gradation of aggregate where there is a higher percentage of course than fine aggregate. Essentially, there are not enough fine particles to fill the voids between the larger rocks. The result of this open-graded mixture is that water can drain laterally through the pavement.

BENEFITS

One of the benefits of this material for WSDOT is its use as a finish overlay over both lanes and shoulders when only the lanes are milled out and replaced. As Class D asphalt is designed for wearing surfaces only, the total pavement structure of the roadway must be in adequate condition prior to placement. This material does not add structural capacity, but acts to seal and restore skid resistance to certain roadways. WSDOT's targeted service life for a Class D overlay is eight years.

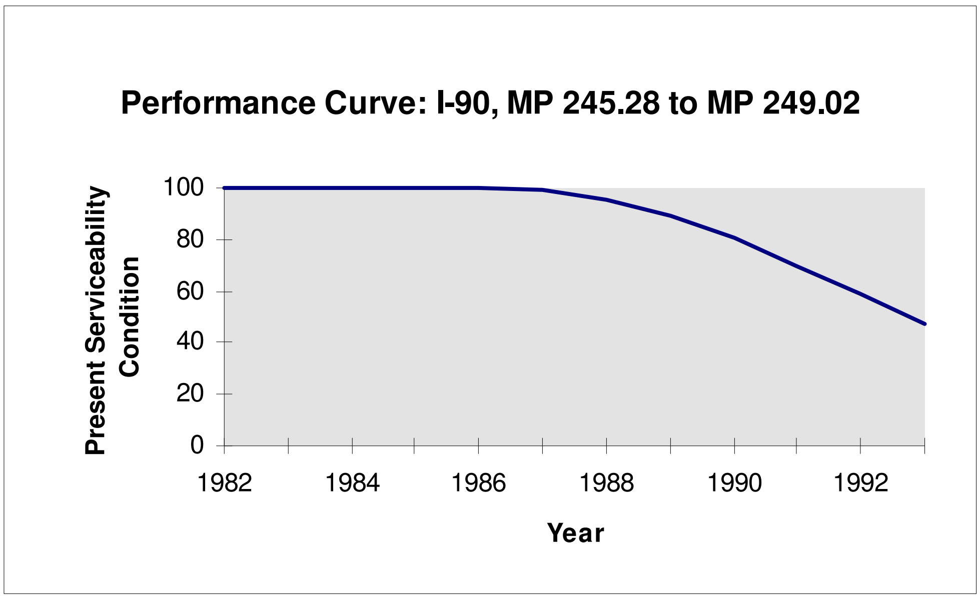
Performance benefits as experienced by WSDOT and outlined in the 1992 NCHRP Synthesis 180 report include the following:

- Improved skid resistance during wet weather
- Reduced hydroplaning potential
- Improved smoothness
- Reduced splash and spray
- Improved visibility of painted traffic markings

- Reduced wet pavement glare at night
- Reduced noise levels

CONCERNS

Initially, the performance of Class D pavements is steady as indicated by a flat performance curve. An example of a performance curve for a section on I-90, MP 245.28 to MP 249.02 follows:



The surface condition as indicated by the present serviceability condition changes little or none for several years. Beyond a certain point, the performance curve drops off rapidly as the pavement becomes brittle, micro-cracks, and then fails quickly due to pavement deterioration (such as raveling or delamination). Typically, WSDOT attempts to resurface roads at a present serviceability condition rating of 50.

The failure modes of Class D experienced by WSDOT included raveling (aggregate particles that are dislodged from the pavement) and delamination (loss of bond between pavement layers). Raveling can be caused by improper mix design, placement during cold or wet weather, and oxidation. Raveling can also be accelerated by the use of studded tires coupled with high ADT. Delamination can be caused by placement during cold or wet weather or the improper application of the tack coat.

The FHWA recommends placing a fog seal at five-year intervals or at the first sign of raveling. The placement of a fog seal may delay raveling, but consequentially some of the internal drainage within the Class D matrix will be lost.

Some other concerns that impact the use of this material are:

- Urban areas with high volume ADT should not be considered due to the higher use of studded tires. Studded tires tend to break apart the aggregate structure and cause premature raveling.
- The beneficial effects of reduced splash and spray seems to last only two to three years depending on the amount of sanding and other fine debris that is deposited on the surface. Thus, the benefits obtained from the open-graded nature may be short lived.
- In order to obtain compaction, Class D asphalt must be placed at temperatures above 60º Fahrenheit. Where nighttime paving is required, this material may not be used. Class D overlays are placed in thin lifts and are susceptible to rapid cooling.
- On higher volume roadways consideration must be given to the effects of traffic disruptions since the life of the Class D is shorter than typical dense graded mixes.
- There can be problems with snow and ice removal. Due to the permeability of the material the retention of deicing solutions is reduced. In addition, ice tends to “stick” to the surface and causes snowplows to ride up over it and pull out aggregate from the surface matrix.
- Due to the lower service life occurring in some regions, life cycle cost analysis does not satisfy the expenditure for using the material.

WSDOT’S EXPERIENCE

WSDOT has been placing Class D overlays with varied success since the early 1980’s. There are sections on Interstates 82 and 90 that were placed in the early 1980’s that are still in service. However, there are sections that were placed more recently on I-90 and I-5 that are not providing the targeted eight-year service life. During 1995, WSDOT estimated there were about 800 lane miles of Class D asphalt placed in the state. This represents less than eight percent of the statewide 10,500 lane miles. The majority of miles already in place are on the primary highway system where chip seals are not a viable option due to heavy traffic volumes.

Eastern Region

The Eastern Region has used Class D asphalt concrete overlays since 1980. Projects that have been selected are sections that are structurally sound but are experiencing some type of surface distress such as rutting or raveling. Five projects along I-90 totaling 36.8 miles or 147.2 lane miles have been constructed. Only 35.3 lane miles of Class D pavement remain in the Eastern Region. These remaining miles will be milled and resurfaced during 1995 leaving no Class D pavements in service.

Construction of the overlays on I-90 included milling the distressed lanes 0.15 ft and inlaying the lanes with a dense graded asphalt such as ACP Class B. The Class D asphalt concrete was overlaid shoulder-to-shoulder 0.06 ft thick followed by a CSS-1 fog seal.

The Eastern Region has obtained varied success with Class D overlays. A summary of the construction history and the years obtained from each overlay in the Eastern Region is as follows:

Eastern Region - Class D Projects

SR Route	Year Constructed	Contract No.	Location	Year Repaved	Pavement Life (years)	Average Daily Traffic
90	1982	2279	MP 191.89 to MP 200.36	1993	11[1]	7,800
90	1982	2293	MP 244 90 to MP 254.31	1993	11[1]	11,600
90	1982	2058	MP 254.32 to MP 257.35	1993	11[1]	12,100
90	1980	1869	MP 270.36 to MP 277.51	1988	8	31,000
90	1991	3958	MP 290.36 to MP 299.19	1995	4	40,000

[1]Noticeable rutting occurred during years seven or eight.

The table indicates some sections have lasted 11 years, well beyond the WSDOT goal of eight years. Actually, the time when rutting becomes noticeable has typically been seven or eight years. Therefore, the service life or the time when rehabilitation should have been performed was indeed closer to eight years. The service life for the project placed during 1980 was closer to six years rather than eight years. The difference in times is the time that rehabilitation was needed and actually programmed.

As was indicated earlier WSDOT does not recommend Class D placement in high volume, urban areas. For the 1980 project (Contract 1869) the current ADT is 31,000. For the 1991 project (Contract 3958) the current ADT is 40,000. For the projects outside the Spokane urban area that obtained 11 years between overlays the current ADT ranges from 7,800 to 12,100.

Review of the construction history shows the Eastern Region has had two Class D projects that did not perform as expected. One project, paved during 1980, was repaved eight years later and another project, paved during 1991, is being repaved during 1995. The failure mode for these projects was raveling accelerated by the use of studded tires. This raveling typically appears as ruts isolated to car wheel paths and proceeds through the full thickness of the Class D overlay.

Other factors may contribute to early raveling, such as late season paving. Late season projects (depending on the weather) do not always allow adequate compaction of the asphalt prior to cooling. Late season projects also do not allow curing of the asphalt before the onset of winter.

Another factor that may contribute to early raveling is the mixing of Class D asphalt higher than the recommended 235° Fahrenheit (asphalt temperatures are sometimes elevated during mixing to compensate for cooler air temperatures). When open-graded mixtures such as Class D are mixed too hot, drain down occurs. The higher mixing temperatures cause the asphalt cement to flow off the rock and settle to the bottom of the mat. The film thickness on the rock at the top of the mat becomes reduced. Heavy asphalt films on the aggregates are essential to resist stripping, oxidation, and ultimately raveling.

Since environmental conditions during paving can adversely affect the performance of any pavement, the 1994 WSDOT Standard Specification was revised to prohibit paving past October 15. The October 15 deadline will improve pavement performance and reduce likelihood of problems such as early raveling.

Eastern Region Class D Construction Costs

Construction costs for the Eastern Regions Class D overlays were researched and are presented in the table that follows:

Eastern Region - Class D Construction Costs

Year	Contract No.	Location	Cost - Class B		Cost - Class D	
			(ton)	(sy)	(ton)	(sy)
1982	2279	MP 244.90 to MP 200.36	$15.90	$1.63	$23.50	$0.97
1982	2293	MP 244.90 to MP 254.31	$13.30	$1.37	$23.10	$0.95
1982	2058	MP 254.31 to MP 257.35	$22.10	$2.27	$23.29	$0.96
1992	3958	MP 290.36 to MP 299.10	$22.25	$2.29	$23.00	$0.95

The square yard prices are based on thickness of 0.15 ft for Class B and 0.06 ft for Class D overlays. The Class B and Class D prices were obtained from the same contract with the exception of the ACP Class B on Contract 3958, which was not placed on this project. A price for Class B asphalt concrete was obtained from similar projects placed during that year.

It should be noted that Class B is usually placed in thicker lifts providing structural support to the roadway. The Class D overlay is merely a wearing surface that adds little structural benefit.

Southwest Region

The Southwest Region's experience has been similar to the Eastern Region's. The typical age of Class D pavements in the Southwest Region is approximately 11 years. Many Class D pavements are still in service although ruts have developed through the 0.06 ft overlays. Discussions with the region revealed noticeable rutting actually occurred during the seventh or eighth year, sometimes earlier. The use of studded tires is not as extensive in the Southwest Region as in the Eastern Region; however, the Southwest Region does feel that the use of tire chains adds considerably to their Class D pavement distress.

Four projects are summarized:

Southwest Region - Class D Projects

SR Route	Year Constructed	Contract No.	Location	Year Repaved	Pavement Life (years)	Average Daily Traffic
5	1986	3044	MP 0.27 to MP 2.42	Future	10+[1]	80,200
5	1984	2591	MP 4.32 to MP 7.53	1996	11[1]	56,000
5	1984	2608	MP 20.11 to MP 22.12	Future	12+[1]	48,400
5	1990	3522	MP 72.29 to MP 73.28 & MP 78.44 to 79.21	Future	6+	48,000

[1]Noticeable rutting occurred during years seven or eight.

South Central Region

The South Central Region has experienced good success with Class D pavements and have nearly 200 miles of Class D pavements that are still in service. Some pavements are currently 12 to 15 years old and have only recently raveled the full 0.06 ft thickness. Discussion with the South Central Materials Lab revealed that they have never had a Class D pavement fail in less then 10 years. Fog seals on class D pavements have not been applied.

A summary of several Class D project follows:

South Central Region - Class D Projects

SR Route	Year Constructed	Contract No.	Location	Year Repaved	Pavement Life (years)[1]	Average Daily Traffic
12	1983	2339	MP 277.09 to MP 281.08	Future	12+	26,000
12	1980	1850	MP 288.95 to MP 290.24	Future	15+	--------
12	1982	2270	MP 295.41 to MP 303.36	Programmed. 1994	13+	9,100
12	1982	3721	MP 304.97 to	1990	8	6,200

SR Route	Year Constructed	Contract No.	Location	Year Repaved	Pavement Life (years)[1]	Average Daily Traffic
12	1983	2339	MP 277.09 to MP 281.08 MP 305.36	Future	12+	26,000
12	1984	2680	MP 314.20 to MP 318.01	1994	10	4,800
24	1985	2957	MP 0.05 to MP 4.11	Programmed 1997	10+	9,600
82	1982	2196	MP 0.62 to MP 3.23	1994	1	11,600
82	1984	2692	MP 23.88 to MP 29.02	Programmed 1996	11+	12,800
82	1983	2310	MP 97.46 to MP 100.66	Programmed 1996	12+	12,400
90	1981	1904	MP 106.34 to MP 110.00	1994	13	20,000
90	1984	2663	MP 110.00 to MP 122.23	Programmed 1998	11+	10,400
90	1982	2231	MP 126.14 to MP 137.19	1994	13	10,400
90	1978	1012	MP 102.61 to MP 103.19	Programmed 1998	17+	18,800
224	1982	2339	MP 7.42 to MP 9.78	1994	12	11,800

[1]Noticeable rutting occurred beyond 10 years

The South Central Region noted that Class D pavements that go beyond 12 years display the full 0.06 ft depth rutting such as experienced in both the Southwest and Eastern Regions.

The South Central Region will continue to consider Class D pavements. Class D overlays have been placed in lieu of chip seals on select routes.

SUMMARY

WSDOT should continue to consider Class D asphalt in the analysis of our pavement designs. Class D overlays have performed well for roadways outside of urban areas and may be cost effective. With recommended overlay cycles of eight years, a life cycle cost analysis is necessary to determine the cost effectiveness. To place a statewide moratorium (as some states have done) on Class D overlays may be premature. However, the use of Class D asphalt in areas of high ADT or high studded tire use should be avoided.

Appendix E

Performance Data for Open-Graded Pavements

The following table was put together by the Pavement Section of the Headquarters Materials Laboratory from historical data derived mainly from the WSPMS, but also in part from other sources within the Pavements Section.

Table 15. Open-graded pavement performance data.

Route	Dir.*	Beg. MP	End MP	Region**	Contract Number	Date Constructed	Age At 1/2 Inch Rutting	ADT Per Lane
23	B	42.64	51.86	E	2293	1982	16	500
90	I	191.89	200.36	E	2279	1982	7	3,000
90	D	191.89	200.36	E	2279	1982	7	3,000
97	D	69.32	74.74	SC	4673	1995	9	3,000
970	B	0.77	5.85	SC	4627	1995	9	3,000
82	D	0.61	3.23	SC	2196	1982	11	4,000
82	I	0.63	3.22	SC	2196	1982	10	4,000
90	I	239.15	244.90	E	2058	1982	8	4,000
90	D	239.15	244.90	E	2058	1982	9	4,000
90	I	244.90	254.31	E	2293	1982	8	4,000
90	D	244.90	254.33	E	2293	1982	7	4,000
90	I	254.13	257.35	E	2058	1982	9	4,000
90	D	254.33	257.35	E	2058	1982	8.5	4,000
12	B	304.51	307.66	SC	3721	1990	14	4,000
22	B	35.98	36.45	SC	4819	1997	7	4,000
90	I	110.00	121.96	SC	2663	1984	12	4,500
90	D	110.00	121.96	SC	2663	1984	10.5	4,500
82	D	82.14	84.35	SC	4819	1997	7	5,000
12	B	302.21	305.36	SC	2270	1982	13	5,000
82	I	97.64	100.66	SC	2310	1983	9	6,000
82	D	97.64	100.66	SC	2310	1983	10	6,000
90	I	102.61	106.34	SC	1012	1978	12.3	7,000
90	D	102.61	106.34	SC	1012	1978	14	7,000
90	I	270.36	275.40	E	1869	1980	8	10,000
90	D	270.36	275.55	E	1869	1980	8	10,000
82	I	33.84	36.29	SC	4102	1993	6	12,000
82	D	33.84	36.29	SC	4102	1993	6	12,000
82	I	30.96	33.84	SC	4346	1994	4	12,500
82	D	30.96	33.84	SC	4346	1994	4	12,500
90	I	290.36	299.10	E	3958	1992	2.5	20,000
90	D	290.36	299.10	E	3958	1992	3	20,000
12	I	2.08	4.94	O	XE2906	1992	7	6,000
12	D	2.08	4.94	O	XE2906	1992	8	6,000
5	I	20.07	22.12	SW	2608	1984	8	8,000
5	D	20.78	22.01	SW	2608	1984	8	8,000
5	I	88.02	98.88	SC	2571	1984	8	14,000
5	D	88.02	98.88	SC	2571	1984	7.5	14,000
5	I	98.88	102.70	O	2571	1984	10	14,000
5	D	98.88	102.70	O	2571	1984	6	14,000
5	I	101.23	102.69	O	3939	1993	7	14,000
5	D	101.23	102.69	O	3939	1993	7	14,000
5	D	70.68	72.24	SW	3934	1991	8.5	15,000
5	I	72.29	73.28	SW	3522	1990	7	15,000

Table 16. (Continued) Open-graded pavement performance data.								
Route	Dir.*	Beg. MP	End MP	Region**	Contract Number	Date Constructed	Age At 1/2 Inch Rutting	ADT Per Lane
5	D	72.29	73.28	SW	3522	1990	8.5	15,000
5	D	77.55	78.44	SW	3934	1991	7	15,000
5	I	4.32	7.53	SW	2591	1984	7.5	16,000
5	D	4.32	7.53	SW	2591	1984	7.5	16,000
5	D	68.96	70.61	SW	2720	1985	8	16,000
5	I	0.27	2.42	SW	3044	1986	8	18,000
5	D	0.27	2.42	SW	3044	1986	8	18,000
5	I	78.44	79.21	O	3522	1990	8	18,000
5	D	78.44	79.21	O	3522	1990	8	18,000
5	I	82.38	83.35	O	3522	1990	8	22,000
5	D	82.38	83.35	O	3522	1990	8	22,000
5	I	135.54	139.50	O	2554	1985	4	22,000
5	D	135.54	139.50	O	2554	1985	6	22,000

*I = Increasing, D = Decreasing, B = Both (for 2 lane undivided highways)
**E = Eastern, O = Olympic, SC = South Central, and SW = Southwest

Appendix F

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

EVALUATION OF LONG-TERM PAVEMENT PERFORMANCE AND NOISE CHARACTERISTICS FOR OPEN-GRADED FRICTION COURSES

Interstate 5

52nd Avenue West to SR-526 – Southbound

Milepost 180.10 to Milepost 189.30

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Washington State Department of Transportation

Introduction

Hot-mix asphalt (HMA) open-graded friction courses (OGFC) can reduce traffic noise and splash and spray from rainfall. These performance benefits come at a cost in durability, greatly reducing pavement life compared to traditional asphalt and concrete pavements. The benefit of noise reduction, and splash and spray reduction degrades over relatively short periods of time, reducing the effectiveness of the OGFC pavement. Pavement lives of less than ten years, and as short as three to four years, have occurred with the use of OGFC pavements in Washington's high traffic corridors. The life of asphalt based quieter pavement in the USA and around the world tends to average between 8 and 12 years. Compare this to an average pavement life of 16 years in western Washington and the loss of durability is clear. Under RCW47.05, WSDOT is instructed to follow lowest life cycle cost methods in pavement management. Less durable pavements do not meet this legislative direction.

Studded tire usage in Washington State is another complicating factor. Studded tires rapidly damage OGFC pavements, resulting in raveling and wear. When OGFC was used on I-5 in Fife, the pavement had significant wear in as little as four years. States where the use of OGFC has been successful (Florida, Texas, Arizona and California) do not experience extensive studded tire usage. Similarly, these states are southern, warm weather states; a clear advantage when placing a product like OGFC with asphalt-rubber. Arizona DOT, for example, requires the existing pavement to have an 85°F surface temperature at the time of placement. Washington State urban pavements, placed at night to avoid traffic impacts, rarely reach this temperature during the available nighttime hours for paving (10:00 p.m. to 5:00 a.m.), even in summer. Other pavements and bridge decks reach such temperatures at night only on rare occasions, making successful placement of rubberized OGFC difficult or impossible at night.

Plan of Study

The objective of this research study will be to determine the long-term pavement performance characteristics of OGFC pavements in Washington State. It will focus primarily on the OGFC's resistance to studded tire wear, its durability and its splash/spray characteristics. In addition, noise reduction characteristics will also be measured. WSDOT, at a minimum, will be evaluating noise levels using sound intensity measurement equipment (additional evaluations to be determined in the next couple of months). The pavement performance and noise intensity measurements will be conducted on an annual basis.

In addition, this study will also document any challenges with the construction of the OGFC during nighttime paving operations.

Scope

This project will construct two OGFC test sections, each ½-mile in length, one with asphalt-rubber and the other with PG70-22. This section of southbound interstate consists of three 12-foot lanes, a 10-foot right and 10-foot left shoulder.

Both sections of the OGFC will be placed full roadway, including shoulders, to a depth of 0.06 feet.

WSDOT will be designing the mixes in accordance with the Arizona DOT specifications for OGFC with asphalt-rubber (AR) and OGFC with a styrene-butadiene-styrene (SBS) modified asphalt binder.

Layout

The first test section will begin at MP 188.65 and end at MP 188.15 and the second will begin at MP 188.15 and end at MP 187.65.

Figure 1. Interstate 5 at MP 188.65

Figure 2. Interstate 5 at MP 188.15

This location was selected for ease of construction (occurs at the beginning of the pavement project), relatively similar terrain and the same level of traffic over both test sections.

Control Section

A ½ mile length of the project will serve as the control for the evaluation of the OGFC mixes. The project calls for a ½ inch Superpave mix using a PG 64-22 binder. The limits of the control section will be determined after construction is completed. The location will be chosen so that it duplicates, as closely as possible, the same environment and traffic conditions as the two test sections.

Staffing

This research project will be constructed as part of a larger rehabilitation project. Therefore the Region Project office will coordinate and manage all construction aspects. Representatives from the WSDOT Materials Laboratory (1 – 3 persons) will also be involved with the process.

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Testing

The following annual testing procedures will be conducted on the test sections and control section.

- Pavement condition
  - Surface condition (cracking, patching, flushing, etc)
  - Rutting/wear (using the INO laser which provides true transverse profile)
  - Roughness
- Some measure of splash and spray characteristics
  - WSDOT is currently in the process of determining if a procedure exists for measuring splash and spray.
  - At a minimum, splash and spray may be documented through photographs during a rainstorm
- Sound intensity noise measurements

Reporting

An "End of Construction" report will be written following completion of the test sections. This report will include construction details of the test sections and control section, construction test results, and other details concerning the overall process. Annual summary reports will also be issued over the next 5 years that document any changes in the performance of the test sections. At this time a final report will be written which summarizes performance characteristics and future recommendations for use of this process.

Cost Estimate

Construction Costs

Description	Quantity	Unit Cost	Unit	Total Cost
OGFC – AR	300	$62.00	Ton	$86,800
OGFC – SBS	300	$55.00	Ton	$77,000
Total				**$163,800**

Testing Costs

The pavement condition survey will be conducted as part of the statewide annual survey (all lanes will be tested).

WSDOT is in the process of purchasing sound intensity measurement equipment and will be installed on the appropriate testing vehicle.

Report Writing Costs

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

TOTAL COST = $178,200

Schedule

Project Ad Date – January 2006
Estimated Construction – August 2006

Date	Pavement Condition Survey	Sound Intensity Measurement	End of Construction Report	Annual Report	Final Report
July 2006	X	X			
January 2007			X		
July 2007	X	X			
October 2007				X	
July 2008	X	X			
October 2008				X	
July 2009	X	X			
October 2009				X	
July 2010	X	X			
October 2010				X	
July 2011	X	X			
October 2011				X	
June 2012					X