Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses Project 3 – Final Report

WA-RD 749.2

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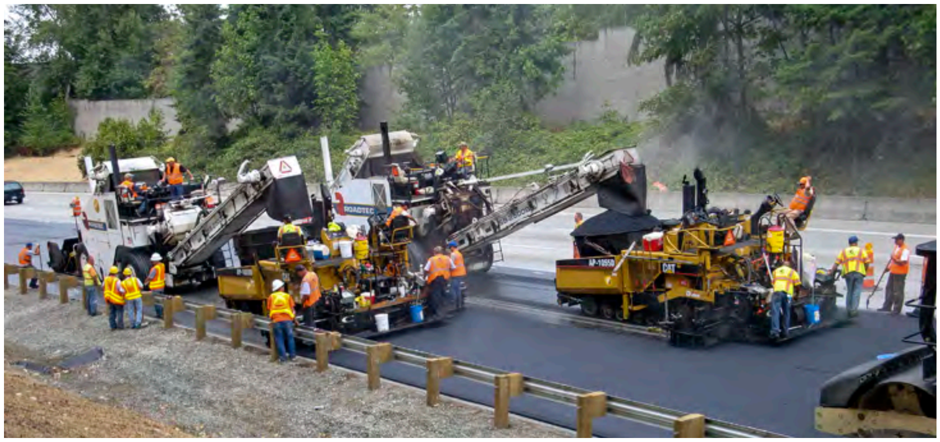
July 2013



Washington State
Department of Transportation
Engineering & Regional Operations
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State Materials Laboratory

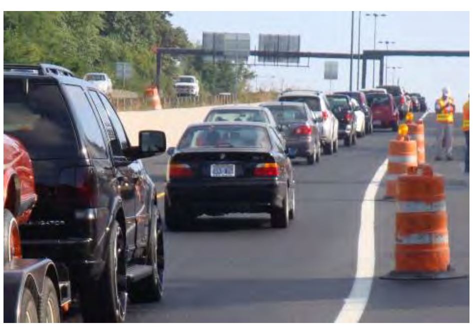
WSDOT Research Report

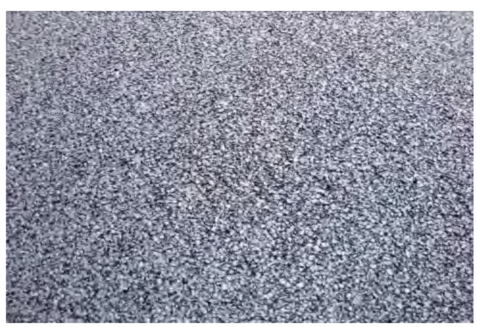
Experimental Feature Report

Post-Construction and Performance Report
Experimental Feature 08-02

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 3 – Final Report

Contract 7283
I-405
112TH AVE SE to SE 8TH ST
MP 9.33 to MP 12.76





Washington State Department of Transportation

Engineering and Regional Operations
Construction Division
State Materials Laboratory

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 749.2		

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 3 – Final Report	July 2013
	6. PERFORMING ORGANIZATION CODE WA 08-02
7. AUTHOR(S) Keith Anderson, Jeff S. Uhlmeyer, Tim Sexton, Mark Russell, 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 Final 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 report describes the third of three experimental installations of open-graded friction course (OGFC) "quieter pavements" designed to reduce the noise generated at the tire/pavement interface. Experimental sections of OGFC were built using asphalt rubber (AR) and styrene-butadiene-styrene (SBS) modified asphalt binders. A section of conventional hot mix asphalt (HMA) served as the control section for the two experimental sections.

The noise level of the OGFC-AR test section was audibly quieter (3 dBA or greater quieter) than the HMA control section for only a period of ten months after construction. The OGFC-SBS section was audibly quieter than the HMA for one month after construction.

The amount of wear/rutting on this project was less than on the other two quieter pavement projects. The reason was that this project was not subject to the same weather and traffic conditions as the other two projects. The other projects were subject to a severe winter storm that resulted in a higher use of studded tires and chains for an extended time period.

Pavement condition data showed that the OGFC-AR pavement was less resistant to reflection cracking than the OGFC-SBS pavement.

Open graded friction course quieter pavements are not recommended for use in Washington State due to the short duration of their noise mitigation properties.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
quieter pavements, rubber asphalt, open-graded friction courses, on board sound intensity measurements, SBS asphalt	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	74	

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Introduction

This is the third in a series of three experimental feature projects involving the construction of open-graded friction course (OGFC) pavements to mitigate tire/pavement noise. The first, on I-5 near the city of Lynnwood, was constructed in August of 2006, and the second, on SR 520 between Lake Washington and I-405 was constructed in July of 2007. All three projects used asphalt rubber (AR) and styrene butadiene styrene (SBS) modified asphalt binders combined with open-graded aggregate structures to produce a quieter pavement surface. The open-graded aggregate structure results in a higher volume of surface voids (around 20 percent air voids) which absorbs some of the noise generated at the tire/pavement interface. The OGFC pavements are thus "quieter" than densely-graded pavements which have between four and eight air percent voids.

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 in 1995 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. Newspaper and other media reports on the success of these types of pavements in other states have prompted the public to ask that they be used to lessen the noise in their neighborhoods.

A major difference between the OGFC test section on I-405 and the test sections on I-5 and SR 520 is the underlying pavement type. The underlying pavement on I-5 and SR 520 is dense graded hot mix asphalt (HMA) while concrete pavement underlies the OGFC placed on I-405. A large portion of the interstate system in the Seattle metropolitan area is comprised of older concrete pavement which can be one of the noisier pavement types. This experimental feature will provide valuable information regarding the performance of OGFC placed over concrete pavement.

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 a shortened pavement life. The life of open-graded pavements is cut short by the studded tire wear mentioned previously. WSDOT experienced pavement lives of less than 10 years, and as short as three to four years on OGFC pavements in the 1980's. 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. ADOT, for example, requires the existing pavement to have a minimum surface temperature of 85°F at the time of placement (ADOT 2008). 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. A more complete discussion of the performance history of open-graded pavements in Washington State is found in the final reports on the first two quieter pavement experimental projects (Anderson et al., 2012a and Anderson et al., 2012b).

Open graded pavements are also popular with the drivers due to benefits beyond noise reduction. 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 as long as they are not rutted. At night the increased drainage capability 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 third experiment is located on northbound I-405 where it crosses I-90. The project, Contract 7283, 112th Ave SE to SE 8th St, added an inside HOV lane in each direction of I-405 between MP 9.33 to MP 12.76. The existing pavement was rehabilitated as part of the project which included placing OGFC in two test sections, one south of I-90 between MP 10.26 and MP 10.93 and one north of I-90 between MP 11.76 and MP 12.40. The average daily traffic (ADT) on this section of I-405 is 165,457 with 6.75 percent trucks. A vicinity map for the project is shown in Figure 1.

Figure 1. Vicinity map for Contract 7283.

Each test section included a segment of both OGFC-AR and OGFC-SBS. Prior to paving, the existing PCCP was ground to remove faulting. The existing PCCP in the northern test section also received a dowel bar retrofit prior to paving while the southern test section did not. Most of the widening for the new lane was toward the median so much of the OGFC in the HOV lane is over new dowelled PCCP. The only section of OGFC that was not placed on PCCP is the southernmost section just north of the bridge over Coal Creek Parkway. The paving depth for all of the OGFC was 0.08 feet. The paving limits for the two test sections are shown in Figures 2 and 3.

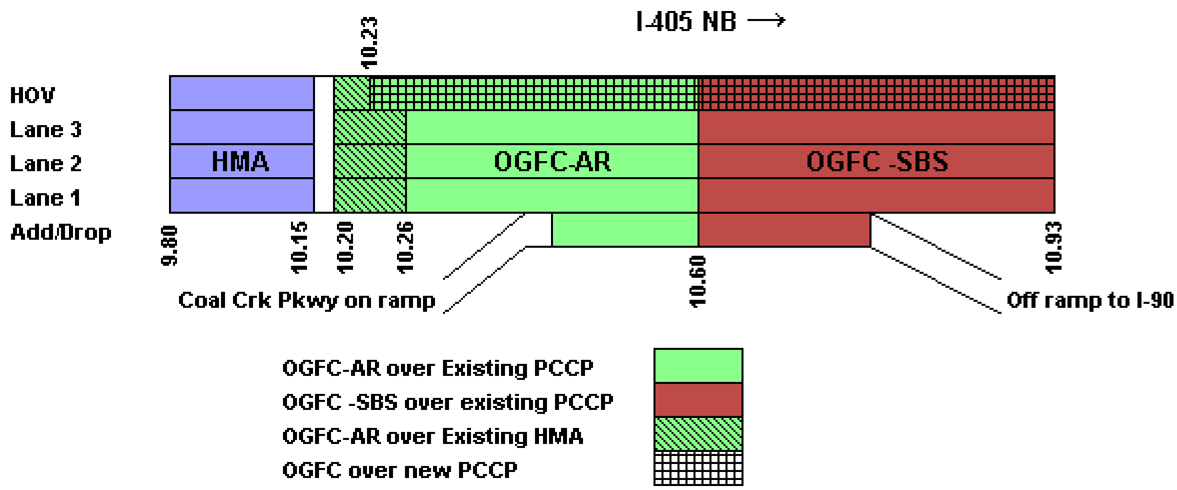


Figure 2. Schematic of paving limits for test sections south of I-90 (south section).

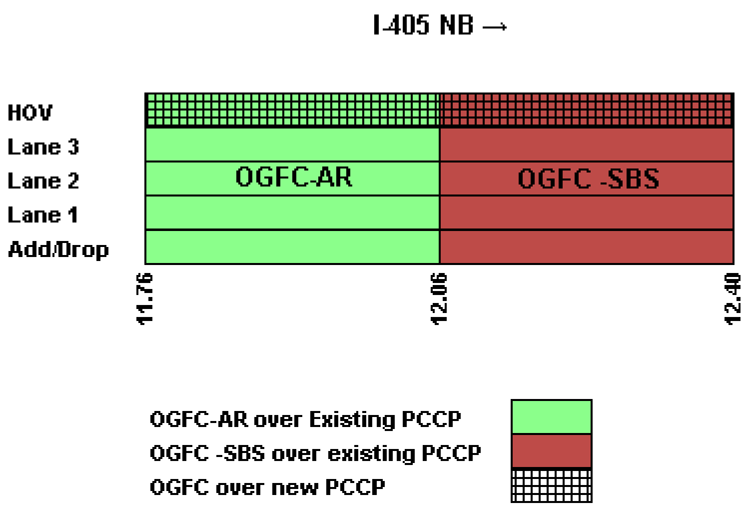


Figure 3. Schematic of paving limits for test sections north of I-90 (north section).

Mix Design Process

Special mix design processes were required for both the asphalt rubber and SBS open-graded pavements. Both mix designs were done in-house in contrast to the first quieter pavement project near Lynnwood that borrowed the services of ADOT to develop the design for the asphalt rubber mix (Anderson et al, 2012a). The asphalt rubber mix design, however, was still patterned after the ADOT process. The SBS mix design was based on the use of a drain down test as was used on the previous projects. Complete discussions of the two mix design processes can be found in the post-construction report for the I-5 Lynnwood project (Anderson et al, 2012a). The mix design reports for this project can be found in Appendix A.

OGFC-AR

The mix design for the OGFC-AR was similar to the design for the I-5 and SR 520 projects (Table 1). The 9.4 percent asphalt content was slightly higher than the first two projects (9.2 percent for I-5 and 9.0 percent for SR 520). Crumb rubber was added at 20 percent of the weight of the binder which was lower than the 22 percent used on I-5 and the 23.5 percent used on SR-520. The aggregate gradation for both the OGFC-AR and the OGFC-SBS was similar to the first two projects but the aggregate came from Lakeside Industries' Issaquah pit (A-189) instead of pit site B-335. An important change in the OGFC-AR mix design on I-405 was the use of lime as the anti-stripping additive. The first two projects followed WSDOT's procedure of using liquid anti-stripping additive to prevent stripping. One of the goals of the I-405 paving was to follow ADOT's procedures as close as possible. ADOT uses hydrated lime as anti-stripping additive in its OGFC mixes so the anti-stripping additive specification was changed to require hydrated lime. Hydrated lime was added at a rate of 1.0 percent of the aggregate weight.

Table 1. Mix design for the OGFC-AR.			
Sieve Size	Gradation	Specifications	Source/Supplier
3/8"	100	100	A-189
#4	35	30-45	A-189
#8	8	4-8	A-189
#200	1.9	0–2.5	A-189
Binder Grade	Percent Asphalt		Source/Supplier
PG64-22	9.4		U.S. Oil, Tacoma WA
Anti-Strip	Percent		Source/Supplier
Hydrated Lime	1% by wt of aggregate		Graymont Inc.
Crumb Rubber	Percent by Wt. of AC		Rubber Granulators Inc.
CRM	20.0		Rubber Granulators Inc.

OGFC-SBS

The mix design for the OGFC-SBS was also similar to the design used for the I-5 and SR 520 projects (Table 2). The asphalt content was 0.3 percent higher than I-5 and 0.2 percent lower than SR 520. As was the case for the OGFC-AR, hydrated lime was used as anti-stripping additive. Fibers were added at a rate of 0.3 percent, to help prevent drain-down, as it was on the other two projects.

Table 2. Mix design for the OGFC-SBS.			
Sieve Size	Gradation	Specifications	Source/Supplier
3/8"	100	100	A-189
#4	38	35-55	A-189
#8	12	9-14	A-189
#200	2.0	0–2.5	A-189
Binder Grade	Percent Asphalt		Source/Supplier
PG70-22	8.6		US Oil, Tacoma, WA
Anti-Strip	Percent		Source/Supplier
Hydrated Lime	1% by wt of aggregate		Graymont Inc.
Fibers	Percent		Source/Supplier
Cellulose Based Paper	0.3		Central Fiber Corporation
Rubber	Percent by Wt. of AC		Source/Supplier
SBS	3.4±1%		U.S. Oil, Tacoma, WA

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 complete OGFC special provisions for Contract 7283 can be found in Appendix B.

OGFC-AR Special Provisions

The Special Provisions required that the asphalt binder for the OGFC-AR be either PG58-22 or PG64-22. The crumb rubber was required to conform to the gradation requirements shown in Table 3. The crumb rubber was required to have a specific gravity of 1.15 ± 0.05 and be free of wire or other contaminating materials. The rubber could also 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 was required to 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 were required to 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 was required to be between 325 and 375°F.

The mixed asphalt-rubber was to be kept thoroughly agitated during the period of use to prevent the settling of the rubber particles. In no case could 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 was required to be cooled and could then be gradually reheated to the prescribed temperature. A batch of asphalt-rubber could only be cooled and reheated in this manner once.

OGFC-SBS Special Provisions

The asphalt binder for the OGFC-SBS was required to be a PG70-22 produced by adding SBS modifier to a neat binder. If needed, fiber stabilizing additive could be included in the mix. 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.

Weather Limitations

ADOT requires a high (by western Washington standards) minimum surface temperature specification of 85°F for paving their OGFC-AR. Traffic volumes on the I-5 and SR 520 projects required paving to occur at night leading to the minimum air temperature specifications of 55°F for the I-5 project and 60°F for the SR 520 project. In order to place the OGFC on I-405 under conditions as close to those of paving in Arizona as possible, WSDOT specified a minimum air temperature of 70°F and allowed placement of the OGFC to occur during the day despite heavy traffic volumes on I-405.

Tack Coat

The tack coat specification on this project was different from the first two OGFC quieter pavement projects. The first two projects required tack coat consisting of emulsified asphalt but a performance grade (PG) asphalt tack coat was required on I-405. ADOT originally only allowed PG asphalt as tack coat for OGFC paving. Even though ADOT now allows the use of emulsions as tack coat, it was decided to follow ADOT's original procedure and use PG asphalt for the tack coat. The specification allowed tack coat to meet the requirements of either PG58-22 or PG64-22. Lakeside Industries chose to use PG64-22 from U.S. Oil in Tacoma, WA.

Asphalt Plant

This project used the dryer-drum type plant located at Lakeside Industries' Issaquah facility. Lakeside brought in a high-shear high-speed blender manufactured by Phoenix Industries to mix the crumb rubber with the PG64-22 asphalt (Figure 4 and 5). Figures 6 and 7 show pallets of fibers for the OGFC delivered to the project and the equipment used to introduce them into the asphalt plant.

Figure 4. High-shear high speed blender used to add crumb rubber to the PG64-22 asphalt.

Figure 5. Adding crumb rubber.

Figure 6. Pallets of fibers to be used in OGFC-SBS.

Figure 7. Equipment for introducing fibers into asphalt plant.

Paving

The test sections were paved during the day over the weekend of August 15th and 16th, 2009. The paving required Northbound I-405 to be restricted to one lane of traffic. A weekend was chosen because the traffic disruption would be less on a weekend than a week day; however the weekend lane closures still resulted in considerable traffic delays. Paving operations began on the 15th with the two leftmost lanes of the test section south of I-90. Paving started at the Coal Creek Parkway Bridge and progressed northward toward I-90. Once the left two lanes of the test section south of I-90 were complete the equipment was moved to the test section north of I-90 to pave the left two lanes there. The process was repeated on the 16th for the right lanes.

The paving operation is captured in Figures 8 through 15. Temperature differentials were not a problem on this project due to the use of the Shuttle Buggy material transfer vehicle (MTV) that was specified in the Special Provisions (Appendix B). A detailed report of the construction that includes infrared images is included as Appendix C.

Figure 8. Distributor applying tack coat.

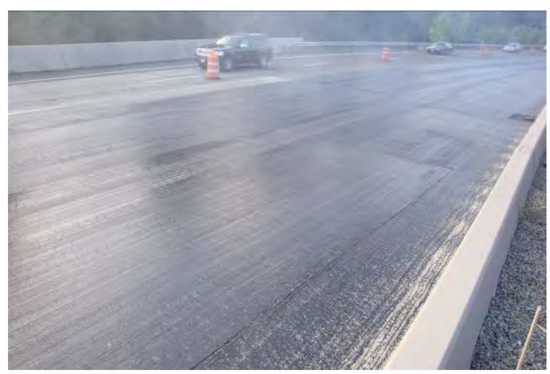


Figure 9. Tack coat application.

Figure 10. CAT AP-1055D paver.

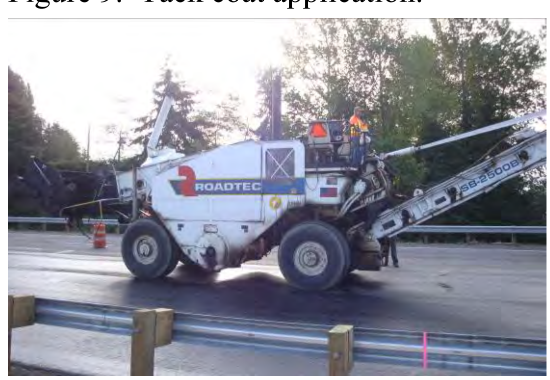


Figure 11. RoadTec Shuttle Buggy.

Figure 12. At times, three paving machines and two Shuttle Buggies were used.

Figure 13. Rollers stayed close behind the paving machines.

Figure 14. Finished OGFC-AR pavement.

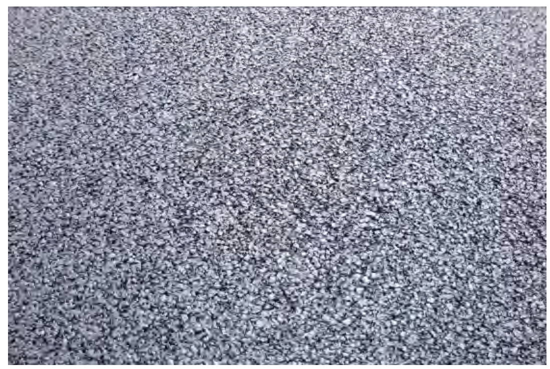


Figure 15. Close-up of OGFC-AR.

Tack Coat Application

The only significant problem encountered while paving the OGFC was the PG asphalt tack coat sticking to tires on the end dumps and the Shuttle Buggies in the new PCCP HOV lane. The tack coat stuck to equipment tires to the point that bare spots were left where there was no tack coverage (Figure 16). The problem with the tack coat was attributed to dust on the surface of the new PCCP in the HOV lane which had not yet been opened to traffic. The dust prevented the tack from adhering to the pavement so it was picked up by equipment tires (Figure 17). The PG asphalt tack coat did perform adequately on the old PCCP and the existing HMA near the Coal Creek Parkway Bridge (Figure 18). It is not clear if an emulsion based tack coat would have performed better. The lower viscosity of emulsified asphalt may have allowed it to better penetrate the dust and stick to the pavement.

Figure 16. PG asphalt tack coat sticking to Shuttle Buggy tire in HOV lane.

Figure 17. Bare streak left after PG asphalt tack picked up by Shuttle Buggy tire.

The PG asphalt tack coat sticking to tires led to isolated fat spots showing up in the mat due to pieces of the mix breaking away from the tires. The buildup of tack occasionally required the paving crew to remove it from the tires (Figure 19). Most of the tack was removed from the roadway but pieces that were left on the mat in front of the paver (Figures 20) would later show up as fat spots in the finished mat (Figure 21).

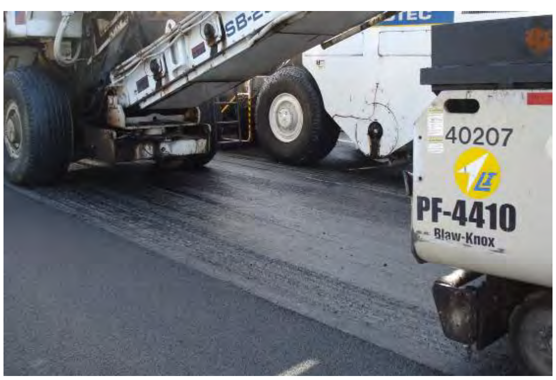


Figure 18. PG asphalt tack coat sticking to tires was not a problem on the old PCCP.

Figure 19. Members of paving crew removing tack buildup.

Figure 20. Piece of tack buildup from tires left in front of paver.

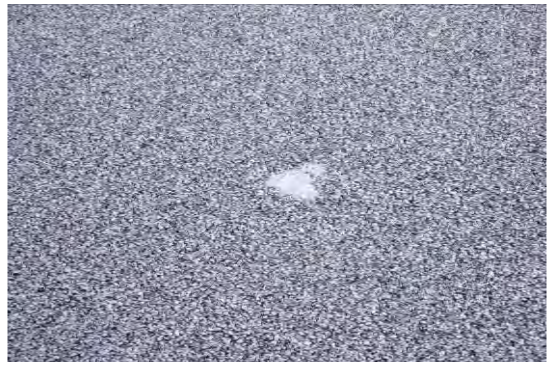


Figure 21. Fat spot resulting from a piece of tack buildup from tires.

Performance Monitoring

Acoustic performance and pavement wear were the two main criteria used to judge the success of the OGFC quieter pavement sections on I-405. For acoustic performance, the two questions to be answered were; (1) are the OGFC pavements audibly quieter than the HMA control section and, (2) how long do they remain audibly quieter? For pavement wear, the question was; how long will the OGFC pavements stand up to the studded tire wear and the climatic conditions of Washington? Ride and friction resistance were also evaluated on both types of OGFC pavements and the conventional HMA.

Noise

Traffic noise is a concern for many residents living along state highways. This study is the third of three trial installations of OGFC pavements designed to reduce the noise generated from our highway facilities and its effects on nearby residents. The first installation was on I-5 in Lynnwood, the second on SR 520 near Medina. Historically, noise barriers have been the most common method for reducing traffic noise. Noise barriers include noise walls and earthen berms that separate traffic noise from adjacent properties. Typical noise reduction is 5 to 10 decibels, with 10 decibels reducing the perceived noise level by 50 percent. While noise barriers can be effective, they can also be expensive to install and are not constructible or effective in all locations.

Table 4 shows the relationship between the sound intensity level change, relative loudness and acoustic energy loss. Acoustic engineers agree that sound intensity levels must differ by at least three decibels to be noticeable to the human ear (audibly quieter). For this study the OGFC sections will be considered “quieter” when their sound intensity levels are at least three decibels lower than the sound intensity level of the HMA control section. The use of OGFC quieter pavements would not be justified if they are not audibly quieter than the HMA for a reasonable period of time.

Table 4. Sound level changes, loudness and acoustic energy loss comparison.

Sound Level Change	Relative Loudness	Acoustic Energy Loss
0 dBA	Reference	0
- 3 dBA	Barely Perceptible Change	50%
- 5 dBA	Readily Perceptible Change	67%
- 10 dBA	Half as Loud	90%
- 20 dBA	1/4 as Loud	99%
- 30 dBA	1/8 as Loud	99.9%

Noise Measurement Equipment

The On-Board Sound Intensity (OBSI) method was used to measure acoustic performance, that is, “noise” on the quieter pavement sections. Measurement methods and equipment are in general conformance with the provisional AASHTO specification TP 76-13 *Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method.* OBSI measures the noise at the tire/pavement interface using two microphone pairs mounted vertically four inches from the outside tire sidewall of the rear passenger side tire (Figure 15). The microphones are suspended three inches above the pavement surface on either side of where the tire meets the roadway. This close proximity to the tire/pavement interface ensures that only the noise from this area is recorded and that traffic noise from other sources like drive train, engine, or exhaust is not captured.

Measured sound intensity data is analyzed using a PULSE multi-channel data analyzer. The PULSE system reports overall sound intensity values that are the sum of A-weighted sound intensity within the 1/3 octave frequencies of 500-5000Hz using a multi-channel analyzer (Figure 16). For each 1/3 octave band, the system also measures the coherence of sound pressure between the two microphones and the pressure-intensity index (PI index).

The Uniroyal Tiger Paw AWP (P225/60R16) mounted on the dedicated WSDOT Ford Taurus sedan used for all OBSI measurements is equivalent to the Standard Reference Test Tire (SRTT) (P225/60R16) as defined in ASTM 2493.

Figure 22. Twin microphones mounted near the rear tire of a vehicle. Note Uniroyal Tiger Paw tire.

Figure 23. Computer used for data collection.

Noise Measurements

Initial measurements were made on the existing pavement prior to the overlay to serve as a base line. After construction of the quieter pavement test sections, OBSI measurements were collected monthly, weather permitting (pavement must be dry), on all four lanes of the three test sections. Three measurements were collected for each lane on each section of pavement. The average sound intensity level for each section (all four lanes) is listed in Table 5. Measurements of the sound intensity levels for the individual lanes within each section are listed in Appendix D.

Table 5. Average monthly sound intensity level measurements (dBA).				
Age (months)	Date	OGFC-AR	OGFC-SBS	HMA
0	September 2009	96.8	96.8	100.9
1	October 2009	99.7	99.0	100.1
3	December 2009	99.0	101.0	103.0
4	January 2010	99.8	100.2	101.9
5	February 2010	101.6	102.0	102.7
6	March 2010	99.9	100.2	102.0
7	April 2010	101.0	100.8	102.4
9	June 2010	100.5	100.5	102.3
10	July 2010	99.0	100.1	102.4
11	August 2010	99.0	99.0	100.5
12	September 2010	100.1	100.3	102.3
14	November 2010	101.2	101.3	103.0
15	December 2010	100.7	100.8	102.8
17	February 2011	103.5	103.4	104.1
18	March 2011	103.3	102.6	104.1
19	April 2011	103.8	103.2	104.7
20	May 2011	103.5	102.6	103.8
22	July 2011	103.3	102.4	104.8
23	August 2011	103.6	102.8	105.2
25	October 2011	104.6	103.4	105.3
27	December 2011	105.8	104.6	106.2
29	February 2012	105.6	104.7	106.3
31	April 2012	104.7	103.9	105.7
32	May 2012	104.9	104.4	105.6
34	July 2012	104.2	103.5	104.9
35	August 2012	104.4	103.9	105.2
36	September 2012	104.4	103.5	105.2
39	December 2012	105.1	104.5	105.3
41	February 2013	105.0	105.0	105.8
43	April 2013	104.5	104.0	105.1
44	May 2013	104.6	104.0	105.3

The sound intensity level of each section increased over time with the OGFC-AR increasing the most and was 7.8 dBA louder after 44 months. The OGFC-SBS had the next highest gain at 7.2 dBA and the HMA the least with a 4.4 dBA increase.

The difference between the average sound intensity of the HMA control section and the average sound intensity of each OGFC section was calculated to determine if the OGFC sections were audibly quieter and the longevity of that attribute (Table 6). The differences are plotted in Figure 24. Data points above the black horizontal line are three decibels quieter than the HMA control section, a difference considered to be audible to the human ear (≥3 dBA). Data points below the line are not audibly quieter. A red horizontal line at 0.0 marks the point below which the OGFC would be noisier than the HMA control section.

Table 6. Difference in average sound intensity level between OGFC sections and HMA control section.

Age (months)	Difference in Sound Intensity Level Between OGFC-AR and HMA (dBA)	Difference in Sound Intensity Level Between OGFC-SBS and HMA (dBA)
0	3.5	4.1
1	0.9	1.5
3	4.0	2.1
4	2.2	1.7
5	1.1	0.6
6	2.1	1.8
7	1.4	1.6
9	1.8	1.9
10	3.4	2.3
11	1.5	1.5
12	2.3	2.0
14	1.0	1.7
15	2.1	2.0
17	0.6	0.7
18	0.8	1.5
19	0.9	1.6
20	0.4	1.2
22	1.6	2.5
23	1.6	2.4
25	0.7	1.9
27	0.4	1.6
29	0.7	1.6

Age (months)	Difference in Sound Intensity Level Between OGFC-AR and HMA (dBA)	Difference in Sound Intensity Level Between OGFC-SBS and HMA (dBA)
31	1.0	1.7
32	0.6	1.1
34	0.7	1.3
35	0.8	1.3
36	0.8	1.8
39	0.2	0.8
41	0.8	0.8
43	0.6	1.1
44	0.6	1.2

Note: Readings highlighted in yellow are audible to the human ear.

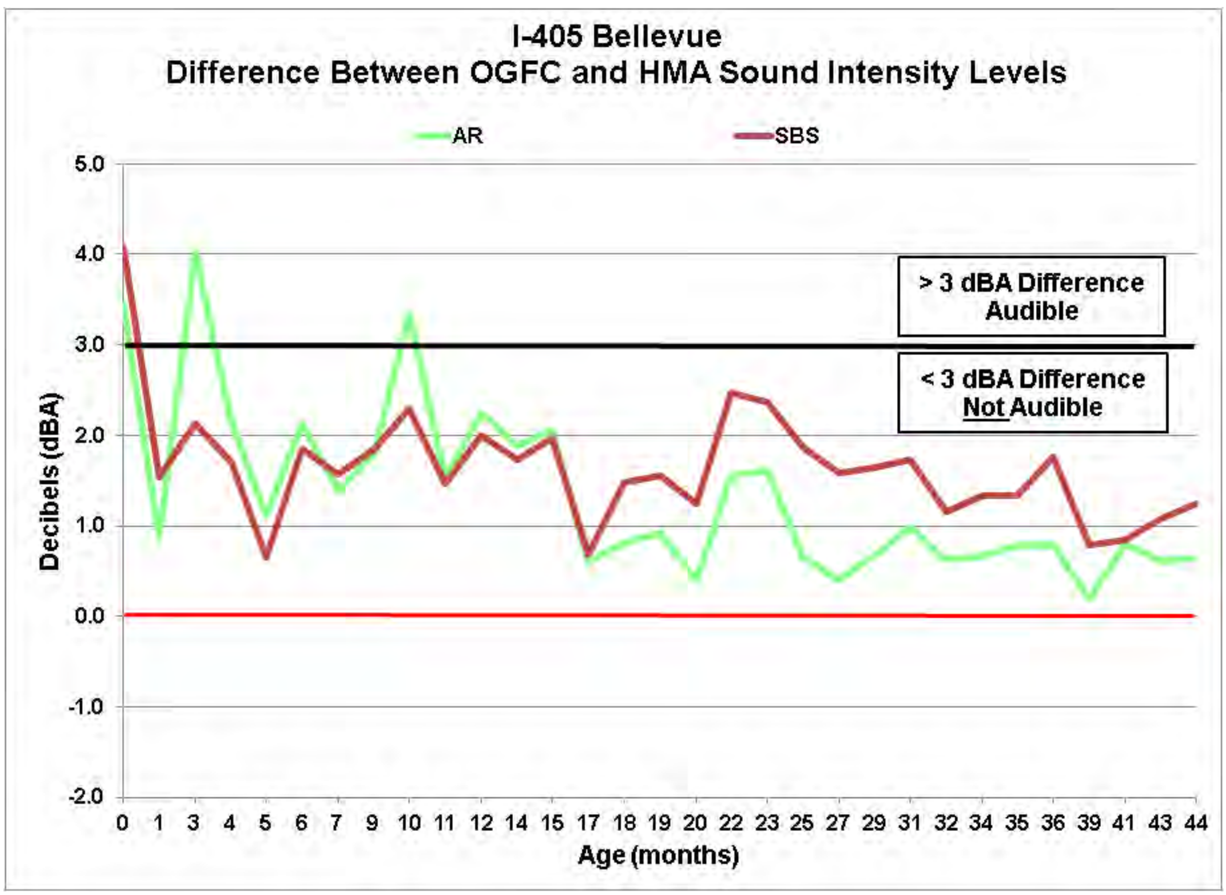


Figure 24. Difference in average sound intensity between the HMA control section and the OGFC-AR and OGFC-SBS quieter pavements.

The OGFC-AR section (green line) was initially audibly quieter than the HMA after construction and in months three and ten. After month 10, the section never again dropped below the below the 3.0 dBA difference line during the 44-month study period. The OGFC-AR was never louder noisier than the HMA.

Like the OGFC-SBS (brown line) was initially audibly quieter than the HMA one month after construction (month zero. Unlike the OGFC-AR the OGFC-SBS was never again audibly quieter than the HMA dropped below the 3.0 dBA difference line right after construction at the one month measurement and never again being audibly quieter than the HMA control section. The OGFC-SBS was never louder than the HMA.

In summary, the OGFC-AR section was audibly quieter for one month with a couple of peaks up to that level at three and ten months. The OGFC-SBS section was only audibly quieter than the HMA for one month.

Seasonal Variations in Sound Intensity Levels

The sound intensity levels of both OGFC sections increased much more during the winter months when studded tires are legal than over the summer months. Table 7 shows the changes in sound intensity levels for all three pavements during the winter when studded tires are legal (November 1 to March 31) and the summer when studded tires are banned (April 1 to October 31). Figure 25 is a line graph of the same information.

Table 7. Change in average sound intensity levels for winter and summer.

Season	Time Between Measurements (months)	OGFC-AR (dBA)	OGFC-SBS (dBA)	HMA (dBA)
Winter 2009-10	6	1.3	1.8	1.4
Summer 2010	5	0.2	0.5	0.8
Winter 2010-11	7	2.6	1.9	1.6
Summer 2011	6	0.8	0.2	0.5
Winter 2011-12	6	0.1	0.5	0.5
Summer 2012	5	-0.3	-0.4	-0.6
Winter 2012-13	7	0.1	0.5	-0.1

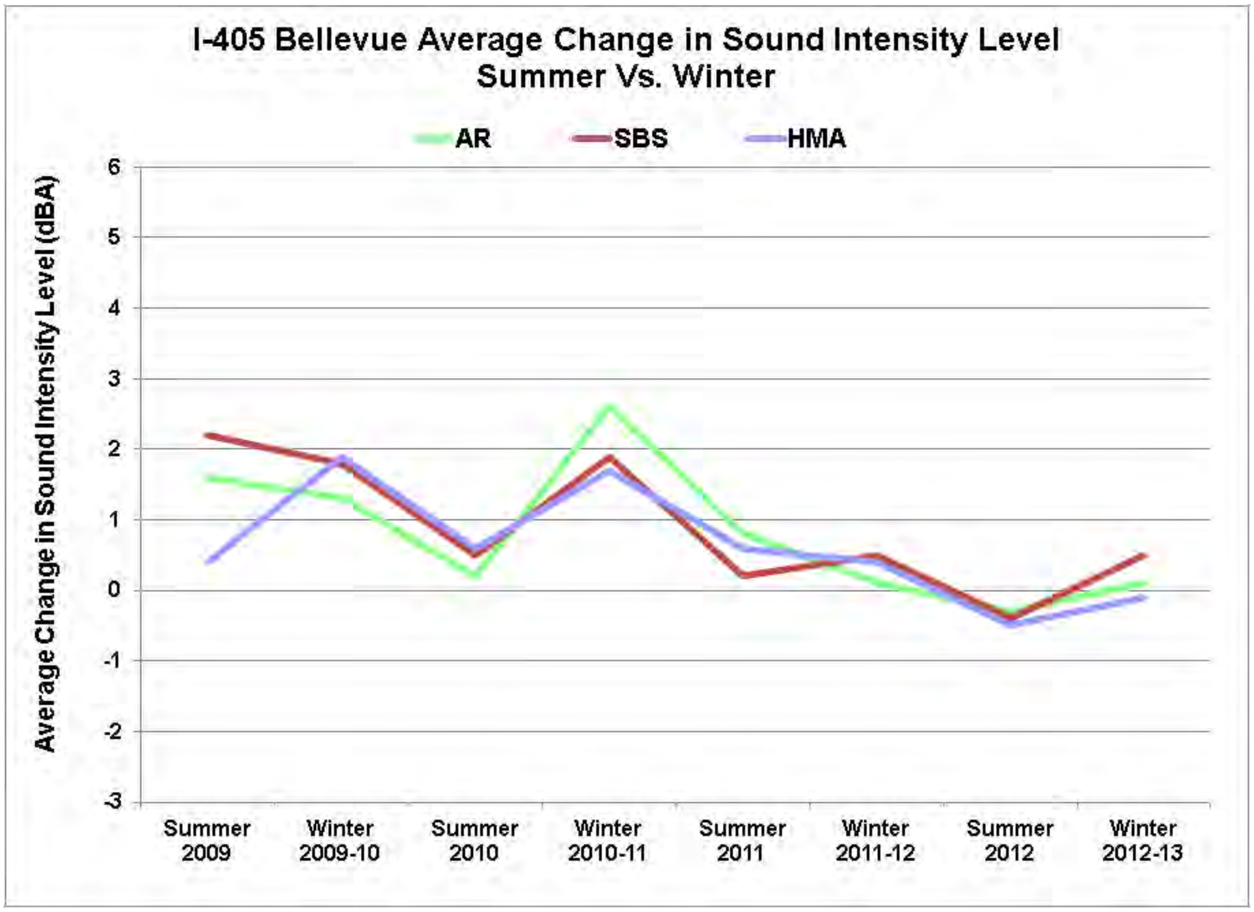


Figure 25. Average change in sound intensity level summer versus winter.

The average sound intensity level trends in the OGFC-AR and OGFC-SBS followed the same pattern observed on the other two quieter pavement projects where sound intensity levels increased mainly during the winter studded tire season. As described in the following section, the rutting/wear measurements also show a pattern similar to Figure 25. The larger increase in sound levels for both OGFC sections (green and brown lines) compared to the HMA section (blue line) suggests that winter conditions (studded tires, tires with chains, or colder temperatures and increased moisture) have a greater negative effect on the acoustic performance of OGFC pavements than on HMA pavements. This is not surprising. Open graded pavements are known to have less strength than dense graded pavements due to their higher void contents. The lower strength makes OGFC pavements more susceptible to damage from studded tires or tires equipped with chains. The higher void content also makes them more susceptible to damage from cycles of freezing and thawing.

Performance Difference between the OGFC-AR and OGFC-SBS

The report on the first two quieter pavement projects included a discussion of the possible causes for the difference in acoustical performance between the OGFC-AR and the OGFC-SBS sections. On this project the difference in the acoustical performance of the two types of OGFC's was smaller, with each changing a total of 7.2 dBA over the 44 month monitoring period. The large performance difference between the OGFC-AR and OGFC-SBS on the other two projects was attributed to the higher rubber content of the OGFC-AR at 20+ percent versus the OGFC-SBS at 3.4±1 percent. The hydrated lime anti-stripping additive may be one possible reason for the similar acoustic performance of the OGFC's on this project. Hydrated lime has been shown to increase the strength of HMA pavements and may increase its ability to withstand rutting and raveling from studded tires. Rutting and raveling pavements decrease smoothness, which increases noise levels.

Noise Summary

The following facts have been determined concerning the noise mitigation performance of the OGFC and HMA sections.

- The OGFC-AR section was only audibly quieter than the HMA control section for three measurements in the first ten months after construction. The section was an average of 1.3 dBA quieter than HMA over the entire 44-month measurement period and averaged 0.6 dBA quieter the final 12 months.
- The OGFC-SBS section was only audibly quieter than the HMA for the initial measurement after construction. The section was an average of 1.6 dBA quieter than HMA over the entire 44-month measurement period and averaged 1.2 dBA quieter the final 12 months.
- Neither of the OGFC sections became noisier than the HMA during the monitoring period.
- The changes in the noise reduction properties of all of the sections occurred during the winter season as a result of studded tire wear.

Wear/Rutting

Wear/rutting measurements were made on all three types of pavement in the spring and fall of each year to bracket the studded tire season. It will be shown later in the report that the majority of the rutting occurs during the winter studded tire season. The wear/rutting measurements are summarized in Table 8 and shown in bar charts for each pavement type in Figures 26-28. The maximum amount of wear/rutting was 7.5 mm for the OGFC-AR in Lane 1, 5.5 mm for the OGFC-SBS in lane 2, and 5.2 mm for the HMA also in Lane 2. The wear/rutting average for all lanes of the OGFC-AR was 5.7 mm, for the OGFC-SBS 4.5 mm and for the HMA 4.3 mm.

The average wear for each section is the lowest recorded for the three projects. The SR 520 Medina had the highest average wear with the OGFC-AR at 7.5 mm, the OGFC-SBS at 4.7 mm and the HMA at 5.0 mm. The I-5 Lynnwood average wear was 6.8 mm for the OGFC-AR, 5.5 mm for the OGFC-SBS, and 4.7 mm for the HMA. The primary reason for the difference is that the other two projects were subject to a severe winter storm that resulted in the increased use of studded tires and chains on the roadway for an extended time period. The wear measurements for these two projects document a dramatic increase in wear during that winter period.

Table 8. Wear/rutting measurements for SR 405, Bellevue.									
Section	Lane	F 2009	S 2010	F 2010	S 2011	F 2011	S 2012	F 2012	S 2013
AR	1	1.9	2.6	3.7	4.3	4.6	6.5	6.1	7.5
AR	2	1.8	2.5	2.6	4.1	4.2	6.0	5.6	7.0
AR	3	1.5	2.1	2.2	3.1	3.5	4.5	4.0	5.3
AR	HOV	1.7	1.8	2.4	2.1	2.1	2.8	2.2	3.0
Average		1.7	2.2	2.7	3.4	3.6	4.9	4.5	5.7
SBS	1	1.9	2.3	2.9	3.5	3.3	4.6	4.6	5.4
SBS	2	1.6	2.3	2.1	3.3	3.6	4.9	4.6	5.5
SBS	3	1.5	2.2	2.1	2.8	3.3	4.2	3.9	4.4
SBS	HOV	1.5	1.6	2.3	1.9	2.0	2.4	2.0	2.8
Average		1.6	2.1	2.3	2.9	3.0	4.0	3.8	4.5
HMA	1	2.1	2.5	2.8	3.2	2.9	3.7	3.4	4.0
HMA	2	2.2	2.7	3.0	3.8	3.4	4.8	4.4	5.2
HMA	3	2.1	2.4	2.9	3.8	3.8	4.5	4.2	4.8
HMA	HOV	1.8	1.8	1.6	2.2	2.2	2.7	2.3	3.0
Average		2.1	2.4	2.6	3.3	3.1	3.9	3.6	4.3

Note: S is for Spring, F for Fall, and W for Winter. The colors of the rows in the table are in the same green for AR, brown for SBS, and blue for HMA color palette as the bars in Figures 26-28.

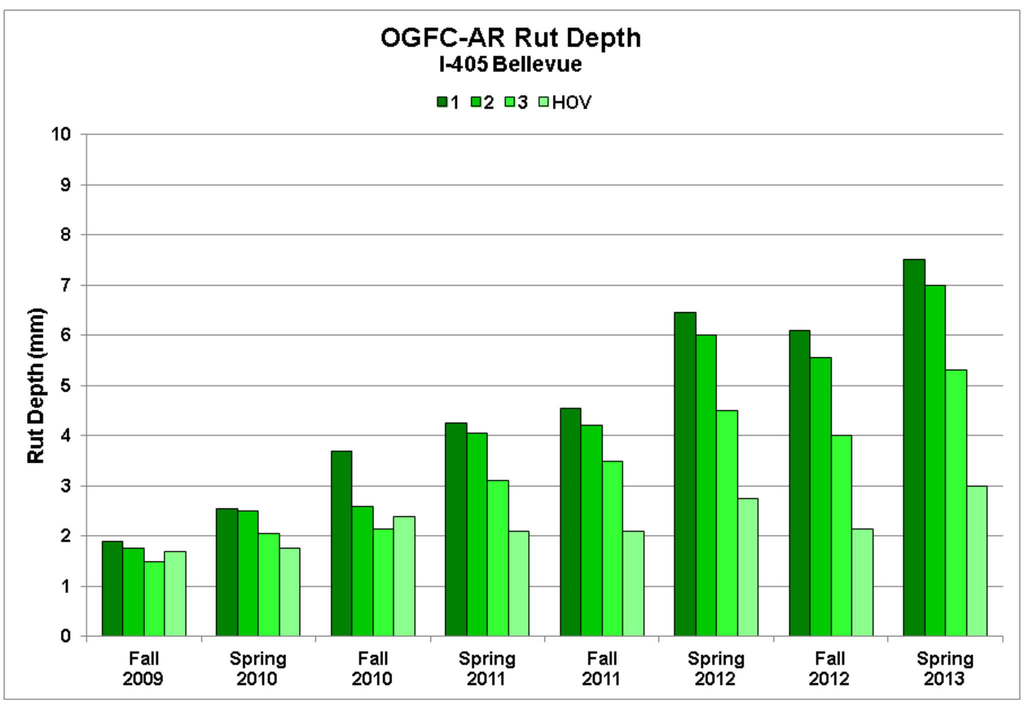


Figure 26. Rut depth for each lane of the OGFC-AR test section.

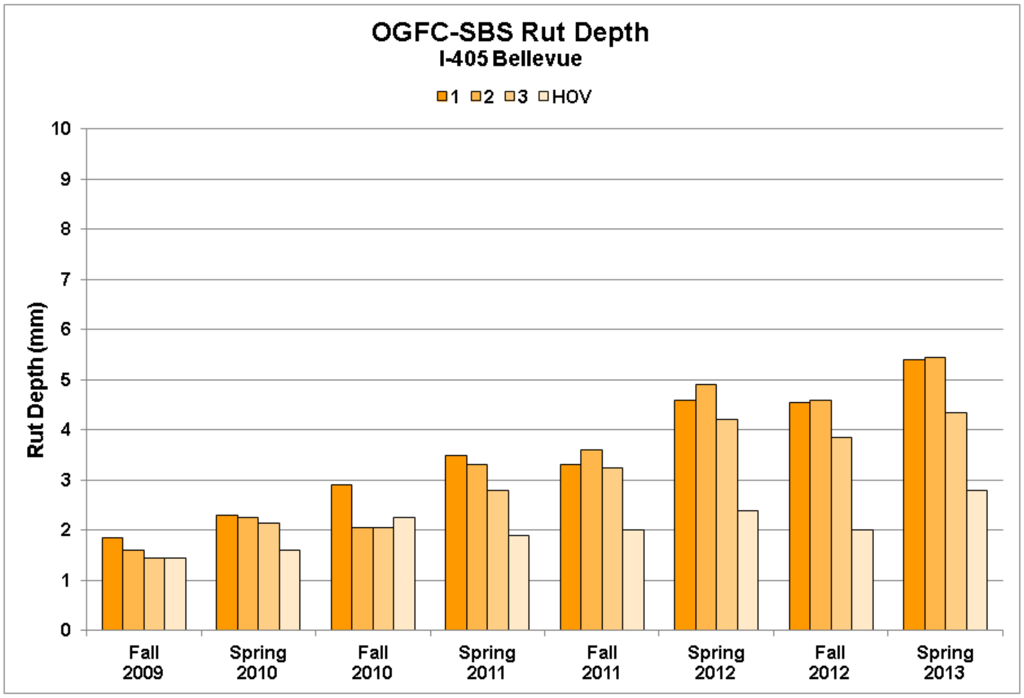


Figure 27. Rut depth for each lane of the OGFC-SBS test section.

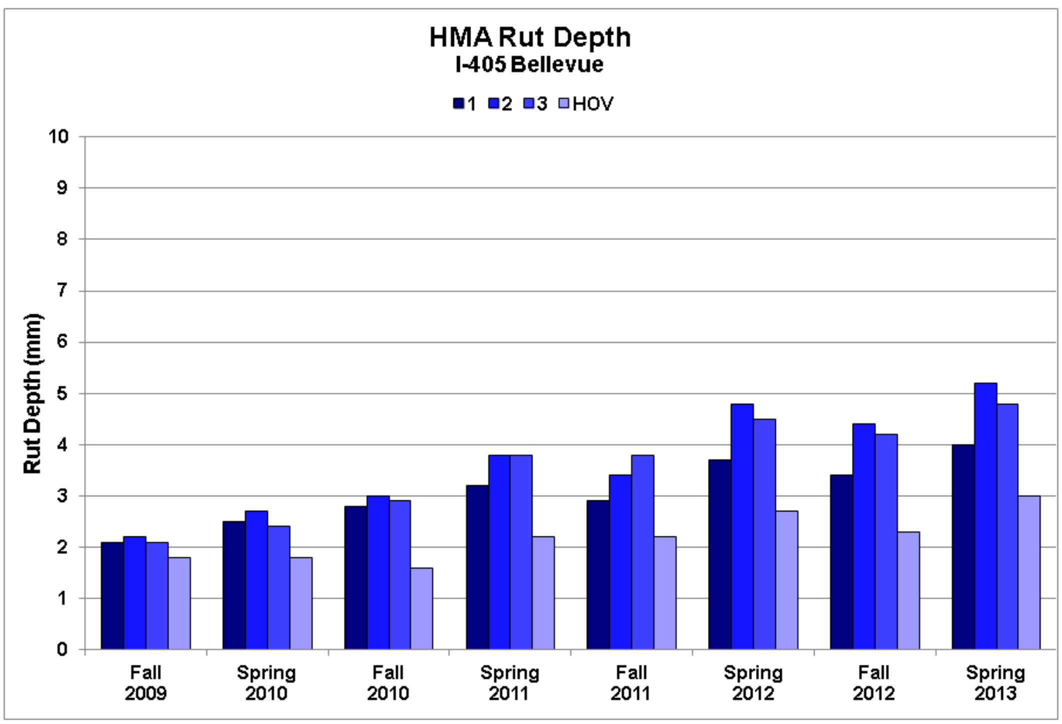


Figure 28. Rut depth for each lane of the HMA test section.

Historical Wear/Rutting of Open Graded Friction Course Pavements

The wear/rutting on this project is not progressing as fast as on the other two quieter pavement projects. It appears that the OGFC sections will not be worn through to the underlying pavement in the four years it took for this to happen on the other two projects. This is due in part to the increased pavement thickness of 25.4 mm (1 inch) as compared to the 19.0 mm (3/4 inch) thickness of the other two quieter pavement projects. The other factor, as noted previously, is the absence of the winter storm experienced by the other two projects. However, the wear/rutting of the OGFC sections on the quieter pavement projects is much higher than the wear/rutting on the HMA control sections.

The accelerated wear/rutting of the OGFC sections is not new to WSDOT. A total of 56 open graded friction course projects were constructed between 1980 and 1997. A moratorium was placed on the use of open graded friction courses following the poor performance of these pavements due to rapid wear/rutting from studded tires. The bar chart in Figure 29 shows that the majority of the projects had a pavement life of between six and ten years with 8.2 years as the average for all projects. This is about half of the current statewide HMA average pavement life which is 15 years. Additional information on the past performance of the open graded friction course projects can be found in the final reports on the I-5 Lynnwood and SR-520 Medina projects (see Reference section for links to these reports).

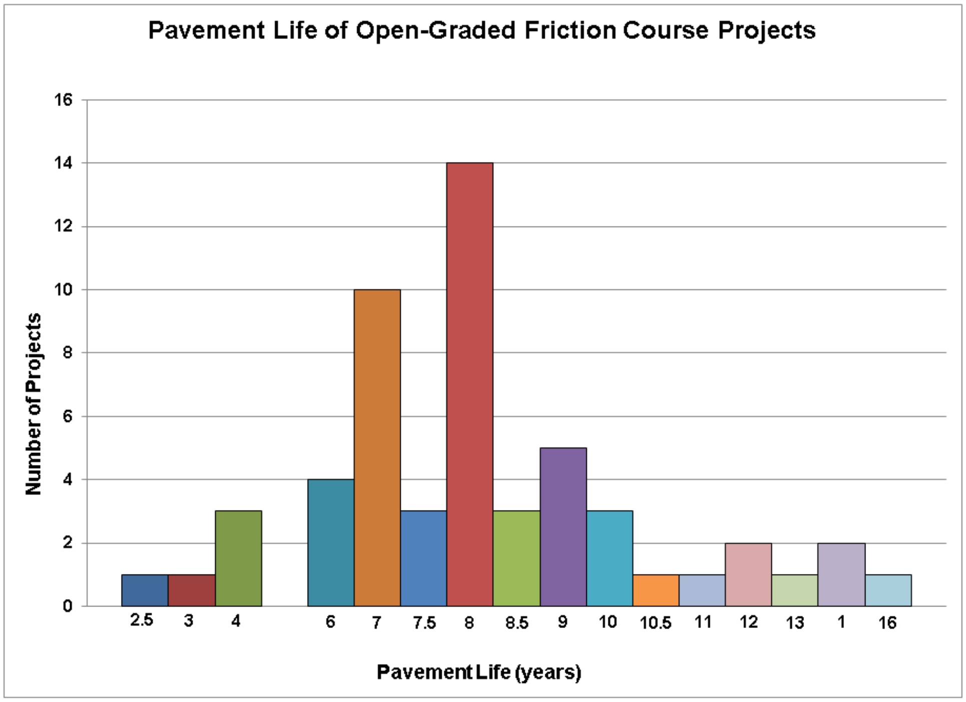


Figure 29. Pavement life of open graded friction course pavement built between 1980 and 1997.

Seasonal Variations in Wear/Rutting

The change in rut depth for all lanes of each section is listed in Table 9 and shown graphically in Figure 30 for the four winter and summer time periods. It shows that the majority of the wear/rutting occurs during winter. The OGFC-AR had an average increase in rutting of 1.2 mm during each winter period as contrasted with the OGFC-SBS and HMA sections which showed smaller increases, both at 0.9 mm. The average increase for all of the sections during the summer period was between negative 0.3 mm and 0.5 mm, therefore, the raveling and rutting on all of the sections is occurring primarily during the winter months. The average change for each season is shown in Figure 31. Negative rutting values can happen when there is wear across the entire lane which would decrease the rut depth as compared to the previous measurement. Negative rut depth measurements can also be the result of variations in the way a section is measured from one year to the next. The greater amounts of wear happening in the studded tire season indicates that colder temperatures, freezing and thawing, abundance of water and studded tires may all play a part in raveling and rutting and that the OGFC-AR is especially vulnerable to these conditions. This may also explain why OGFC-AR quieter pavements are more successful in states like Arizona, California, Texas and Florida which do not have winter weather conditions or high volumes of vehicles with studded tires.

Table 9. Change in the depth of the ruts in each section for each time period of studded tire use or no studded tire use.

Season	OGFC-AR (mm)	OGFC-SBS (mm)	HMA (mm)
Winter 2009-10	0.5	0.5	0.3
Summer 2010	0.5	0.2	0.2
Winter 2010-11	0.7	0.6	0.7
Summer 2011	0.2	0.2	-0.2
Winter 2011-12	1.3	1.0	0.9
Summer 2012	-0.4	-0.2	-0.3
Winter 2012-13	1.2	0.7	0.7
Summer Average	0.1	0.1	-0.1
Winter Average	0.9	0.7	0.7

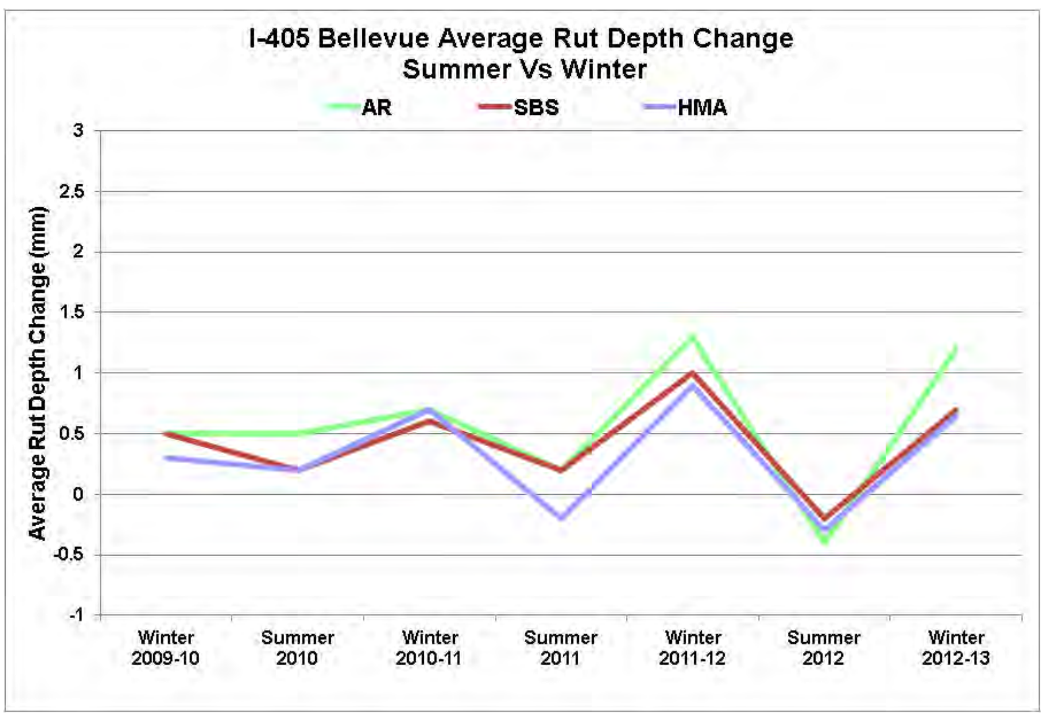


Figure 30. Average change in rut depth summer versus winter.

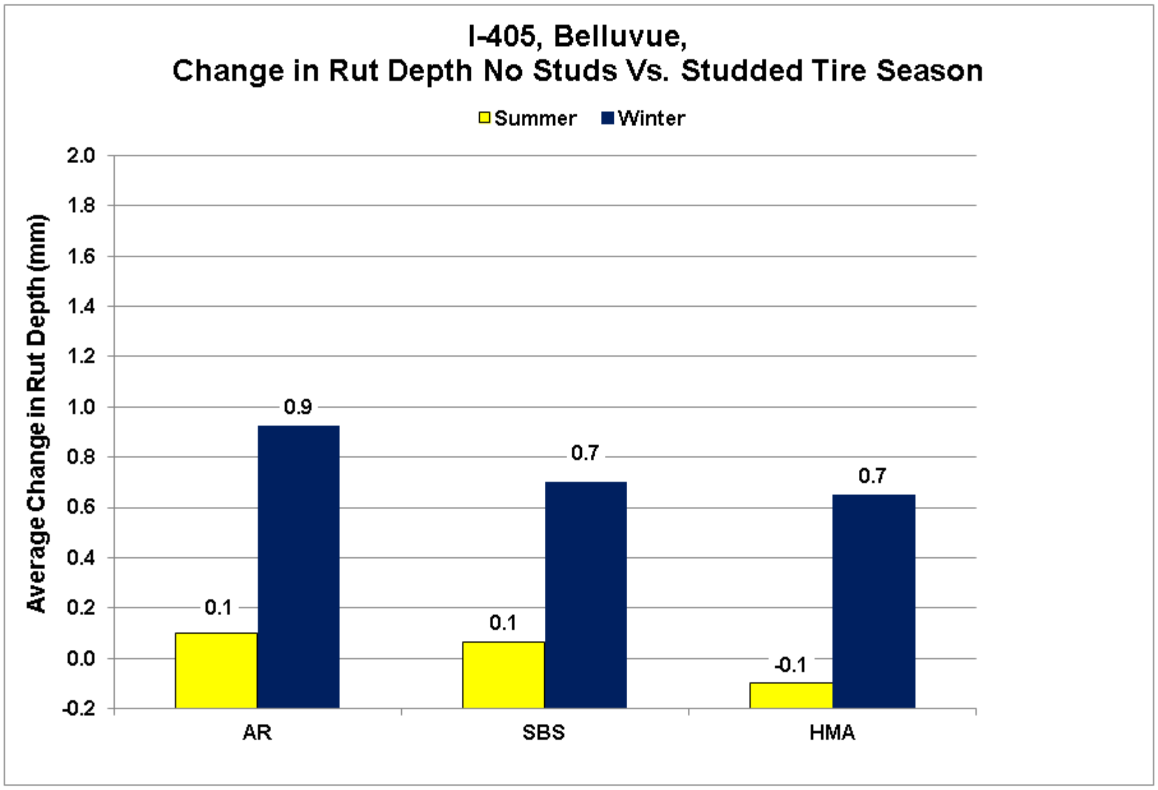


Figure 31. Average change in the depth of the rut during the legal studded tire season as compared to the rest of the year.

Wear/Rutting Summary

The following facts have been determined concerning the wear/rutting performance of the OGFC and HMA sections.

- The OGFC-AR section experienced the greatest amount of wear/rutting followed by the OGFC-SBS and then the HMA section.
- The average wear/rutting on the three pavement types was less than the average wear/rutting for the pavement types on the other two quieter pavement projects.
- The wear/rutting on all three sections is occurring primarily during the winter studded tire season.

Friction

Friction resistance measurements for the OGFC-AR, OGFC-SBS and HMA sections are summarized in Figure 32 and Table 10. The measurements were made in the spring and fall of each year bracketing the studded tire season. The friction numbers were excellent for all three pavement types. The readings for all three pavement types hovered around and FN of 50 indicating excellent friction resistance.

Table 10. Friction resistance measurements I-405, Bellevue.

Section	Lane	F 2009	F 2010	S 2011	F 2011	S 2012	F 2012	S 2013
AR	1	-	48.7	48.1	48.4	51.5	50.0	53.6
AR	2	51.3	50.8	52.9	50.6	55.4	52.0	52.9
AR	3	50.4	50.6	54.0	50.6	55.9	50.5	55.3
AR	HOV	45.7	51.7	53.2	51.6	55.8	51.1	54.6
Average		49.1	50.4	52.0	50.3	54.6	50.9	54.1
SBS	1	-	49.2	53.5	50.0	53.0	50.0	49.9
SBS	2	49.4	50.5	51.6	48.0	51.0	49.0	49.6
SBS	3	48.9	50.9	52.8	48.1	50.1	47.7	49.7
SBS	HOV	46.0	51.2	52.7	50.8	52.1	48.1	53.9
Average		48.1	50.4	52.6	49.2	51.5	48.7	50.7
HMA	1	-	52.2	51.8	48.8	51.6	50.2	52.0
HMA	2	58.6	50.6	49.7	47.3	52.0	46.5	49.1
HMA	3	57.5	51.3	50.9	47.6	52.8	45.8	50.7
HMA	HOV	57.9	53.0	53.0	49.8	54.3	49.1	51.2
Average		58.0	51.8	51.4	48.4	52.7	47.9	50.8

***F = Fall, S = Spring. Row colors in the table match the bars in Figure 32.**

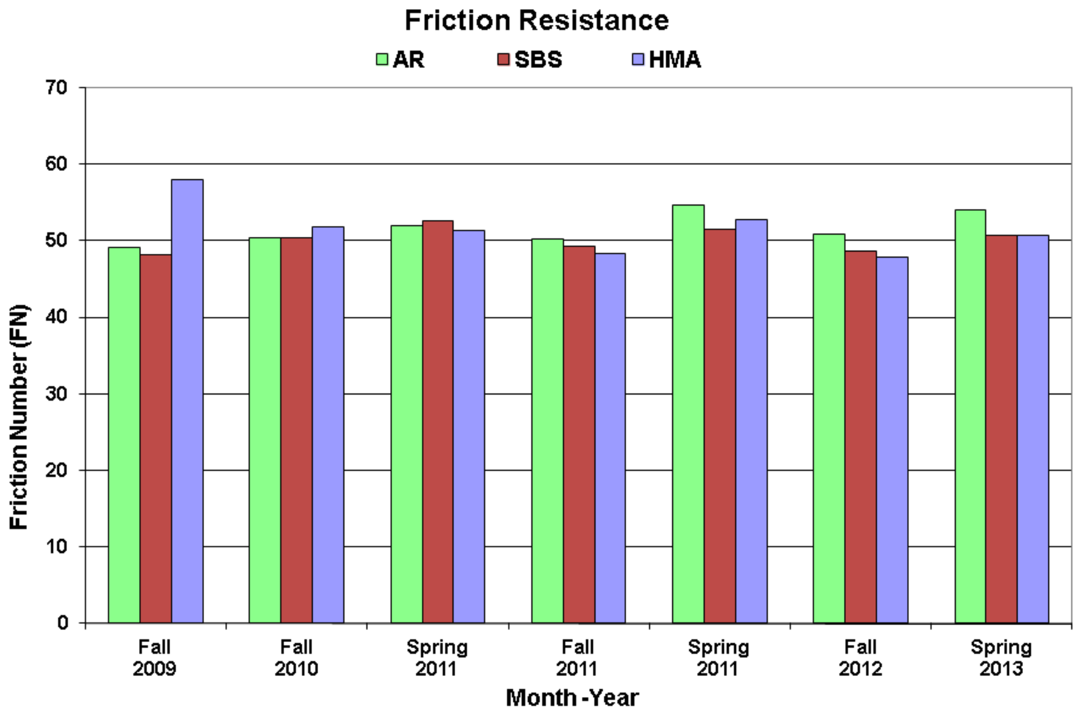


Figure 32. Average friction resistance for each pavement type.

Ride

Ride measurements for the OGFC-AR, OGFC-SBS and HMA are summarized in Table 11 and shown in the bar chart in Figure 33. Ride measurements were made on all sections in the spring and fall of each year bracketing the studded tire season. The ride measurements are in International Roughness Index (IRI) units of inches per mile. An IRI of 60 in/mi or lower is typical of good pavement construction. Initial ride scores after construction were excellent with the OGFC-AR lanes averaging an IRI of 61 in/mi with a range of 53-69. The OGFC-SBS lanes averaged 55 in/mi with a range of 46 to 68 and the HMA averaged 45 in/mi with a 37-65 range in IRI. The OGFC-AR and OGFC-SBS showed increases in ride of between 18 and 12 inches per mile, respectively, during the monitoring period whereas the HMA increased only 5 inches per mile. The larger change in the ride for the OGFC sections may be because of the rutting and raveling from studded tire wear.

Table 11. Ride (IRI) measurements for the SR 520 project. Units are inches per mile.

Section	Lane	F 2009	S 2010	F 2010	S 2011	F 2011	S 2012	F 2012	S 2013
AR	1	65	67	66	79	74	85	84	88
AR	2	53	56	56	64	61	70	64	73
AR	3	59	60	61	66	63	69	62	71
AR	HOV	69	70	72	78	74	82	78	83
Average		61	63	63	72	68	77	72	79
SBS	1	49	50	49	55	52	60	56	65
SBS	2	46	48	47	51	51	56	52	55
SBS	3	58	58	55	62	61	61	69	66
SBS	HOV	68	77	81	84	72	76	81	84
Average		55	58	58	63	59	63	64	67
HMA	1	65	68	69	71	67	69	70	72
HMA	2	40	41	42	43	43	44	43	45
HMA	3	39	42	40	40	40	42	40	42
HMA	HOV	37	37	38	40	40	41	40	41
Average		45	47	47	49	48	49	48	50

F = Fall, S = Spring. Row colors in the table match the bars in Figure 33.

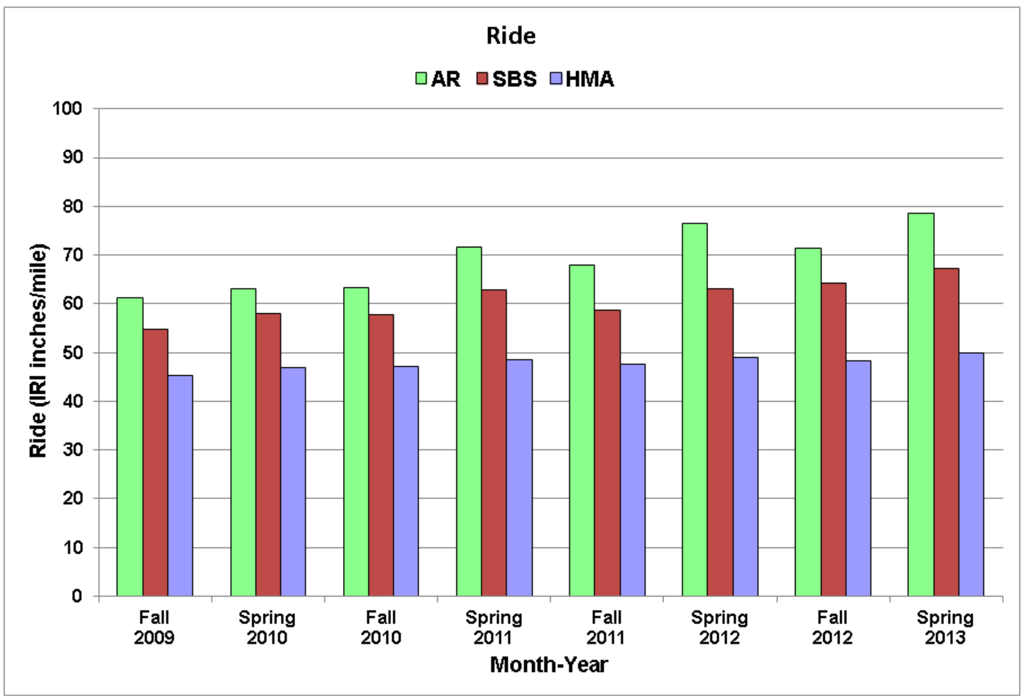


Figure 33. Average ride measurements for each pavement type.

Pavement Condition

The 2012 pavement condition data for the project shows that the OGFC-AR section is not performing as well as the OGFC-SBS section. Table 12 shows the type and extent of the distress for both sections. The distress noted for the OGFC-AR includes a minor amount of low severity alligator and longitudinal cracking but a significant number of low severity transverse cracks and sealed transverse cracks. In contrast, the data shows only a few low severity transverse cracks for in the OGFC-SBS section. The 82 transverse cracks reflecting through the OGFC-AR overlay from the underlying concrete pavement are 33 percent of the possible cracks as contrasted with the 5 cracks in the OGFC-SBS overlay which is only 5 percent. The age of the underlying concrete pavement ranged from 42 to 50 years with a weighted average of 44 years. This would indicate that all of the transverse cracks throughout both the AR and SBS sections would be wide and worn by traffic and very prone to reflect through an HMA overlay. The cracking data indicates that the OGFC-AR has less resistance to cracking than the OGFC-SBS. Pavement condition data for the HMA control section is not presented because it is not underlain by concrete pavement and therefore would not be subject to reflection cracking.

Table 12. 2012 pavement condition data for the OGFC-AR and OGFC-SBS.

Section	Low Severity Alligator Cracks (ft)	Low Severity Longitudinal Cracks (ft)	Low Severity Transverse Cracks (Number)	Sealed Transverse Cracks (Number)	Transverse Cracks in Underlying Concrete (Number)
OGFC-AR	7	81	46	36	246
OGFC-SBS	0	0	5	0	235

Figure 34. I-405 OGFC-AR section, note wear pattern in the wheel paths. (Photo taken 2/11/2011.)

Figure 35. Transverse reflection crack from underlying concrete pavement in OGFC-AR section. (Photo taken 2/11/2011.)

Life Cycle Cost Analysis

WSDOT uses life cycle cost analysis (LCCA) to compare the cost of different pavement options. LCCA is a method of economic analysis that takes into account the initial as well as the future costs. Cost data on this project was unavailable because it was a design/build project. On a design/build project the cost numbers are not broken down by bid item as they are in a conventional project. LCCA on the first two projects can be found in the final reports (see Referenced section).

Discussion of Results

The special test sections of OGFC-AR and OGFC-SBS pavement were constructed, from all indications, according to the contract specifications. The use of an MTV ensured 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 pavements placed were up to standards and suitable for the long-term evaluation of the benefits of open-graded pavements with respect to friction resistance, ride, rutting, and tire/pavement noise mitigation (Appendix E, Experimental Feature Work Plan).

The sound intensity level data, the wear/rutting data, and the ride data indicated that studded tires had a major affect on the performance of the OGFC-AR section and to a somewhat lesser extent on the performance of the OGFC-SBS. The wear/rutting on this project was less than the other two quieter pavement projects. The primary reason for the difference is the winter storm that greatly accelerated the wear/rutting on the first two projects. The pavement condition data indicates that the OGFC-AR pavement is less resistant to cracking than the OGFC-SBS.

The work plan for this experimental feature can be found in Appendix E.

Conclusions

The following conclusions were derived concerning the performance of the OGFC quieter pavements.

- The OGFC-AR mix produced a pavement that was audibly quieter than a conventional dense graded asphalt pavement on three measurement periods in the first ten months after construction.
- The OGFC-SBS mix produced a pavement that was audibly quieter than the conventional HMA for one month.
- The OGFC-AR and OGFC-SBS pavements are susceptible to raveling and rutting by studded tires that significantly shortens the useful life of the pavement.
- The OGFC-AR pavement is less resistant to cracking than the OGFC-SBS pavement.

Recommendations

WSDOT's use of open graded friction course mixes as quieter pavements is not recommended based on the short duration of their noise mitigation properties and susceptibility to excessive raveling and rutting leading to an unacceptable life cycle cost.

References

Anderson, K., Uhlmeyer, J., Sexton, T., Russell, M., Weston, J. (2008) **Evaluation of Long-Term Performance and Noise Characteristics of Open-Graded Friction Courses – Project 1: Post-Construction and Performance Report,** Washington State Department of Transportation, WA-RD 683.1, March 2008.

Anderson, K., Uhlmeyer, J., Sexton, T., Russell, M., Weston, J. (2012a) **Evaluation of Long-Term Performance and Noise Characteristics of Open-Graded Friction Courses – Project 1: Final Report**, Washington State Department of Transportation, WA-RD 683.2, June 2012.

Anderson, K., Uhlmeyer, J., Sexton, T., Russell, M., Weston, J. (2012b). **Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 2: Final Report.** Washington State Department of Transportation. WA-RD 691.2, June 2012.

ADOT (2008). **2008 Standard Specifications for Road and Bridge Construction.** Arizona Department of Transportation.

Appendix A

Mix Designs

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)
DATE SAMPLED: 7/24/2009
DATE RECVD HQS: 7/24/2009
SR NO: 405
SECTION: I-405 112th AVE SE TO SE 8TH STREET WIDENING

WORK ORDER NO: 007283
LAB ID NO 00000104bc7
TRANSMITTAL NO: 104bc7
MIX ID NO: MD090084
CONTRACTOR: LAKESIDE

---------CONTRACTOR'S PROPOSAL---------

Mat'l:	3/8" - 1/8"	SAND	COMBINED	SPECIFICATIONS
Source:	A-189	A-189		
Ratio:	90%	10%		
3/8"	100.0	100.0	100	100
No. 4	31.2	100.0	38	35 – 55
No. 8	3.5	85.0	12	9 – 14
No. 200	1.9	2.5	2.0	0 – 2.5

VALID FOR 2009

---------LABORATORY ANALYSIS---------

ASPH% BY TOTAL WT OF MIX:	8.1	8.6	9.1	SPECIFICATIONS
% VOIDS @ Ndes: 50	20.0	18.0	16.8	15.0 Min.
% VMA @ Ndes: 50	33.5	32.8	32.8	24.0 Min.
% Gmm @ Ndes: 50	80.0	82.0	83.2	82.0 Max.
Draindown @ 337°F		0.1		0.3 Max.
Stabilizing Additive (Cellulose Fiber)	0.3	0.3	0.3	0.2 – 0.5
Gmm – MAX S. G. FROM RICE w/ admix	2.557	2.538	2.514	
Gmb – BULK S. G. OF MIX	2.046	2.080	2.091	
Gsb – OF AGGREGATE BLEND	2.828	2.828	2.828	
Gsb – OF FINE AGGREGATE	2.581	2.581	2.581	
Gb – SPECIFIC GRAVITY OF BINDER	1.022	1.022	1.022	

CONTRACT 7283 ONLY

---------LOTTMAN STRIPPING EVALUATION---------

% ANTI-STRIP	0.0%	1.0 % HYDRATED LIME	
Visual Appearance:	NONE	NONE	
% Retained Strength:	95	119	80% Min.

---------RECOMMENDATIONS---------AGGREGATE TEST DATA---------

SUPPLIER	U.S. OIL
GRADE	PG70-22
% ASPHALT (By Total Wt. Mix)	8.6
% ANTI-STRIP (By Wt. Aggregate)	1.0
TYPE OF ANTI-STRIP	HYDRATED LIME
MIX ID NUMBER	MD090084
MIXING TEMPERATURE	337°F

TEST	VALUE	SPECIFICATIONS
FRACTURE	99	85 Min. (2 Faces)
SAND EQUIVALENT	86	45 Min.

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.: S. JAVERI --X(2)

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

REMARKS:

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol
(360)709-5421
Date: 8 / 7 / 2009

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 ASPHALT RUBBER (OGFC-AR)
DATE SAMPLED: 7/24/2009
DATE RECVD HQS: 7/24/2009
SR NO: 405
SECTION: I-405 112th AVE SE TO SE 8TH STREET WIDENING

WORK ORDER NO: 007283
LAB ID NO: 00000104bcc
TRANSMITTAL NO: 104bcc
MIX ID NO: MD090085
CONTRACTOR: LAKESIDE

CONTRACTOR'S PROPOSAL

Mat'l:	3/8"–1/8"	SAND	COMBINED	SPECIFICATIONS
Source:	A-189	A-189		
Ratio:	95%	5%		
3/8"	100.0	100.0	100	100
No. 4	31.2	100.0	35	30 – 45
No. 8	3.5	85.0	8	4 – 8
No. 200	1.9	2.5	1.9	0 – 2.5

VALID FOR 2009

LABORATORY ANALYSIS

		SPECIFICATIONS
L.A. ABRASION % @ 500 REVOLUTIONS*	12	
SAND EQUIVALENT (WSDOT T-176)	86	40 MAX
FRACTURE, % (WSDOT TP-61 2 FACES)	99	45 MIN.
FLAKINESS INDEX, % (AZ 233)	11	85 MIN.
CARBONATES, % (AZ 238)	1.9	25 MAX
COMBNED SPECIFIC GRAVITY (AZ 814)	2.843	30 MAX
COMBNED SPECIFIC GRAVITY (AZ 814 w/ admix)	2.835	2.350 – 2.850
COMBINED WATER ABSORPTION, % (AZ 814)	1.06	
Pba-ASPHALT ABSORPTION	0.8	2.50 MAX
Gsb – OF COARSE AGGREGATE (AZ 210)	2.858	1.00 MAX
Gsb – OF FINE AGGREGATE (AZ 211)	3.581	
Gb – SPECIFIC GRAVITY OF BINDER	1.047	
Gmm – MAX S. G. FROM RICE @ 4.0% Pb (AZ 806)	2.704	
Gmb – BULK S. G. OF MIX (AZ 814)	130.9	

CONTRACT 7283 ONLY

RECOMMENDATIONS

SUPPLIER	U.S. OIL
GRADE	PG64-22
% ASPHALT RUBBER (By Total Wt. Mix)	9.4
CRUMB RUBBER MODIFIER TYPE	B
RUBBER SOURCE	RUBBER GRANULATORS
CRM SPECIFIC GRAVITY	1.150
% BY WT. OF ASPHALT CEMENT	20.0
% ANTI-STRIP (By Wt. Aggregate)	1.0
TYPE OF ANTI-STRIP	HYDRATED LIME
MIX ID NUMBER	MD090085
MIXING TEMPERATURE	325°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.: S. JAVERI –X(?)

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

REMARKS: ***L.A. ABRASION ONLY RUN @ 500 REVOLUTIONS**

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol
(360)709-5421
Date: 8 / 7 / 2009

Appendix B

Contract Special Provisions

2.7.6 Quieter Pavement Surface Treatments and Pavements

2.7.6.1 Hot Mix Asphalt

2.7.6.1.1 Description The first paragraph of WSDOT Standard Specification 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 and other additives properly proportioned, mixed and applied on a paved surface.
- OGFC-AR shall consist of a mixture of rubberized asphalt, mineral aggregate and other additives properly proportioned, mixed and applied on a paved surface.

2.7.6.1.2 Materials

WSDOT Standard Specification Section 5-04.2 is supplemented with the following:

- The use of RAP shall not be permitted in the production of OGFC or OGFC-AR.
- 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.

2.7.6.1.2.1 Asphalt-Rubber

- Asphalt Binder

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

- 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.

Manufacturers Certificate of Compliance conforming to Section 2.25.6.1 shall be submitted to WSDOT. 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.

2.7.6.1.2.2 Asphalt-Rubber Proportions

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

2.7.6.1.2.3 Asphalt-Rubber Properties

Manufacturers Certificate of Compliance conforming to Section 2.25.6.1 shall be submitted to WSDOT showing that the asphalt-rubber conforms to the following:

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

2.7.6.1.2.4 Asphalt-Rubber Binder Design

At least 15 business days 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.

2.7.6.1.3 Construction Requirements

WSDOT Standard Specification 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 WSDOT.

2.7.6.1.3.1 Mixing of Asphalt-Rubber

The temperature of the asphalt binder shall be between 350°F and 400°F at the time of addition of the crumb rubber. No agglomerations of rubber particles in excess of two inches in the least dimension shall be allowed in the mixing chamber. The crumb 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°F 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 must conform to the asphalt-rubber properties described in Section 2.7.6.1.2.3, which is to be furnished by the Contractor or supplier.

2.7.6.1.3.2 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°F 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°F 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 calendar days.

For each load or batch of asphalt-rubber, the Contractor shall provide the Design-Builder with the following documentation:

- The source, grade, amount and temperature of the asphalt binder prior to the addition of rubber.

- The source and amount of rubber and the rubber content expressed as percent by the weight of the asphalt binder.
- Times and dates of the rubber additions and resultant viscosity test.
- 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.

2.7.6.1.3.3 HMA Mixing Plant

WSDOT Standard Specification Section 5-04.3(1) is supplemented with the following:

2.7.6.1.3.3.1 Fiber Supply System

When fiber stabilizing additives are required for OGFC, a separate feed system that meets the following will be required:

- Accurately proportions by weight the required quantity into the mixture in such a manner that uniform distribution will be obtained.
- 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.

1. 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 Design-Builder. The batch dry mixing time shall be increased by 8 to 12 seconds, or as directed by the Design-Builder, 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.

2.7.6.1.3.3.2 Surge and Storage Systems

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

2.7.6.1.3.4 Hot Mix Asphalt Pavers

WSDOT Standard Specification 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.

2.7.6.1.3.5 Rollers

WSDOT Standard Specification Section 5-04.3(4) is supplemented with the following:

- The wheels of the rollers used for OGFC and OGFC-AR shall be wetted with water, or if necessary soapy water, or a product approved by the Design-Builder 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.

2.7.6.1.3.6 Preparation Of Existing Surfaces

WSDOT Standard Specification 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 Design-Builder.

2.7.6.1.3.7 Mix Design

WSDOT Standard Specification Section 5-04.3(7)A is supplemented with the following:

Mix Design (OGFC-AR). Approximately 500 pounds of produced mineral aggregate, in proportion to the anticipated percent usage, shall be obtained. The mineral aggregate must be representative of the mineral aggregate to be utilized in the OGFC-AR production. The material submitted shall be in individual bags weighing no more than outlined in WSDOT *Materials Manual*, WSDOT FOP for AASHTO T2.

The Design-Builder shall also furnish two sets of representative samples of each of the following materials: a five-pound sample of the crumb rubber proposed for use, four quarts of asphalt binder from the intended supplier, twenty quarts of the proposed mixture of binder and rubber, and one-pint of the liquid anti-strip to be used in the OGFC-AR.

Along with the samples furnished for mix design testing, the Design-Builder 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 and the asphalt-rubber supplier.

Within 15 business days of receipt of all samples and the Contractor's letter in the WSDOT HQ Materials Laboratory, WSDOT 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 gradation and any special or limiting conditions for the use of the mix.

Mix Design (OGFC) Approximately 500 pounds of produced mineral aggregate, in proportion to the anticipated percent usage, shall be obtained and submitted to the WSDOT State Materials Laboratory in Tumwater. The mineral aggregate must be representative of the mineral aggregate to be utilized in the OGFC production. The material submitted shall be in individual bags weighing no more than outlined in WSDOT *Materials Manual*, WSDOT FOP for AASHTO T2.

The Design-Builder shall also furnish two sets of representative samples of each of the following materials: four quarts of asphalt binder from the intended supplier, and one-pint of the liquid anti-strip to be used in the OGFC. Along with the samples furnished for mix design testing, the Design-Builder 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.

Within 15 business days of receipt of all samples and the Design-Builder's letter, the WSDOT will provide the Design-Builder with the percentage of asphalt to be used in the mix, the percentage to be used from each of the stockpiles of mineral aggregate, the composite mineral aggregate gradation and any special or limiting conditions for the use of the mix.

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 maximum.

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 WSDOT, or without requesting a new mix design.

During production of OGFC and OGFC-AR, the Design-Builder, on the basis of field test results, may request a change to the approved mix design. WSDOT will evaluate the proposed changes and notify the Design-Builder of WSDOT's decision within two business 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 additional mix designs after a mix design acceptable to the Department has been developed shall be borne by the Contractor.

WSDOT Standard Specification Section 9-02.1(4) shall be supplemented with the following:

The phase angle on the unaged PG70-22 binder used in the production of OGFC shall be no more than 75 degrees.

WSDOT Standard Specification Section 9-03.8(1) is supplemented with the following:

Tests on aggregates outlined in the following table, other than abrasion, shall be performed on materials furnished for OGFC-AR mix design purposes and composited to the mix design gradation. Abrasion shall be performed separately on samples from each source of mineral aggregate. All sources shall meet the requirements for abrasion.

MINERAL AGGREGATE CHARACTERISTICS		
Characteristic	**Test Method**	**Requirement**
Combined Bulk Specific Gravity	Arizona Test Method 814	2.35 – 2.85
Combined Water Absorption	Arizona Test Method 814	0 – 2.5%
Fractured Coarse Aggregate Particles	Arizona Test Method 212	Minimum 85% (two fractured faces)
Flakiness Index	Arizona Test Method 233	Maximum 25
Carbonates in Aggregate	Arizona Test Method 238	Maximum 30%
Abrasion	AASHTO T 96	100 Rev., Max. 9% 500 Rev., Max. 40%

WSDOT Standard Specification Section 9-03.8(2) is supplemented with the following:

The OGFC mixture shall meet the following criteria:

Design Parameter	Design Criteria
Percent of G_{mm} at N_d of 50 gyrations (AASHTO T 209)	$\leq$ 82%
Effective air voids	$\geq$ 15%
VMA at N_d of 50 gyrations	$\geq$ 24%
WSDOT FOP for AASHTO TP 61 (two fractured faces)	Minimum 85%
WSDOT T 718 Method of Test for Determining Stripping of Asphalt Concrete	TSR 80% min
Draindown, maximum, percent of total mass (AASHTO T 305)	0.3

WSDOT Standard Specification Section 9-03.8(4) is supplemented with the following:

For use with OGFC and OGFC-AR, blending sand shall meet the following quality requirement in accordance with WSDOT FOP for AASHTO T 176:

Sand Equivalent: Minimum 45

Fiber Stabilizing Additive. If needed, cellulose fiber stabilizing additive shall meet the properties described below. Dosage rates given are typical ranges but the actual dosage rate used shall be approved by the Design-Builder.

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 Design-Builder. 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: 80-95%
      Passing No. 40 sieve: 45-85%
      Passing No. 100 sieve: 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.

WSDOT Standard Specification Section 9-03.8(6) is supplemented with the following:

OGFC Mineral Aggregate

Mineral aggregate shall conform to the following grading limits:

Sieve Size	Percent Passing
⅜ Inch	100
No. 4	35 – 55
No. 8	9 – 14
No. 200	0 – 2.5

The percent of fractured coarse aggregate particles is at least 85 (two fractured faces) when tested in accordance with WSDOT FOP for AASHTO TP 61.

OGFC-AR Mineral Aggregate

Sieve Size	Percent Passing
⅜ Inch	100
No. 4	30 - 45
No. 8	4 - 8
No. 200	0 - 2.5

The percent of fractured coarse aggregate particles shall be at least 85 (two fractured faces) when tested in accordance with WSDOT FOP for AASHTO TP 61.

2.7.6.1.3.8 Acceptance Sampling and Testing - HMA Mixture

All acceptance testing will be performed by WSDOT or their representatives.

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

- Item 1 is supplemented with the following:
- Nonstatistical evaluation will be used for the acceptance of OGFC & OGFC-AR.
- Item 3 is supplemented with the following:

Sampling - OGFC and OGFC-AR

OGFC and OGFC-AR will be evaluated for quality of gradation, sand equivalency and fracture 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 each approximate 300 tons of OGFC, at least one sample of mineral aggregate shall be taken. Samples shall be taken in accordance with WSDOT FOP for AASHTO T-2 on a random basis just prior to the addition of bituminous materials. 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
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 FOP for AASHTO T-2 on a random basis just prior to the addition of 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

- Item 7 is supplemented with the following:

  Prior to starting any OGFC or OGFC-AR paving operation, including calibration sections, the Contractor shall provide at least 14 business days written notice to the Design-Builder so that the Design-Builder can provide notification to WSDOT.

  Calibration Section – OGFC

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

  The minimum calibration section shall be 12 ft wide by 200 ft long. For an onsite calibration section, the minimum placement temperature shall satisfy 2.7.6.1.3.9, "Weather Limitations." For an off-site calibration section, the minimum air temperature for placement shall be 60°F. If the calibration section is to be left in place as a permanent pavement feature, it shall meet requirements defined in 2.7 of the Technical Requirements.

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

  Calibration Section - OGFC-AR

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

  The minimum calibration section shall be 12 ft wide by 200 ft long. For an onsite calibration section, the minimum placement temperature shall satisfy 2.7.3.1.3.9, "Weather Limitations." For an off-site calibration section, the minimum air temperature for placement shall be 60°F. If the calibration section is to be left in place as a permanent pavement feature, it shall meet requirements defined in 2.7 of the Technical Requirements.

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

2.7.6.1.3.9 Weather Limitations

WSDOT Standard Specification 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. In the northbound direction, OGFC and OGFC-AR shall not be placed when the air temperature is less than 70°F. In the southbound direction, OGFC and OGFC-AR shall not be placed when the air temperature is less than 60°F.

2.7.6.1.3.10 Traffic Limitations

The OGFC and OGFC-AR pavement must cool to minimum surface temperature of 100°F prior to being opened to general traffic.

2.7.6.1.3.11 Temporary Pavement Marking Limitations

WSDOT Standard Specification Section 8-23.3(1) is supplemented with the following:

In order not to damage permanent OGFC and OGFC-AR work caused by removing temporary pavement markings the Design-Builder should consider the use of either removable tape or temporary raised pavement markers. If paint is used as a temporary pavement marker, it must be located along the permanent edge line or lane line.

2.7.7 Submittals

2.7.7.1 Pavement Design

The Design-Builder shall prepare and submit a draft and final pavement report to WSDOT. The final pavement report must be approved by WSDOT prior to the start of any permanent paving on the Project. Supplemental submittals may also be required as described in Section 2.7.4.1 for temporarily running traffic on the shoulders of I-405 to accommodate construction activities.

2.7.7.2 Asphalt-Rubber Binder Design Submittal

Fifteen business days prior to the use of asphalt-rubber, the Design-Builder shall submit to the WSDOT an asphalt binder design. See section 2.7.6.1.2.4 for submittal details.

2.7.7.3 Mix Design OGFC-AR

See section 2.7.6.1.3.7 for submittal requirements for OGFC-AR mineral aggregate, crumb rubber proposed for use, asphalt binder from the intended supplier, mixture of binder and rubber, liquid anti-strip to be used in the OGFC-AR and accompanying letter.

The above materials and letter shall be shipped to the WSDOT HQ Materials Laboratory at 1655 South 2nd Avenue, Tumwater, WA 98512. Along with the appropriate transmittal for each component, WSDOT Form 350-056 EF

2.7.7.4 Mix Design OGFC

See section 2.7.6.1.3.7 for submittal requirements for OGFC mineral aggregate, asphalt binder from the intended supplier, liquid anti-strip to be used in the OGFC and accompanying letter.

The above materials and letter shall be shipped to the WSDOT HQ Materials Laboratory at 1655 South 2nd Avenue, Tumwater, WA 98512. Along with the appropriate transmittal for each component, WSDOT Form 350-056 EF

Appendix C

Construction Comments

Eastside Quite Pavements
I-405, 112th Ave SE to SE 8th St
Construction Comments

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

TACK APPLICATION
During the paving of Interstate 405 a Bear Cat (CRC, Computerized Rate Control) tack truck applied paving grade asphalt (PG64-22) to the pavement surface. The rate of application for coverage was 0.08 gallons per square yard which remained unchanged for the duration of paving. Application was very consistent with uniform distribution on the pavement surface.

Image of tack application on new PCCP surface

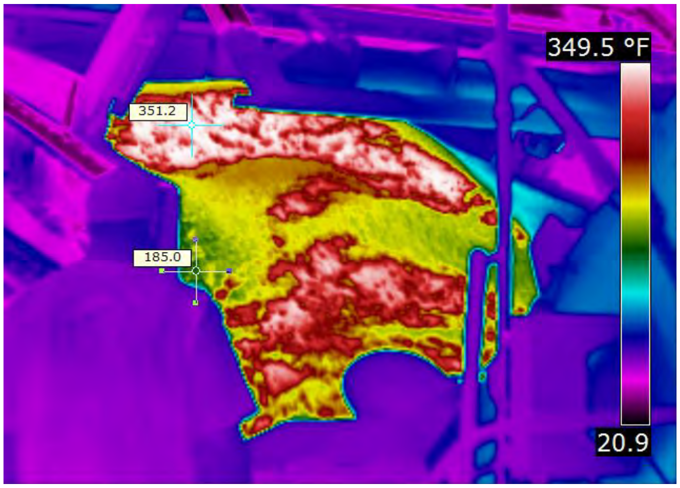
Tack placed on portions of the new PCCP located along the HOV lane was generally picked up by the RoadTec Shuttle Buggy material transfer device (MTD). Although sweeping equipment was used to clean all paved surfaces prior to paving, fine dust and curing compound was not completely removed from the roadway. Tracking was seen within the wheel paths caused by the MTD and delivery truck tires for portions of the new concrete roadway. This was likely a result of the lane not being opened to traffic prior to the placement of the OGFC materials. As ambient air temperature increased (≥75°F), along with pavement surface temperature, pickup of the tack coat material was minimized from the pavement surface. For the remaining portions of the project, pickup was not an issue.

Image of tack pickup on new PCCP

Pickup of tack when temperature was warmer

DELIVERY VEHICLES

During this particular project trucks and trailers were used to deliver OGFC-AR and OGFC-SBS to the project limits. Project limits were about seven miles from plant operations. Typical temperatures of the cooler outer crust which formed on the loads during transport were around 185ºF with internal temperatures around 345ºF. Delivery vehicles were not having to wait for paving operations to catch up but rather paving, at times, needed to wait for delivery vehicles. This was predominant during production of OGFC-AR.



Delivery vehicle dumping into Shuttle Buggy (Note internal and crust temperatures).

MATERIAL TRANSFER VEHICLE

This project employed the use of two (on two occasions three were utilized) RoadTec Shuttle Buggy's as the material transfer device (MTD). Because of the remixing characteristics and storage ability of this vehicle, it was an ideal transfer device for this project. Temperatures from the MTD into the paver hopper were typically around 325ºF. The insulating and remixing capability of this device allowed for the pavement to have consistent temperatures across the mat and behind the screed even as three pavers were utilized at the same time.

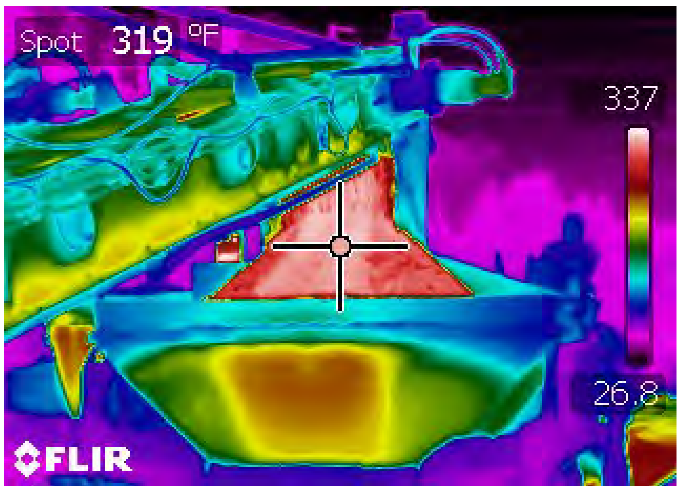


Image of temperature from MTD to paver hopper

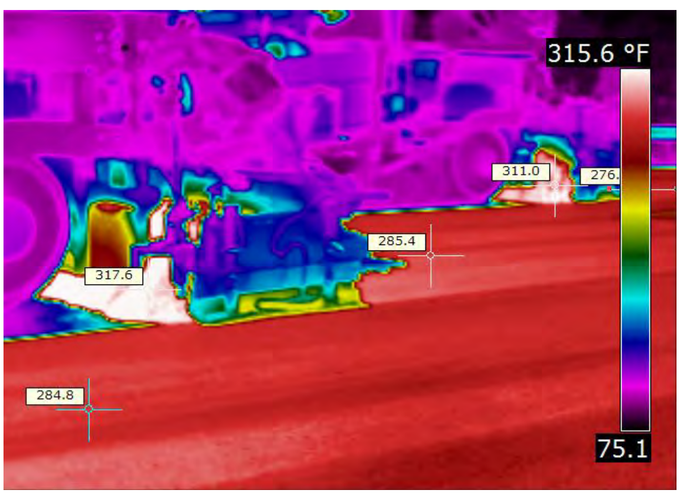


Image from back of screed looking towards the rollers

PAVER

For this project two pavers were predominantly used with a third used on two occasions. All three pavers were CAT AP-1055D. All three were equipped with a hopper box and Carlson EZ screed. The two predominant pavers utilized the Carlson EZ IV screed and the third paver was equipped with the Carlson EZ III screed. The CAT pavers are equipped with reverse augers near the gearbox.

Looking towards the three pavers

ROLLERS

There were a total of six rollers (three for each paver) typically used for the paving of OGFC-AR and OGFC-Polymer. When the third paver was added so were three additional rollers. Of the breakdown rollers, one was an Ingersoll-Rand DD-118 and the other was a Dynapac CC-522. The remaining rollers were all Dynapac CC-522 rollers. All rollers were used in static mode as specified in the contract Special Provisions. In addition, all rollers worked in unison with the breakdown rollers taking three passes for complete coverage of the lane. All remaining compaction equipment stayed approximately 100 feet behind the roller in front of it and also worked in tandem shadowing the rollers in front.

Looking at breakdown and intermediate rollers

One issue that was a problem with the first Quieter Pavement project was that of matching the longitudinal joint. Because most of the paving was done using two or three pavers (hot-lapping), there was only one cold joint caused from the previous days paving. Matching the joint on this project was not an issue and the longitudinal joint does not show any defects.

Image of the longitudinal joint

OGFC-AR

OGFC-AR liked to adhere to the paving equipment (i.e.: rakes, truck beds, MTD tires, etc.). Because of this, working with material that was placed near utilities often created results that were not as aesthetically pleasing as most hot mix asphalt (HMA) applications. This material also seemed to promote the use of release agent on all the equipment used.

Temperatures behind the screed were 290 to 300ºF. These temperatures were consistent with those found in Arizona when paving with the same materials. The pavement surface gave the impression that the material was setting up directly behind the paver.

On this particular project paving with OGFC-AR was consistent although hauling was impacted by traffic in the area and on a few occasions the paver had to stop. The greatest impact to the production of OGFC-AR was that the existing PCCP had been milled, but the milling was not able to remove all the rutting caused by studded tires. Because the binder used in OGFC-AR has to be blended in advance, it takes time to manufacture this material. The quantity of binder produced is based on the amount of OGFC-AR to be placed (depth x width x length). Because the milling was not perfectly smooth the calculated yield quantities were underestimated. This resulted in a few hundred feet of shoulder that was paved with OGFC-SBS that was originally designed to be OGFC-AR. Below are photos showing the amount of rutting or mismatched milling present.

Amount of rutting present after milling

OGFC-SBS

This material was more easily produced and paving operations were not halted as often as that of the OGFC-AR. The paving grade (PG64-22) tack coat used on this project worked well. Globules were not present as they were with the CRS-2P.

INSPECTION

The one common thread that must be emphasized in the inspecting of HMA placement is temperature. Large temperature differences can result in substantial surface defects if not addressed. Because of this, it is recommended that an infrared (IR) camera be present for all production paving or at a minimum, a temperature gun. The use of a stick thermometer is not practical since the surface thickness and aggressive roller operations would likely destroy it. In addition, it would likely damage the pavement when removed because of the adhesion characteristics of the asphalt.

In the case of this project, the Project Engineering Office did an outstanding job of collecting temperature information. Although the predominant means of collecting temperature information was a temperature gun, temperature was collected at the truck, paver hopper, at the paver augers and behind the screed. In addition, the IR camera was used to collect temperature images behind the screed during the placement of OGFC-AR and OGFC-Polymer materials. The systematic method of collecting temperature on this project was quite impressive.

RECOMMENDATIONS

- The use of performance grade asphalt as tack coat material should be considered as an alternative to standard tack coat materials in areas where time is a consideration. Since this material does not need to break, once it is placed, paving can begin.
- Specify that tarps be used on delivery vehicles as "mandatory" to ensure heat retention is maximized.
- Because of the thin surface of the OGFC material and the need for even temperature distribution, the Roadtec Shuttle Buggy or equivalent equipment should be specified for use.
- Keep paving production, delivery vehicles, and paving operations consistent. Impacts of traffic have to be considered in the equation.
- Systematic documentation of the temperature of OGFC materials at the truck, paver hopper, paver augers and behind the screed is fundamental to the correct assessment of the proper construction of the pavement.
- Provide an IR camera to inspection staff.

INSTRUCTION FOR INSPECTORS AND CONTRACTORS

- Pay careful attention to the construction of longitudinal joints to avoid high points.
- Make sure the screed temperature is as close to paving temperature as possible prior to paving.
- The timing of construction is primary to keeping rollers within 300 feet of paver (specification).
    - 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 paver doesn't speed up until rollers have completed the work at a construction joint.
- Minimize handwork as much as possible.
- Keep delivery trucks and MTD 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 roadway, or build-up on tires becomes excessive, clean thoroughly.
- Remember that this is a thin surface and large defects will reflect through.
- Record Temperature Information (preferably by use of the IR camera)

Appendix D

Sound Intensity Level Data

Table 13. Sound intensity level data for OGFC-AR in dBA.					
Date	Lane 1	Lane 2	Lane 3	HOV	Average
9/2/2009	95.9	96.0	100.3	-	97.4
10/6/2009	-	102.8	97.5	98.8	99.7
12/2/2009	99.2	99.0	98.7	99.1	99.0
1/7/2010	100.2	99.6	99.7	99.9	99.8
2/25/2010	102.1	101.6	101.8	100.8	101.6
3/24/2010	100.6	99.8	99.9	99.3	99.9
4/10/2010	101.4	101.4	101.2	100.0	101.0
6/10/2010	101.3	201.2	100.4	99.3	100.5
7/13/2010	99.3	99.4	99.2	98.1	99.0
8/16/2010	99.2	99.2	99.4	98.2	99.0
9/30/2010	100.4	100.7	99.7	99.5	100.1
11/8/2010	101.7	101.3	101.5	100.2	101.2
12/7/2010	101.6	101.4	100.6	99.4	100.7
2/9/2011	104.7	103.3	103.5	102.6	103.5
3/17/2011	103.9	104.2	103.3	101.8	103.3
4/19/2011	103.3	104.9	104.1	103.0	103.8
5/17/2011	104.5	104.2	102.8	102.3	103.5
7/12/2011	104.0	104.0	103.2	102.0	103.3
8/31/2011	104.0	104.0	104.0	102.3	103.6
10/4/2011	105.0	105.5	104.8	103.4	104.6
12/13/2011	106.4	106.1	105.9	104.9	105.8
2/23/2012	106.1	106.4	105.6	104.5	105.6
4/9/2012	105.4	105.1	104.4	103.8	104.7
5/30/2012	105.6	105.7	104.8	103.9	104.9
7/11/2012	104.7	104.6	104.2	103.4	104.2
8/27/2012	105.1	104.7	104.6	103.5	104.4
9/26/2012	104.9	105.0	104.3	103.6	104.4
12/17/2012	105.8	105.6	104.7	104.4	105.1
2/19/2013	105.4	105.5	105.2	104.1	105.0
4/24/2013	104.8	105.2	104.2	103.9	104.5
5/30/2013	105.3	105.0	104.6	103.8	104.6

Table 14. Sound intensity level data for OGFC-SBS in dBA.					
Date	Lane 1	Lane 2	Lane 3	HOV	Average
9/2/2009	99.6	95.5	95.2	96.7	96.8
10/6/2009	-	95.2	98.6	103.3	99.0
12/2/2009	103.3	99.9	99.8	100.6	100.9
1/7/2010	99.4	100.6	101.0	99.9	100.2
2/25/2010	101.1	101.8	102.9	102.4	102.0
3/24/2010	99.4	100.4	100.4	100.4	100.2
4/10/2010	100.2	101.5	101.1	100.4	100.8
6/10/2010	100.1	101.1	101.0	99.8	100.5
7/13/2010	101.5	99.7	100.1	99.1	100.1
8/16/2010	97.9	99.5	100.4	98.5	99.0
9/30/2010	99.9	101.0	100.6	99.8	100.3
11/8/2010	100.8	101.6	101.8	101.1	101.3
12/7/2010	100.0	101.2	101.0	101.2	100.8
2/9/2011	103.9	103.5	103.6	102.7	103.4
3/17/2011	102.3	103.5	102.8	102.0	102.6
4/19/2011	103.0	103.8	103.5	102.5	103.2
5/17/2011	103.2	101.5	103.2	102.5	102.6
7/12/2011	101.7	103.2	102.9	101.7	102.4
8/31/2011	102.1	103.3	103.6	102.4	102.8
10/4/2011	101.7	104.5	104.1	103.4	103.4
12/13/2011	103.8	105.1	105.5	104.2	104.6
2/23/2012	103.6	105.4	105.5	104.2	104.7
4/9/2012	103.9	104.5	104.1	103.2	103.9
5/30/2012	104.8	104.7	104.6	103.5	104.4
7/11/2012	103.2	103.9	104.0	103.1	103.5
8/27/2012	104.1	104.1	104.1	103.4	103.9
9/26/2012	103.2	104.2	103.7	102.8	103.5
12/17/2012	104.4	104.8	104.8	104.2	104.5
2/19/2013	105.0	105.3	105.4	105.4	104.2
4/14/2013	103.7	104.7	104.2	103.6	104.0
5/30/2013	103.8	104.6	104.4	103.4	104.0

Table 15. Sound intensity level data for HMA in dBA.

Date	Lane 1	Lane 2	Lane 3	HOV	Average
9/2/2009	101.4	-	100.3	-	100.9
10/6/2009	100.3	99.8	100.5	101.5	100.5
12/2/2009	102.5	102.6	102.3	104.6	103.0
1/7/2010	101.6	102.0	102.2	101.9	101.9
2/25/2010	101.7	103.2	103.3	102.5	102.7
3/24/2010	101.3	102.5	102.5	101.7	102.0
4/10/2010	101.8	102.9	102.8	101.9	102.4
6/10/2010	101.5	103.3	102.8	101.7	102.3
7/13/2010	101.7	103.2	103.3	101.2	102.4
8/16/2010	100.5	102.0	98.5	101.0	100.5
9/30/2010	101.8	103.2	102.8	101.4	102.3
11/8/2010	102.9	104.0	103.2	102.0	103.0
12/7/2010	102.9	103.5	103.0	101.7	102.8
2/9/2011	103.6	104.5	105.0	103.2	104.1
3/17/2011	103.8	104.6	104.7	103.4	104.1
4/19/2011	105.0	105.7	104.3	103.9	104.7
5/17/2011	-	103.2	104.9	103.4	103.8
7/12/2011	104.8	105.8	105.4	103.3	104.8
8/31/2011	104.7	105.8	105.6	104.6	105.2
10/4/2011	105.1	105.9	105.8	104.3	105.3
12/13/2011	105.4	107.1	106.9	105.4	106.2
2/23/2012	105.7	106.9	106.9	105.7	106.3
4/9/2012	105.7	106.3	105.7	104.9	105.7
5/30/2012	105.6	106.3	105.5	104.8	105.6
7/11/2012	104.7	105.5	105.4	103.8	104.9
8/27/2012	105.4	105.7	105.5	104.3	105.2
9/26/2012	105.4	105.7	105.1	104.7	105.2
12/17/2012	105.4	105.6	105.5	104.7	105.3
2/19/2013	105.8	106.7	105.9	104.9	105.8
4/14/2013	105.1	105.6	105.7	104.0	105.1
5/30/2013	105.4	106.2	105.1	104.4	105.3

Appendix E

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

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

I-405
112TH AVE SE to SE 8TH ST
Quieter Pavement Test
MP 9.33 to MP 12.76

Washington State Department of Transportation
State Materials Laboratory – Pavement Section

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 10 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 eight 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. It will focus primarily on the OGFC surface's resistance to studded tire wear, its durability, its friction resistance, and its splash/spray characteristics. In addition, noise reduction characteristics will also be a major part of the evaluation effort. WSDOT, at a minimum, will be evaluating noise levels using sound intensity measurement equipment to capture tire/pavement noise, in-vehicle noise and wayside noise.

Scope

This project will construct three types of asphalt pavement and diamond grinding existing PCC pavement as noted in the following description of the project:

- 10.19 to 10.85, NB lanes – install one section of open-graded rubberized asphalt and one section of open-graded polymer modified asphalt over existing and proposed Portland cement concrete (no pre-conditioning of concrete prior to installation)

- 11.76 to 12.37, NB lanes – install one section of open-graded rubberized asphalt and one section of open-graded polymer modified asphalt over existing and proposed Portland cement concrete (pre-conditioning of concrete prior to installation)
- The Next Generation Concrete Surface originally planned for this project will be constructed on I-5 under a separate experimental feature.

The OGFC will be placed to a depth of 0.06 ft (3/4 inch) on the existing asphalt pavement sections and 0.08 ft (1 inch) on the existing PCC pavement sections. Class ½-inch HMA will be placed to a depth of 0.15 ft following the milling of the existing pavement to the same depth.

The OGFC mixes will be designed in accordance with the Arizona DOT specifications rubberized and polymer modified open-graded pavements.

Layout

The specific location and number of test sections will be determined after the project has been constructed. At a minimum there will be test sections on the OGFC-asphalt rubber, on the OGFC-polymer.

Staffing

This research project will be conducted through the combined efforts of the WSDOT Materials Laboratory and the WSDOT Acoustics Program Office. The Northwest Region Project office will coordinate and manage all aspects of the construction. Representatives from the WSDOT Materials Laboratory (one – three persons) will also be involved in monitoring the construction activities.

Contacts

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Testing

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

- Pavement condition (bi-annually)
  - Surface condition (cracking, patching, flushing, etc)
  - Rutting/wear (using the INO laser which provides true transverse profile)
  - Roughness
  - Friction
- Sound intensity noise measurements (monthly)
- Wayside noise measurements
- In-vehicle noise measurements

Reporting

An "End of Construction" report will be written following completion of the test sections. This report will include details of the construction of the test sections and control section, construction test results, and initial sound, friction, roughness and rutting/wear results from all of the test sections. Annual summary reports will also be issued over the next five years that document any changes in the performance of the test sections. A final report will be written at the end of the five year evaluation period which summarizes performance characteristics and future recommendations for use of the OGFC pavements.

Cost Estimate

Construction Costs

Construction costs are unknown at the time of the development of this work plan, however, the following table summarizing the costs from the first two quieter pavement projects should provide some idea of the possible costs of the three types of asphalt pavements included in the study.

Bid Item	I-5, Lynnwood			SR-520 Bellevue		
	Tons	Cost	Cost (ln-mi)	Tons	Cost	Cost (ln-mi)
Class ½ " HMA	28,853	$ 62.50	$ 45,188	2,840	$ 85.00	$ 61,455
OGFC-AR	1,686	$ 130.00	$ 39,091	910	$ 285.00	$ 85,700
OGFC-SBS	2,441	$ 90.00	$ 27,063	1,190	$ 155.00	$ 46,609

Testing Costs

Funds for all testing will come from the Quieter Pavements testing budget.

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 Evaluation Cost = $14,400

Schedule

Estimated Project Ad Date – April 2008
Estimated Construction – August 2009

Date	Pavement Condition Survey	Roughness Wear/Rutting	Friction	Sound Intensity	End of Construction Report	Annual Report	Final Report
Summer 2009		X	X	X			
October 2010		X		X	X		
April 2010	X	X	X	X			
October 2010		X		X		X	
April 2010	X	X	X	X			
October 2010		X		X		X	
April 2011	X	X	X	X			
October 2011		X		X		X	
April 2012	X	X	X	X			
October 2012		X		X		X	
April 2013	X	X	X	X			
October 2013		X		X			
December 2013							X