Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 2

WA-RD 691.2

Keith W. Anderson
Jeff S. Uhlmeyer
Tim Sexton
Mark Russell
Jim Weston

June 2012

Washington State Department of Transportation
Office of Research & Library Services

WSDOT Research Report

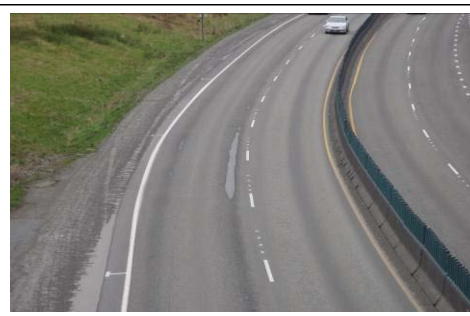
Experimental Feature Report

Final Report
Experimental Feature 07-01

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 2

Contract 7353
SR-520
Eastside Quieter Pavement Evaluation Project
MP 4.24 to MP 5.82



Washington State Department of Transportation

Engineering and Regional Operations
Construction Division
State Materials Laboratory

Experimental Feature Report

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 691.2		

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 2	June 2012
	6. PERFORMING ORGANIZATION CODE WA 07-01
7. AUTHOR(S) Keith W. Anderson, Jeff S. Uhlmeyer, Tim Sexton, Mark Russell, and Jim Weston	8. PERFORMING ORGANIZATION REPORT NO.
9. 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 second 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 than the HMA control section for only a period of five months after construction. The OGFC-SBS section was not initially audibly quieter than the HMA and never attained that level of noise reduction for the entire monitoring period of four years. The OGFC-AR test section was prone to excessive raveling and rutting and in places wore through to the underlying pavement. The OGFC-AR was removed by grinding in January of 2012 because of safety concerns with the rutting and in preparation for a project that reconstructs the entire corridor.

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

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	82	

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

Introduction 1
Background 1
Project Description 2
Mix Design Process 4
  OGFC-AR 4
  OGFC-SBS 5
Construction 6
  OGFC-AR Special Provisions 6
  OGFC-SBS Special Provisions 7
  Weather Special Provisions 7
  Asphalt Plant 7
  Paving Operations 7
  Cost 11
Performance Monitoring 11
  Noise 11
    Noise Measurement Equipment 12
    Noise Measurements 13
    Season Variations in Sound Level 18
    Seattle Area 2008 Winter Storm 20
    Center of Lane Noise Measurements 20
    Performance Difference Between the OGFC-AR and OGFC-SBS 22
    Noise Summary 23
  Wear/Rutting 24
    OGFC-AR Wear/Rutting 25
    OGFC-SBS and HMA Wear/Rutting 26
    Historical Wear/Rutting of Open Graded Friction Course Pavements 27
    Seasonal Variations in Wear/Rutting 30
    Wear/Rutting Summary 33
  Friction 34
  Ride 35
Life Cycle Cost Analysis 37
Discussion of Results 40
Conclusions 41
Recommendations 41
References 42
Appendix A Mix Designs 43
Appendix B Special Provisions 46
Appendix C Infrared Images and Construction Comments 60
Appendix D Sound Intensity Level Measurements 68
Appendix E Experimental Feature Work Plan 72

LIST OF FIGURES

Figure 1. Location of Contract 7353 near Medina, Washington. ... 3
Figure 2. Plan map of section layout. ... 3
Figure 3. Distributor applying tack coat. ... 9
Figure 4. Tack coat application. ... 9
Figure 5. Blaw-Knox PF5510 paver. ... 9
Figure 6. RoadTec Shuttle Buggies. ... 9
Figure 7. Paving operation with two pavers and two Shuttle Buggies. ... 9
Figure 8. Roller operation. ... 9
Figure 9. Excess suds from soap added to water used to keep OGFC-AR from sticking to rollers. ... 10
Figure 10. OGFC-AR with excess suds after rolling. ... 10
Figure 11. Finished OGFC-AR pavement. ... 10
Figure 12. Close-up of OGFC-AR. ... 10
Figure 13. Close-up of OGFC-AR showing aggregate breakage. ... 10
Figure 14. Texture of OGFC-SBS. ... 10
Figure 15. Twin microphones mounted near the rear tire of a vehicle. Note Uniroyal Tiger Paw tire. ... 13
Figure 16. Computer used for data collection. ... 13
Figure 17. Difference in sound intensity between the HMA control section and the OGFC-AR and OGFC-SBS quieter pavements. ... 17
Figure 18. Change in sound intensity level during the winter and summer. ... 19
Figure 19. Sound intensity levels in the center of the lane and in the wheel path versus the initial readings after paving. ... 22
Figure 20. Rut depth for each lane of the OGFC-AR test section. Red arrow marks the severe winter of 2008/2009. ... 25
Figure 21. Rut depth for each lane of the OGFC-SBS test section. Red arrow marks the severe winter of 2008/2009. ... 26
Figure 22. Rut depth for each lane of the HMA test section. Red arrow marks the severe winter of 2008/09. ... 27
Figure 23. Pavement life of open graded friction course pavement built between 1980 and 1997. ... 28
Figure 24. Rutting in EB Lane 1 (far left lane in photo) of OGFC-AR test section on SR 520. (February 2011) ... 29
Figure 25. Wear/rutting in EB Lane 1 (far right lane in photo) of the OGFC-AR test section on SR 520. (February 2011) ... 29
Figure 26. Change in the depth of the ruts in the wheel paths during the period when studded tires are legal versus the change during the remainder of the year. ... 31
Figure 27. Average change in the depth of the rut during the legal studded tire season as compared to the rest of the year. ... 33
Figure 28. Average friction resistance for each pavement type. ... 35
Figure 29. Average ride for each pavement. ... 37

Figure 30. Life cycle cost based on audible noise reduction. 38
Figure 31. Life cycle cost passed on WSPMS performance data. 39
Figure 32. Image of typical tack application with some pickup visible in the wheelpaths. 61
Figure 33. Thermal image of the mix as it leaves the SB and enters the paver hopper at 295°F. 62
Figure 34. Image looking towards the paver from behind the screed... 62
Figure 35. Digital image looking at the paver screed from behind with chain seen near the tracks but not between.. 63
Figure 36. Streaking OGFC of first paver (spot 2) and the consistent mat behind second paver (spot 1). 63
Figure 37. View of trucks loading MTV's and pavers with view of breakdown rollers 64
Figure 38. Image of distance between rollers. 65
Figure 39. Image of aggregate breakage in paved lanes (brown surface). 65
Figure 40. Thermal image of construction joint at startup.. 66

LIST OF TABLES

Table 1. Mix design for the OGFC-AR. 5
Table 2. Mix design for the OGFC-SBS.. 5
Table 3. Gradation requirement for crumb rubber. 6
Table 4. Paving sequence and temperatures behind the paver.. 8
Table 5. Cost comparison information... 11
Table 6. Sound level changes, loudness and acoustic energy loss comparison. 12
Table 7. Average monthly sound intensity level measurements (dBA). 14
Table 8. Difference in average sound intensity level between OGFC sections and HMA control section. 15
Table 9. Change in sound intensity levels for winter and summer. 18
Table 10. Sound intensity level results for the center of the lane compared to wheel path results and initial results following construction. 21
Table 11. Comparison of OGFC-AR and OGFC-SBS mix designs. 23
Table 12. Wear/rutting measurements for SR 520, Medina Quieter Pavement Evaluation. 24
Table 13. Change in rut depth winter versus summer. 30
Table 14. Change in the depth of the ruts in each section for each time period of studded tire use or no studded tire use. 32
Table 15. Friction resistance measurements SR 520, Eastside Quieter Pavement Evaluation.... 34
Table 16. Ride (IRI) measurements for the SR 520 project. Units are inches per mile. 36
Table 17. OGFC-AR sound intensity readings (dBA). 69
Table 18. OGFC-SBS sound intensity readings (dBA). 70
Table 19. HMA sound intensity readings (dBA). 71

Introduction

This is the second of three experimental feature projects involving the construction of open-graded friction course (OGFC) pavements to mitigate tire/pavement noise. The first, on Interstate 5 near the town of Lynnwood, was constructed in August of 2006 using asphalt rubber (AR) and styrene butadiene styrene (SBS) 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 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 dense graded pavements which have between four and eight 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 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 was prompted by the 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. News reports on rubberized open graded pavement as the answer to making pavements quieter has encouraged the public to ask that these types of pavement be used to lessen the noise in their neighborhoods.

Background

There are downsides with the use of open graded pavements. Open graded pavements are very susceptible to excessive wear from studded tires. This excessive wear produces ruts in the pavements that fill with water during rainy periods and pose the additional hazard of hydroplaning. The other downside is pavement life. The life of open graded pavements is cut short by the studded tire wear mentioned previously. Pavement life of less than 10 years, and as short as three to four years were experienced with OGFC’s in the 1980’s in Washington. States where the use of OGFC has been successful (Florida, Texas, Arizona and California) do not experience extensive studded tire usage. Similarly, these states are southern, warm weather states; a clear advantage when placing a product like OGFC with asphalt-rubber. Arizona DOT, for example, requires the existing pavement to have an 85°F surface temperature at the time of placement. Paving in urban areas must, by necessity to lessen traffic impacts, be done at night when temperatures rarely approach 85ºF even in summer, making successful placement of this type of pavement a challenge. A more complete discussion of the performance history of open-graded pavements in Washington is found in the report on the first quieter pavement experimental project (Anderson et al., 2012).

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. 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 second experiment is located on SR-520 in Medina which is between the Evergreen Point Floating Bridge on the west and the city of Bellevue on the east. The project, Contract 7353, Eastside Quieter Pavement Evaluation Project, paved all lanes of SR-520 from MP 4.18 to MP 5.82. Wilder Construction Company* from Everett, Washington placed the OGFC after grinding off the existing surface to the depth of the overlay. The average daily traffic (ADT) on this section of SR-520 is 47,274 with three percent trucks. A vicinity map for the project is shown in Figure 1.

*****Note: Wilder Construction Company was sold to Granite Construction Company in early 2008.

Figure 1. Location of Contract 7353 near Medina, Washington.

The open graded sections were placed 0.06 feet thick (3/4 inches) on the two general purpose lanes in each direction and on the HOV lane in the westbound direction. The HOV lane on SR-520 is the outside lane instead of the normal location on the inside. The Class ½ inch Hot Mix Asphalt (HMA) was placed 0.15 feet thick on all lanes including the HOV with an 18 foot taper section at each end to transition to the thinner open-graded sections. The paving limits for three different pavement types are shown in Figure 2. This was a simple overlay process with no pre-leveling required.

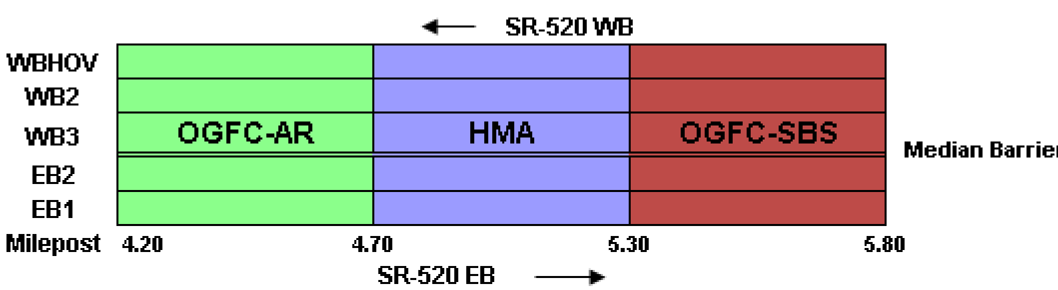


Figure 2. Plan map of section layout.

The pavement that underlies the quieter pavement section consists of 0.50 feet of untreated base, 0.50 feet of Class B HMA, 0.14 feet of Class B HMA with a rubberized binder (granulated recycled tires), and 0.15 feet of Class A HMA with a PBA-6 binder. The PBA-6 binder was a performance based binder that pre-dated the Superpave performance based binder classification system. The rubberized binder using granulated recycled tires is the "Arizona Refining" or "wet process" for introducing the recycled tire rubber into the binder. The granulated rubber is mixed with the asphalt binder in an agitated tank for four hours prior to its use in producing the HMA.

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 pavements project near Lynnwood that borrowed the services of the Arizona Department of Transportation (ADOT) to develop the design for the asphalt rubber mix (Anderson et al., 2008). The asphalt rubber mix design, however, was still patterned after the ADOT process and used the same aggregate gradation as the Lynnwood project. The SBS mix design was based on the use of a drain down test as was used on the Lynnwood project. Complete discussions of the two processes can be found in report WA-RD 683.1 (Anderson et al., 2008). The mix design reports from the HQ Materials Laboratory can be found in Appendix A.

OGFC-AR

The mix design for the OGFC-asphalt rubber was almost identical to the design for the Lynnwood project, see Table 1. The source for the PG64-22 was Paramount RB out of Seattle rather than Tesoro, out of Anacortes. The asphalt percentage was slightly higher (0.2 percent), the anti-strip additive was lower, and the percent of crumb rubber was slightly higher as compared to the Lynnwood design. The source for the aggregate was the same as the Lynnwood project.

Table 1. Mix design for the OGFC-AR.			
Sieve Size	**Gradation**	**Specifications**	**Source/Supplier**
3/8"	100	100	B-335
#4	31	30-45	B-335
#8	8	4-8	B-335
#200	1.6	0–2.5	B-335
Binder Grade	**Percent Asphalt**		**Source/Supplier**
PG64-22	9.0		Paramount RB, Seattle, WA
Anti-Strip	**Percent**		**Source/Supplier**
ARR-MAZ 6500	0.25		Custom Chemicals, Mulberry, FL
Crumb Rubber	**Percent by Wt. of AC**		**Source/Supplier**
CRM	23.5		Crumb Rubber Manufacturers, Rancho Domingo, CA

OGFC-SBS

The mix design for the OGFC-SBS was also very similar to the design used for the Lynnwood project, see Table 2. The asphalt content was 0.5 percent higher but all other specifications and suppliers were identical to the Lynnwood mix design.

Table 2. Mix design for the OGFC-SBS.			
Sieve Size	**Gradation**	**Specifications**	**Source/Supplier**
3/8"	100	100	B-335
#4	36	35-55	B-335
#8	12	9-14	B-335
#200	2.3	0–2.5	B-335
Binder Grade	**Percent Asphalt**		**Source/Supplier**
PG70-22	8.8		US Oil, Tacoma, WA
Anti-Strip	**Percent**		**Source/Supplier**
ARR-MAX 6500	0.25		Custom Chemicals, Mulberry, FL
Stabilizing Additive	**Percent**		**Source/Supplier**
Recycled paper	0.30		Hi-Tech Asphalt Solutions
Rubber	**Percent by Wt. of AC**		**Source/Supplier**
SBS	3.4±1-18		U.S. Oil, Tacoma, WA

Construction

The Special Provisions for the contract contain 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 Special Provisions for Division 5, Surface Treatments and Pavements, for Contract 7353 can be found in Appendix B.

OGFC-AR Special Provisions

The Special Provisions required that the asphalt binder for the OGFC-AR would be a PG58-22 or PG64-22. The crumb rubber was required to conform to the gradation requirements shown in Table 3 and 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 non air blown or oxidized PG58-22 or PG64-22. The fibers required in the mixture could be cellulose fibers, cellulose pellets, or mineral fibers. If the mix was produced in a dryer-drum plant, fibers were required to be added to the aggregate and uniformly dispersed prior to the injection of the asphalt binder. Storage time for the OGFC-SBS was not to exceed four hours.

Weather Special Provisions

Paving of the open-graded mixes could not occur unless air temperature was above 60°F. This is in contrast to Arizona DOT that requires an 85°F minimum surface temperature.

Asphalt Plant

This project used the dryer-drum type plant located at Wilder Construction's Smith Island facility. The same set-up was used on the Lynnwood project with the exception that the equipment for the mixing of the asphalt-rubber binder was not borrowed from Granite Construction, but brought in from another source. A complete description of the plant set-up is documented in the I-5 Lynwood project report (Anderson et al., 2008).

Paving Operations

In order to pave the section as rapidly as possible with the shortest disruption to traffic, the entire roadway was closed to traffic for the weekend of July 14-15, 2007. The median barrier which separated the eastbound from the westbound lanes was removed in order to facilitate moving of the paving equipment across all 5 lanes of the roadway. Paving operations began at the Evergreen Point Floating Bridge (west) end of the project and progressed eastwardly toward Bellevue. Paving of the OGFC-AR began at 7:00 a.m. Saturday morning and was completed by 2:00 p.m. that afternoon. The control section of HMA was paved during the afternoon and evening on Saturday. The OGFC-SBS paving began at 12:30 a.m. on Sunday morning and was completed by 7:00 a.m. The median barrier was put back in place and the lane lines were painted and reflective pavement markers were installed. SR-520 was reopened to traffic at 5:00 a.m. on Monday morning. Table 4 summarizes the details of the paving.

Table 4. Paving sequence and temperatures behind the paver.

Section	Date	Time	Event	Temperature Behind Paver (ºF)
OGFC-AR	7/14/07	7:00 am	Begin AR Paving	260
OGFC-AR	7/14/07	8:00 am		280, 272, 270
OGFC-AR	7/14/07	10:00 am		280, 278, 290
OGFC-AR	7/14/07	11:30 am		290, 291, 297
OGFC-AR	7/14/07	2:00 pm	Finished AR paving	277, 280, 290
Class 1/2 Inch HMA	7/14/07	2:30 pm	Begin HMA paving	
Class 1/2 Inch HMA	7/14/07	10:30 pm	Finish HMA paving	
OGFC-SBS	7/15/07	12:30 am	Began SBS paving	
OGFC-SBS	7/15/07	7:00 am	Finished SBS paving	287, 290, 292

Elements of the paving operation are shown in Figures 3 through 14. There were minor problems that included occasional spills of materials in front of the paver, stoppage of the paver waiting for mix, less than full coverage of the tack coat application, and minor problems at the plant. The inspectors' daily reports indicate that the roller operators were rolling the pavement well beyond the cessation temperature (the point at which no further compaction can occur) and this caused some aggregate breakage as can be seen in Figure 13. 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 construction report on the project with images of the mix and pavement is included as Appendix C.

Figure 3. Distributor applying tack coat.

Figure 4. Tack coat application.

Figure 5. Blaw-Knox PF5510 paver.

Figure 6. RoadTec Shuttle Buggies.

Figure 7. Paving operation with two pavers and two Shuttle Buggies.

Figure 8. Roller operation.

Figure 9. Excess suds from soap added to water used to keep OGFC-AR from sticking to rollers.

Figure 10. OGFC-AR with excess suds after rolling.

Figure 11. Finished OGFC-AR pavement.

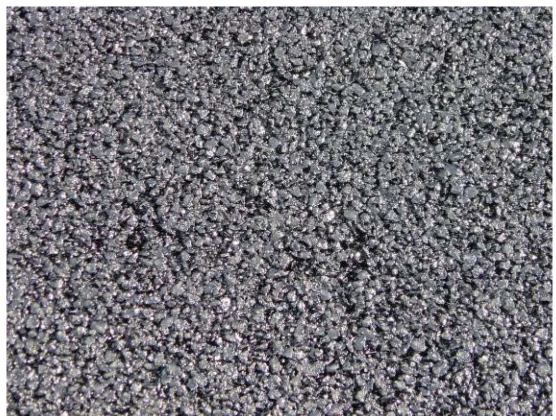


Figure 12. Close-up of OGFC-AR.

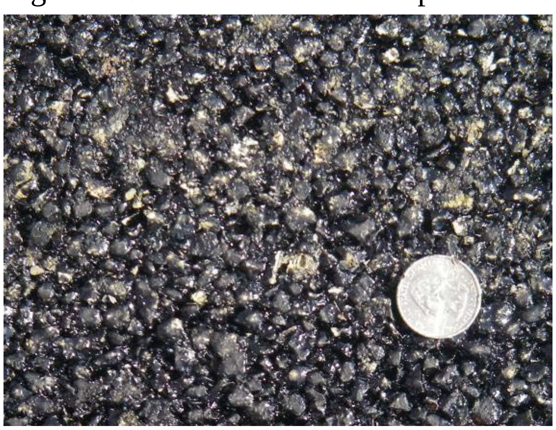


Figure 13. Close-up of OGFC-AR showing aggregate breakage.

Figure 14. Texture of OGFC-SBS.

Cost

The bid prices, total quantity used, and total cost for all three types of pavement are shown in Table 5. The bid prices of all three mixes were considerably higher than the Lynnwood project (HMA $62.50, AR $130.00 and SBS $90.00), however, due to the smaller quantities on this project the total cost of the OGFC placed was approximately equal for both projects (Lynnwood at $438,870 versus Medina at $443,800).

Table 5. Cost comparison information.

Bid Item	Estimated Quantity (Tons)	Low Bid ($/Ton)	Total Cost
Class 1/2 inch HMA	2,840	$85.00	$241,400
OGFC-AR	910	$285.00	$259,350
OGFC-SBS	1,190	$155.00	$184,450

Performance Monitoring

Acoustic performance and pavement wear were the two main criteria used to judge the success of the OGFC quieter pavement sections on SR-520. 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 for all OGFC pavements and the conventional HMA.

Noise

Traffic noise is a concern for many residents living along state highways. This study is the second 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. 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 6 shows the relationship between the sound intensity level change, relative loudness and acoustic energy loss. Noise experts 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 6. 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) defined in ASTM 2493.

Figure 15. Twin microphones mounted near the rear tire of a vehicle. Note Uniroyal Tiger Paw tire.

Figure 16. 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. This pavement, placed in 1997, had sound intensity levels of 104.6 dBA prior to construction. After construction of the quieter pavement test sections, OBSI measurements were collected monthly, weather permitting (pavement must be dry), on all five 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 five lanes) is listed in Table 7. Measurements of the sound intensity levels for the individual lanes within each section are listed in Appendix D.

Table 7. Average monthly sound intensity level measurements (dBA).

Date	OGFC-AR	OGFC-SBS	HMA
July 2007	96.1	97.8	99.8
August 2007	96.3	99.1	100.1
September 2007	97.6	100.4	101.9
October 2007	97.9	99.1	102.0
December 2007	98.2	99.1	101.5
January 2008	99.3	100.2	102.2
February 2008	99.3	99.2	101.3
April 2008	100.4	100.4	102.5
May 2008	99.7	99.8	101.9
July 2008	97.2	98.5	100.3
August 2008	98.1	98.9	100.2
December 2008	100.8	101.7	102.7
January 2009	103.7	103.0	103.8
February 2009	102.9	102.6	103.5
March 2009	103.4	102.9	103.6
April 2009	102.3	101.9	102.8
May 2009	102.1	101.1	102.4
August 2009	103.0	102.2	102.8
September 2009	102.2	101.1	102.2
October 2009	103.1	102.2	102.7
December 2009	104.7	104.0	104.2
January 2010	105.4	104.1	104.5
February 2010	104.6	103.6	103.9
March 2010	103.6	102.8	103.3
April 2010	103.7	103.0	103.7
June 2010	103.8	103.0	103.7
July 2010	103.4	102.6	102.8
August 2010	102.7	101.1	102.5
September 2010	103.7	102.6	103.3
November 2010	104.9	103.6	104.1
December 2010	104.5	103.0	103.5
February 2011	105.5	104.6	104.8
March 2011	104.8	103.8	104.0
April 2011	105.2	104.3	104.7
July 2011	104.7	103.7	104.7

The sound intensity levels of each section increased over time with the OGFC-AR increasing the most with an 8.6 dBA gain after 48 months. The OGFC-SBS gained the next highest at 5.9 dBA and the HMA gained the least at 4.9 dBA. At the end of the four year monitoring period the sound intensity levels of OGFC-AR and the HMA were at essentially the same sound intensity level as the existing pavement prior to construction. The OGFC-SBS at 103.7 dBA was one decibel lower than the pre-construction measurement.

To answer the questions concerning the performance of the OGFC sections regarding being audibly quieter than the HMA and the longevity of that attribute, the difference between the average sound intensity of the HMA control section and the average sound intensity of each OGFC section was calculated (Table 8). Data points above the black horizontal line are three decibels quieter than the HMA control section and considered to be audible to the human ear (≥3 dBA). Data points below the line are not audibly different. A red horizontal line at 0.0 marks the point below which the OGFC becomes noisier than the HMA control section.

Table 8. Difference in average sound intensity level between OGFC sections and HMA control section.

Pavement 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	3.6	2.0
1	3.8	1.1
2	4.3	1.5
3	4.1	2.9
4	4.1	2.9
5	3.3	2.4
6	2.9	1.9
7	2.0	2.1
8	2.0	2.1
9	2.1	2.1
10	2.2	2.2
11	2.2	2.2
12	3.1	1.8
13	2.1	1.3
14	2.1	1.3
15	2.1	1.3
16	2.1	1.3

Table 8. (Continued).		
Pavement Age (months)	Difference in Sound Intensity Level Between OGFC-AR and HMA (dBA)	Difference in Sound Intensity Level Between OGFC-SBS and HMA (dBA)
17	1.9	1.0
18	0.2	0.8
19	0.6	0.9
20	0.2	0.7
21	0.5	0.9
22	0.3	1.3
23	0.3	1.3
24	0.3	1.3
25	-0.2	0.6
26	0.1	1.1
27	-0.4	0.5
28	-0.4	0.5
29	-0.5	0.2
30	-0.9	0.3
31	-0.7	0.2
32	-0.3	0.5
33	-0.1	0.7
34	-0.1	0.7
35	-0.1	0.8
36	-0.6	0.2
37	-0.2	1.4
38	-0.4	0.7
39	-0.4	0.7
40	-0.9	0.4
41	-1.0	0.5
42	-1.0	0.5
43	-0.8	0.2
44	-0.8	0.2
45	-0.5	0.4
46	-0.5	0.4
47	-0.5	0.4
48	0.0	1.0

Note: Readings in yellow are audible to the human ear; readings in green indicate the OGFC section is noisier than the HMA.

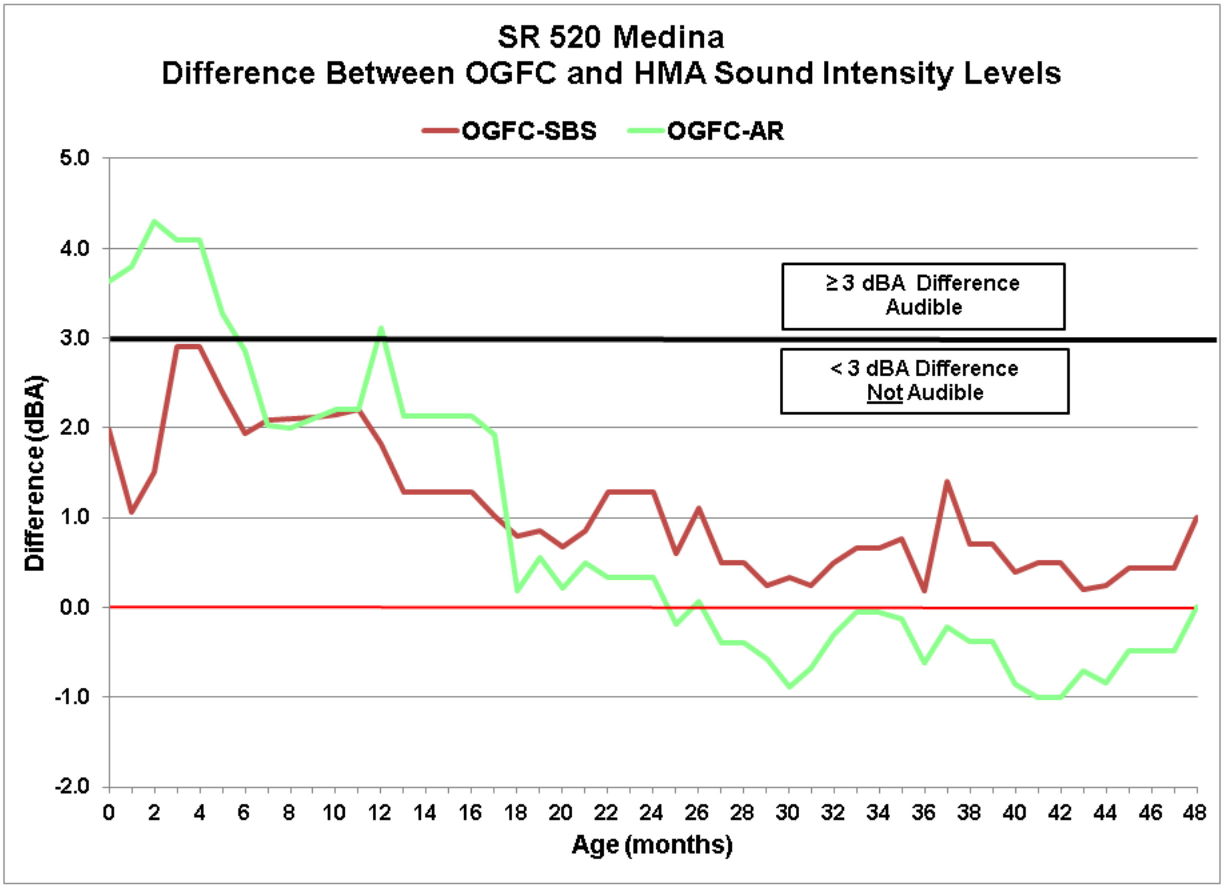


Figure 17. Difference in average sound intensity between the HMA control section and the OGFC-AR and OGFC-SBS quieter pavements.

Figure 17 shows that the OGFC-AR section (green line) was audibly quieter than the HMA for five months before it dropped below the black line and never returned except for one anomalous reading at 12 months (July 2008). The OGFC-AR sound intensity level followed a downward trend that indicates increasing noise levels over time. In August 2009, it drops below the zero level (red line) which means that it is noisier than the HMA. It was noisier for the remainder of the evaluation period.

The OGFC-SBS (reddish-brown line) was never becomes audibly quieter than the HMA control section. The OGFC-SBS also followed a downward trend that indicates increasing noise level over time. Unlike the OGFC-AR, it did not become noisier than the HMA. In summary, the OGFC-AR section was audibly quieter for five months and the OGFC-SBS section was never audibly quieter than the HMA.

Season Variations in Sound Level

The sound intensity levels of both OGFC sections increased much more over the July 2007 to July 2011 monitoring period than the HMA control section (Table 7). The increases are almost identical to the ones experienced on the I-5 Lynwood sections.

- OGFC-AR increased 8.6 dBA (I-5 Lynnwood 8.2 dBA)
- OGFC-SBS increased 5.9 dBA (I-5 Lynnwood 5.8 dBA)
- HMA increased 4.9 dBA (I-5 Lynnwood 4.1 dBA)

The sound intensity level increases were also accompanied by higher rates of rutting and raveling of the OGFC section as compared to the HMA section (detailed later in this report). Table 9 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 18 is a line graph of the same information.

Table 9. Change in average sound intensity levels for winter and summer.

Season	Time Between Measurements (months)	OGFC-AR (dBA)	OGFC-SBS (dBA)	HMA (dBA)
Summer 2007	3	1.8	1.3	2.2
Winter 2007-08	6	2.5	1.3	0.5
Summer 2008	4	-2.3	-1.5	-2.3
Winter 2008-09*	7	5.3	4.0	3.4
Summer 2009	7	-0.3	-0.7	-0.9
Winter 2009-10	6	0.6	0.8	1.0
Summer 2010	7	0.0	-0.4	-0.4
Winter 2010-11	5	1.5	1.7	1.4

*** Severe winter storm in December of 2008 produced increases in noise levels and rutting.**

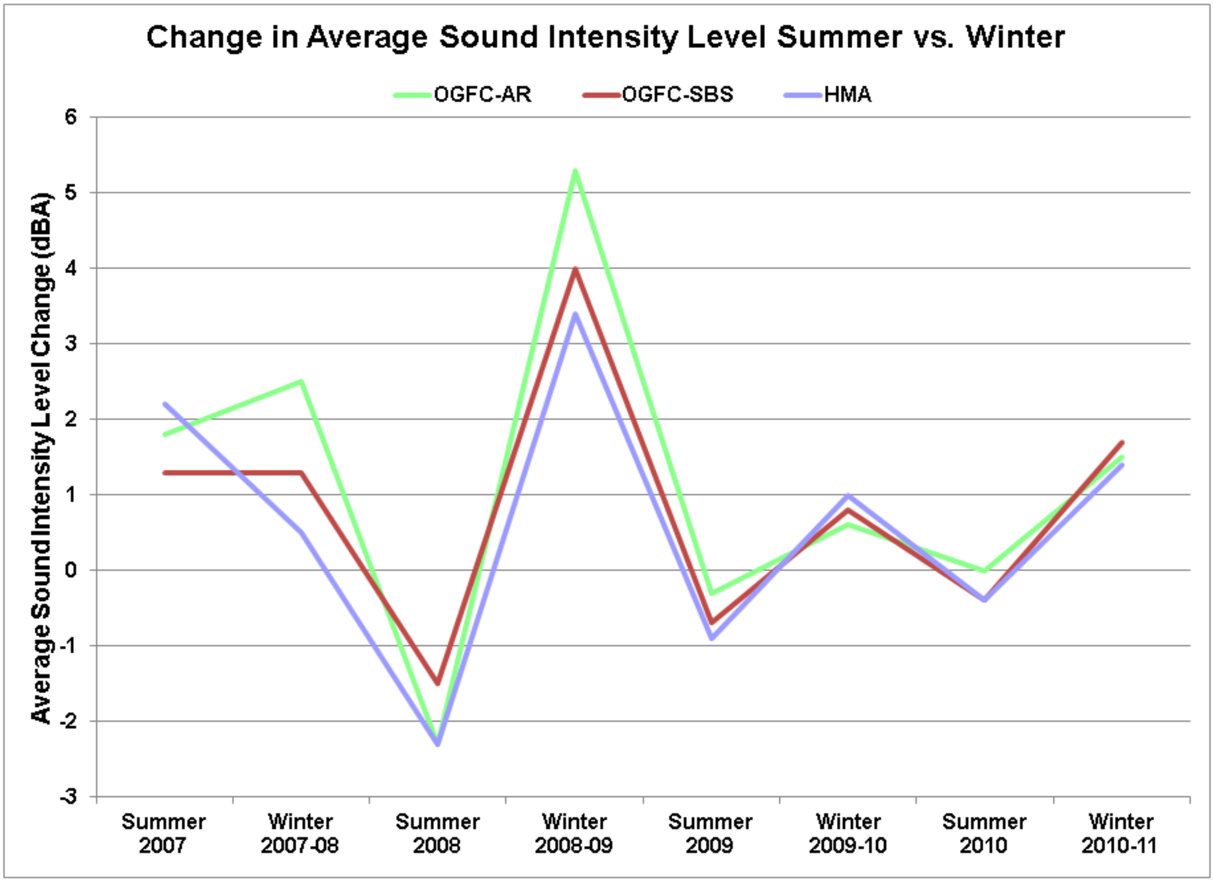


Figure 18. Change in average sound intensity level during the winter and summer.

The average sound intensity level trends in the OGFC-AR and OGFC-SBS followed the same pattern observed on the I-5 Lynnwood quieter pavement section with the increases in the sound intensity levels occurring mainly during the winter studded tire season. The very large change in sound intensity for all of the sections in the 08-09 studs season corresponded to the severe winter storm in December of 2008. WSDOT Maintenance personnel reported high tire chain usage during this period and noted large amounts of aggregate on the shoulders that were attributed to raveling of the OGFC pavements. As will be shown later, the rutting/wear measurements also show a pattern similar to Figure 18. The larger increase in sound levels for both OGFC sections (green and reddish-brown lines) than the HMA pavement (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 pavement than HMA pavement. This is not surprising since open graded pavements are known to have less strength than dense graded pavements due to their higher void contents. Their lower strength makes the OGFC pavements more susceptible to damage from studded tires or tires equipped with chains. Their higher content of voids also makes them more susceptible to damage from moisture and freezing and thawing.

Seattle Area 2008 Winter Storm

The Puget Sound region experienced multiple storms for a period of two weeks starting on December 13, 2008. Freezing temperatures, snow, sleet, freezing rain, heavy rain and high winds produced significant challenges to travel throughout the region between December 13 and the 27th. Seattle recorded 13.9 inches of snow when typical December accumulations average 2.2 inches. The storm resulted in more consecutive hours of snow on the ground than any other storm in the last 20 years. Statistics from the National Weather Service Forecast Office show that the average low temperature for the event was 25.4ºF with three days setting record lows of 22, 19, and 14 degrees. Snowfall was recorded on 11 of the 14 days with five of the days receiving record amounts for Seattle. “Metro, the Seattle areas transit system, put tire chains on 80 percent of its 1,329-bus fleet overnight. But after the chains kicked up sparks on bare pavement during the morning commute, forcing drivers to go 35 mph or less to avoid tearing up the roadways, the chains were removed” (see link below).
http://www.azcentral.com/offbeat/articles/2008/12/17/20081217seattlesnow.html

Center of Lane Noise Measurements

Additional evidence pointing to studded tires as the major contributor to increases in sound intensity levels is found in data from special OBSI testing done in May of 2008 (10 months after installation). The center of the lane, the area between wheel paths, was measured for all of the sections. The center of the lane receives much less traffic than the wheel paths. Similar changes in the sound intensity levels in *and* between the wheel paths would suggest climate, not traffic, was the cause of increased sound intensity levels in the wheel paths. The center of the lane measurements are listed in Table 10 and shown graphically in Figure 19. The center of the lane measurements (May 2008) were similar to the initial wheel path results (July 2007) for both OGFC sections differing by of 0.6 dBA for the OGFC-AR and 1.3 dBA for the OGFC-SBS. The difference for the HMA section was at 2.0 dBA. This contrasted with the comparison of center of lane measurements compared to wheel path results collected on the same date (May 2008). Center of the lane measurements were 3.0 dBA lower for the OGFC-AR, 0.9 dBA lower for the OGFC-SBS and 3.8 dBA lower for the HMA.

The larger change in sound intensity levels in the wheel paths as compared to the center of the lane measurements indicates that for the OGFC-AR and HMA, studded tires are the major factor in the increase in sound intensity level. The evidence is not as strong for the OGFC-SBS, which seems to be less susceptible to studded tire wear on SR 520 than it did on I-5 where both of the OGFC sections increased dramatically in the wheel path measurements versus the center of the lane measurements.

Table 10. Sound intensity level results for the center of the lane compared to wheel path results and initial results following paving.

Date/Test Location	OGFC-AR	OGFC-SBS	HMA
May 2008/Wheel Path	99.7	100.0	101.6
May 2008/Center of Lane	96.7	99.1	97.8
Wheel Path After Paving*	96.1	97.8	99.8

* After paving **values for each pavement are from Table 7.**

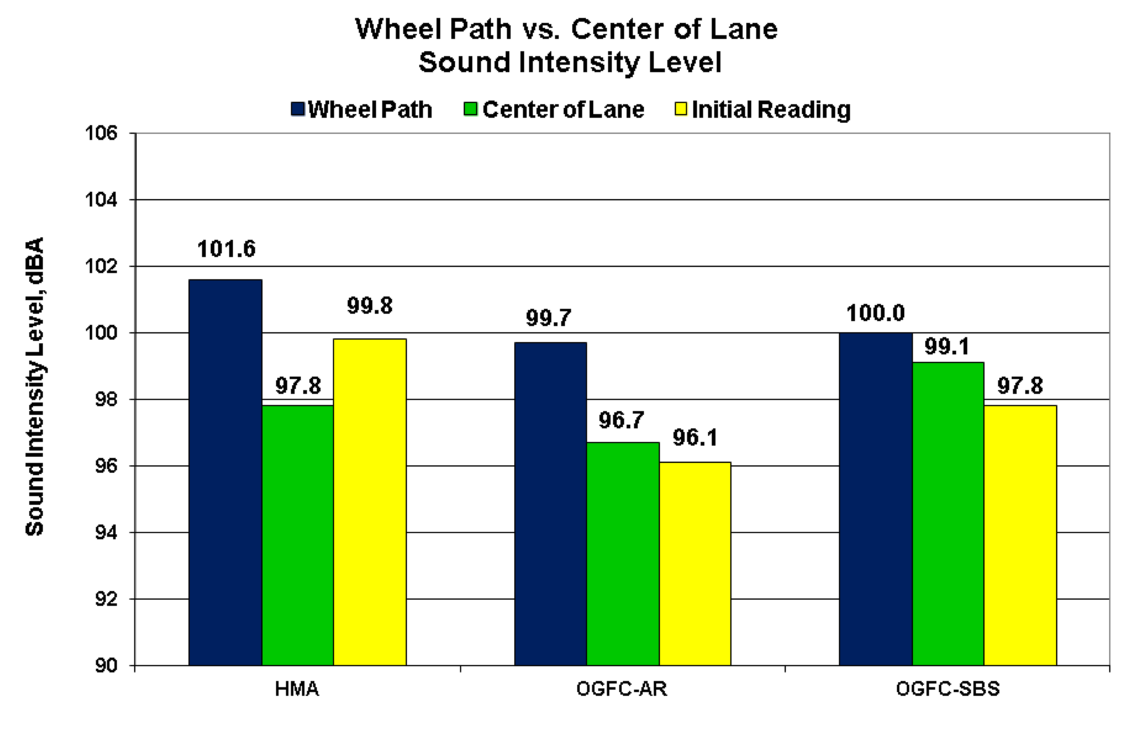


Figure 19. Sound intensity levels in the center of the lane and in the wheel path versus the initial readings after paving.

Performance Difference Between the OGFC-AR and OGFC-SBS

The report on the I-5 quieter pavement project included a discussion of the possible causes for the difference in acoustical performance between the OGFC-AR and the OGFC-SBS. The similarity in performance of the two projects would indicate that the theory proposed for the I-5 project would also hold true for this project; that is, the difference in the type and amount of rubber in the mix is the cause of the differential performance. Table 11 compares the mix designs for the two OGFCs. The similarity between the two mix designs is evident. The same source was used for the aggregate, pit B-335. The gradations of the aggregates are very similar. The asphalt binder grades are very close as was the percent of the binder used. The anti-strip additive was identical in both the type and amount. The only major difference between the two mixes is the type and amount of rubber added to the asphalt binder. The OGFC-AR used crumb rubber from the recycling of rubber tires. The OGFC-SBS used a liquid synthetic rubber polymer. The crumb rubber made up 23.5 percent of the asphalt binder in the OGFC-AR and the polymer rubber 3.4±1 percent of the asphalt binder in the OGFC-SBS. The OGFC-AR thus had more than six times the rubber content of the OGFC-SBS and it was a different type of rubber. The higher rubber content of the binder may be the cause of the accelerated raveling and rutting noted in the OGFC-AR section as well as the increase in sound intensity level.

Table 11. Comparison of OGFC-AR and OGFC-SBS mix designs.

Mix Characteristic		OGFC-AR	OGFC-SBS
Aggregate Source		B-335	B-335
Gradation	3/8" sieve	100	100
	#4 sieve	31	36
	#8 sieve	8	12
	#200 sieve	1.5	2.3
Asphalt Binder Grade		PG64-22	PG70-22
Asphalt Binder Percent		9.0	8.8
Anti-Strip		0.25 % ARR-MAZ 6500	0.25 % ARR-MAZ 6500
Rubber Type		Crumb	Synthetic Liquid
Percent Rubber in Binder		23.5 %	3.4±1 %

Noise Summary

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

- The OGFC-AR section was audibly quieter than the HMA control section for five months.
- The OGFC-SBS section was not initially audibly quieter than the HMA and never attained the level of noise reduction throughout the entire monitoring period.
- The OGFC-AR section became noisier than the HMA at two years and remained so for the remainder of the four year monitoring period.
- The OGFC-SBS did not become noisier than the HMA at any time.
- The changes in the noise reduction properties of all of the sections occurred during the winter season as a result of studded tire wear, chain usage, and snow plowing.
- Traffic is the primary cause of the changes in the noise properties of all three sections as attested to by the center of the lane measurements at ten months showing essentially no change in the noise readings as compared to the post-construction values.
- The greater loss in the noise reduction properties of the OGFC-AR may be related to the type and quantity of rubber incorporated into the asphalt binder.

Wear/Rutting

It has already been shown that the changes in sound intensity levels during the winter studded tire season are greater than the change during the summer for all of the sections. The first quieter pavement installation showed a similar correlation between the wear/rutting and the presence or absence of vehicles with studded tires. The same may hold true for this second project. Wear/rutting measurements for the OGFC-AR, OGFC-SBS and HMA are summarized in Table 12 and shown graphically in Figures 20-22. Measurements were made in the spring and fall of each year bracketing the studded tire season (November 1 to April 1).

Table 12. Wear/rutting measurements for SR 520, Medina Quieter Pavement Evaluation.

Section	Lane	S 2007	F 2007	S 2008	F 2008	W 2009	S 2009	F 2009	S 2010	F 2010	S 2011
AR	EB1	1.4	1.4	2.1	2.4	7.3	8.4	8.0	8.6	8.2	11.3
AR	EB2	1.6	1.6	2.3	2.8	3.3	4.1	4.0	4.8	4.7	5.8
AR	WB3	1.1	1.5	2.1	2.7	3.2	4.1	3.7	4.7	4.5	5.2
AR	WB2	1.6	1.9	2.9	3.7	8.3	9.5	9.5	10.6	10.4	12.5
AR	HOV	1.3	1.3	1.6	1.9	5.7	5.0	4.0	5.5	4.1	7.5
Average		1.4	1.5	2.2	2.7	5.6	6.2	5.8	6.8	6.4	8.5
SBS	EB1	1.4	1.4	1.9	2.2	3.1	3.8	3.3	4.1	3.7	4.5
SBS	EB2	1.7	1.8	2.2	3.1	3.2	3.7	3.7	4.4	4.1	4.6
SBS	WB3	1.4	1.6	2.4	3.0	3.2	3.8	3.6	4.4	4.5	4.9
SBS	WB2	2.5	2.5	3.1	3.9	4.6	5.1	5.1	6.0	6.0	6.6
SBS	HOV	1.5	1.5	1.8	1.9	2.3	2.9	2.4	3.0	2.5	2.7
Average		1.7	1.8	2.3	2.8	3.3	3.9	3.6	4.4	4.2	4.7
HMA	EB1	1.1	1.1	1.5	1.9	2.5	3.1	2.9	3.5	3.2	3.7
HMA	EB2	1.2	1.3	1.7	2.5	2.7	3.1	3.4	3.8	3.7	4.1
HMA	WB3	1.7	1.9	2.4	3.9	4.1	4.6	4.9	6.5	7.0	7.4
HMA	WB2	1.9	2.3	2.9	4.7	5.1	5.6	6.2	7.3	7.6	8.4
HMA	HOV	1.7	1.4	1.6	2.3	2.6	3.0	3.1	3.8	3.6	3.8
Average		1.4	1.6	2.0	3.1	3.4	3.9	4.1	5.0	5.0	5.6

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 17-19.

OGFC-AR Wear/Rutting

The wear/rutting in the OGFC-AR section showed a gradual increase up to the winter of 2008-09 when a severe winter storm attacked the Puget Sound Region. The average rut depth doubled from the Fall 2008 to the Winter 2009 readings with large jumps in the rutting of the two travel lanes, EB1 and WB2. The rutting continued to increase, especially in these two lanes, all the way to the end of the monitoring period at four years. The maximum rut depths for the EB1 and WB2 lanes were 11.3 and 12.5 mm, respectively.

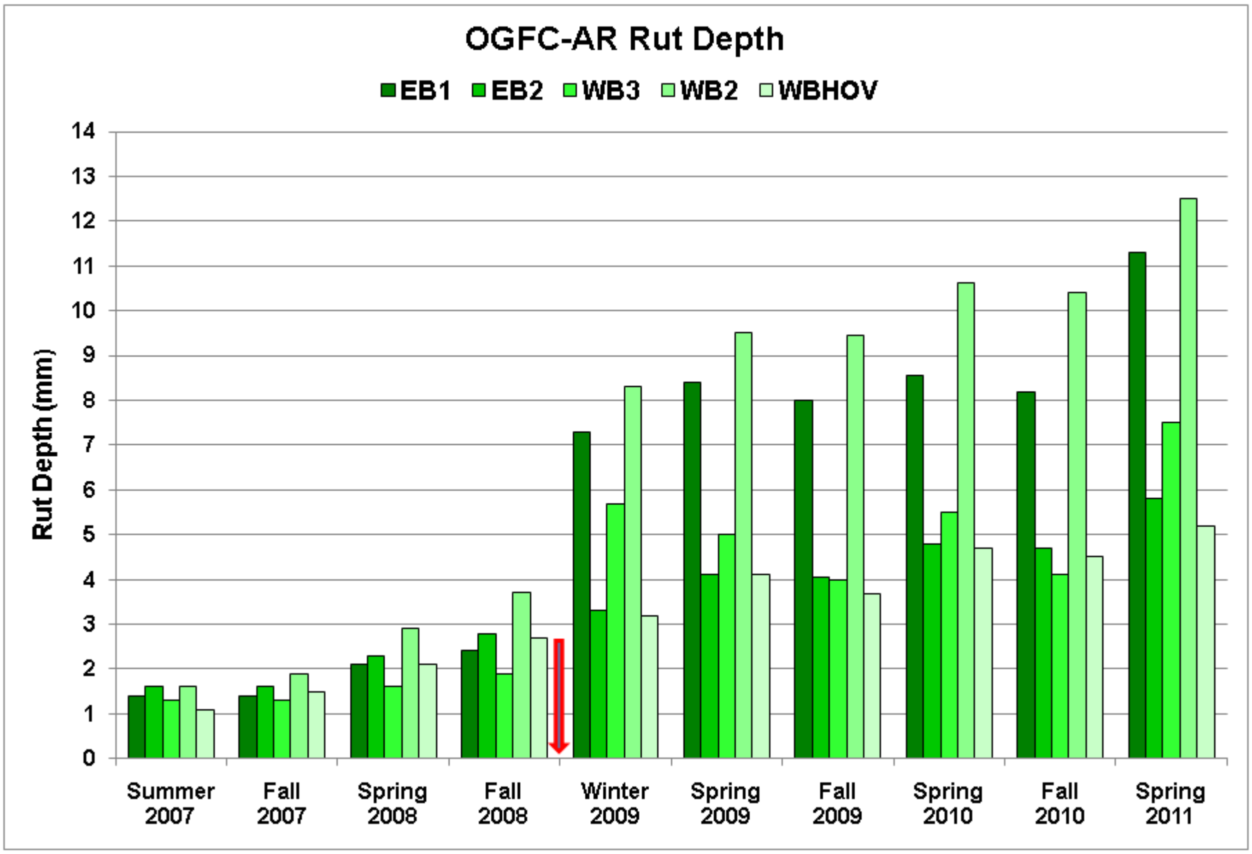


Figure 20. Rut depth for each lane of the OGFC-AR test section. Red arrow marks the severe winter of 2008/2009.

OGFC-SBS and HMA Wear/Rutting

In contrast to the OGFC-AR, the increase in wear for the OGFC-SBS and HMA test sections is relatively linear with no big increases noted during the winter of 2008-2009 (Figures 21 and 22). The maximum rut depths for the OGFC-SBS and HMA were 6.6 and 8.4, respectively, each recorded in the WB2 lane in April of 2011. Of interest is that EB1 in the OGFC-SBS and HMA is not showing the high wear/rutting as was true for the OGFC-AR. Also of note is that the HMA is showing more wear than the OGFC-SBS in all of the WB lanes, but especially WB2 and WBHOV.

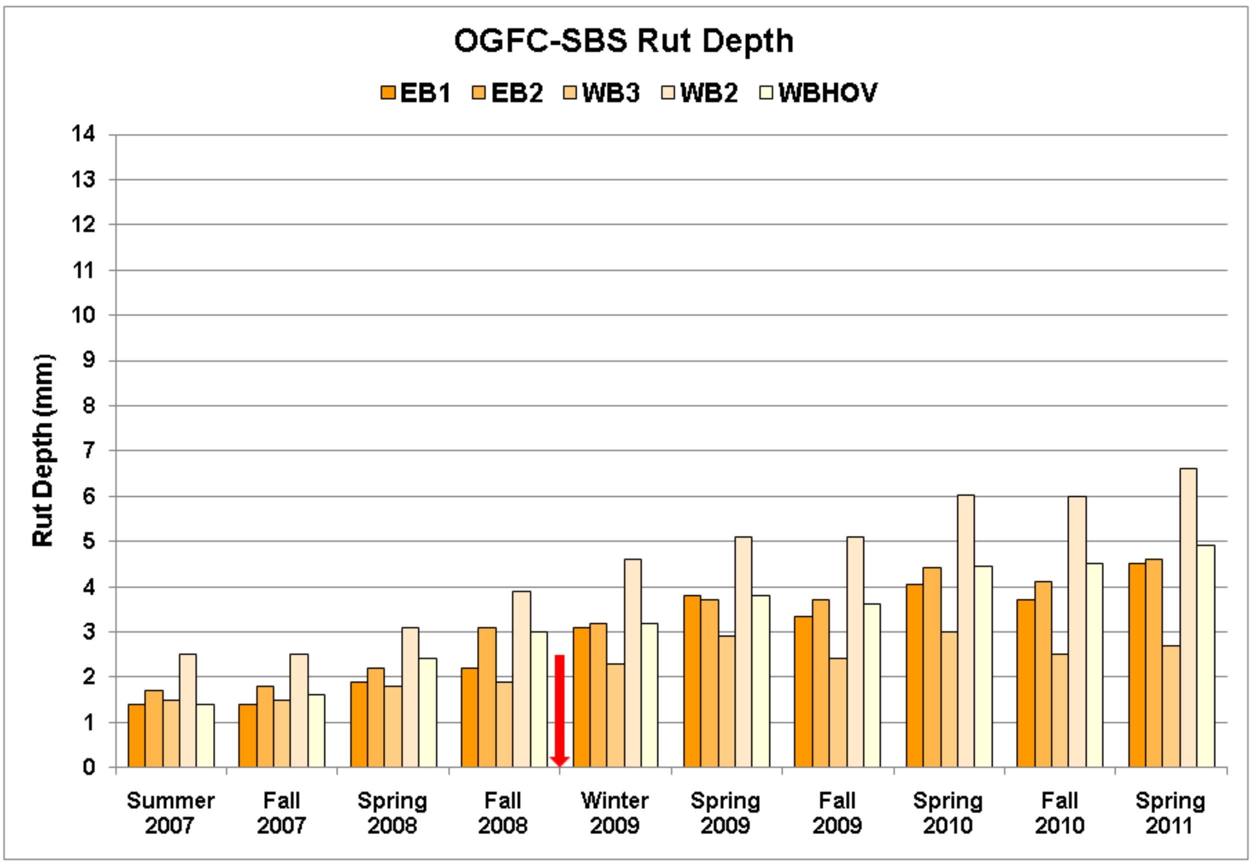


Figure 21. Rut depth for each lane of the OGFC-SBS test section. Red arrow marks the severe winter of 2008/2009.

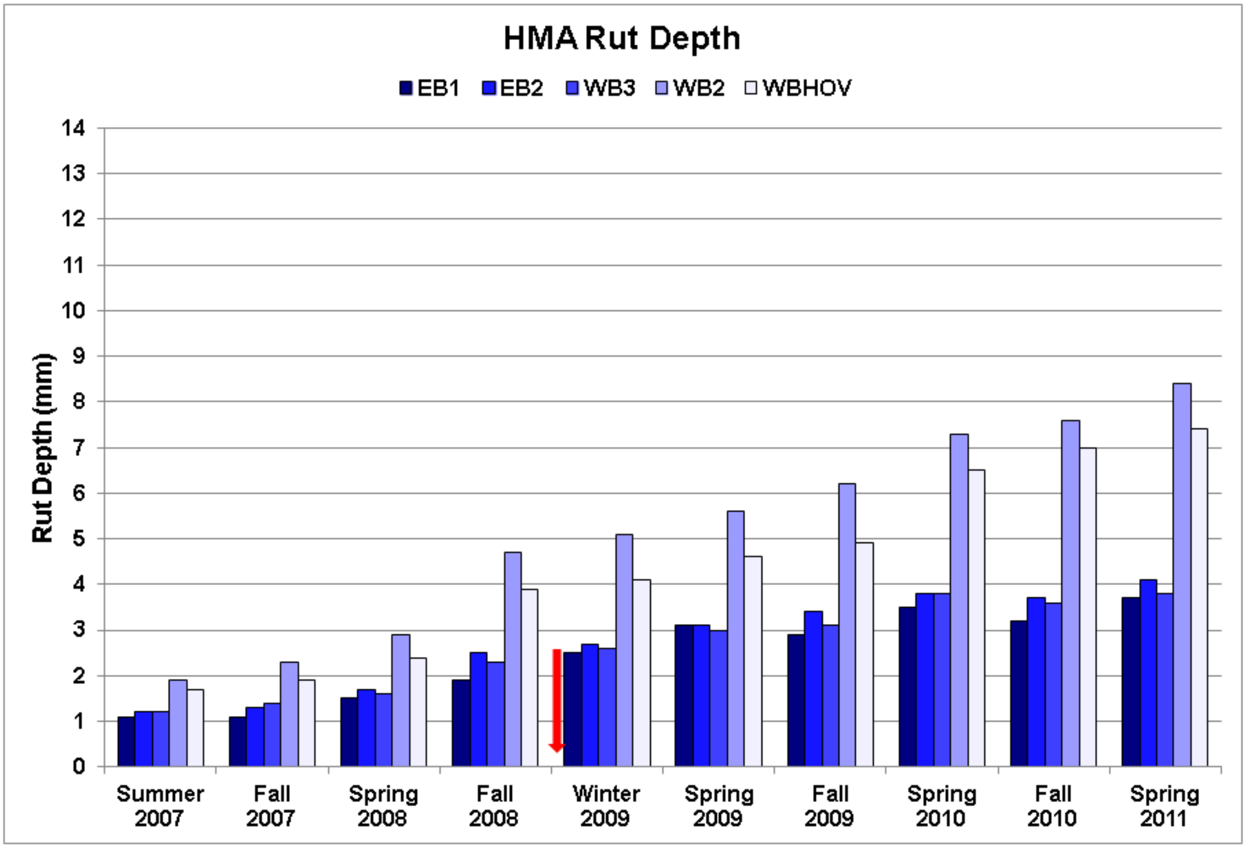


Figure 22. Rut depth for each lane of the HMA test section. Red arrow marks the severe winter of 2008/09.

Historical Wear/Rutting of Open Graded Friction Course Pavements

The rapid wear/rutting of the quieter pavement sections on this project is consistent with our past experience with open graded friction courses and the first quieter pavement test section built on I-5 in Lynnwood. WSDOT built 56 open graded friction course projects between 1980 and 1997. A moratorium on the use of open graded friction courses followed the poor performance of these pavements due to rapid wear/rutting from studded tires. The bar chart in Figure 23 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. The current statewide HMA average pavement life is 15 years with the west side of the state averaging 17 years and the east side 11 years. The failure of the OGFC-AR sections due to raveling and rutting at four years is on the lower end of the performance scale as compared to past history with open graded friction course pavements. Photos of the wear/rutting in the OGFC-AR section is shown in Figures 24 and 25. Additional information on the pass performance of the open graded friction course projects can be found in the I-5 Lynnwood Quiet Pavements Final Report (see References).

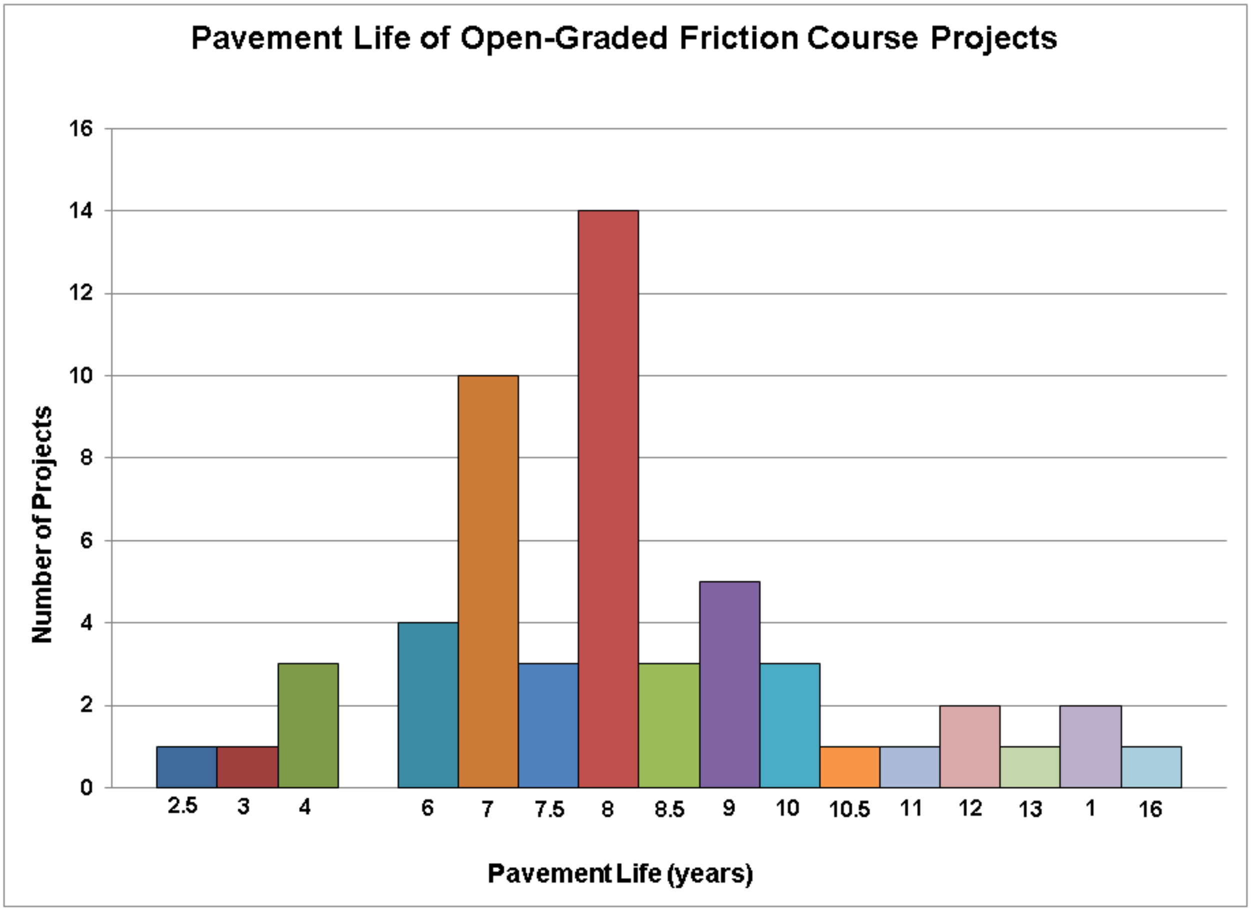


Figure 23. Pavement life of open graded friction course pavement built between 1980 and 1997.

Figure 24. Rutting in EB Lane 1 (far left lane in photo) of OGFC-AR test section on SR 520. (February 2011)

Figure 25. Wear/rutting in EB Lane 1 (far right lane in photo) of the OGFC-AR test section on SR 520. (February 2011)

Seasonal Variations in Wear/Rutting

The winter versus summer change in the depth of the rutting in the wheel paths shows a pattern similar to what was observed in the sound intensity readings with greater amounts of rutting occurring during the time when studded tire use is allowed (winter). Table 13 shows the average change in the depth of the wheel path ruts for all the lanes for each of the fall and spring readings and the calculated difference. The change in rut depth is calculated by subtracting the previous reading from the current reading. For example, the OGFC-AR difference of 3.5 mm for the Spring of 2009 is calculated by subtracting the Fall 2008 previous reading from the Spring 2009 current reading (6.2 - 2.7 = 3.5). The change in rutting for each season is shown graphically in Figure 26. The majority of the wear and rutting is occurring during the winter studded tire season. The large change in the OGFC-AR (green line) in the middle of the line graph marks the severe winter storm event in December of 2008. It is apparent that the OGFC-AR section was more susceptible to studded tire wear than either the OGFC-SBS or the HMA section.

Table 13. Change in rut depth winter versus summer.

Section	Summer 2007	Fall 2007	Spring 2008	Fall 2008	Spring 2009	Fall 2009	Spring 2010	Fall 2010	Spring 2011
OGFC-AR	1.4	1.5	2.2	2.7	6.2	5.8	6.8	6.4	8.5
Difference		0.1	0.7	0.5	3.5	-0.4	1.0	-0.5	2.1
OGFC-SBS	1.7	1.8	2.3	2.8	3.8	3.6	4.4	4.2	4.7
Difference		0.1	0.5	0.5	1.1	-0.2	0.8	-0.2	0.5
HMA	1.4	1.6	2.0	3.1	3.9	4.1	5.0	5.0	5.5
Difference		0.2	0.4	1.1	0.8	0.2	0.9	0.0	0.5

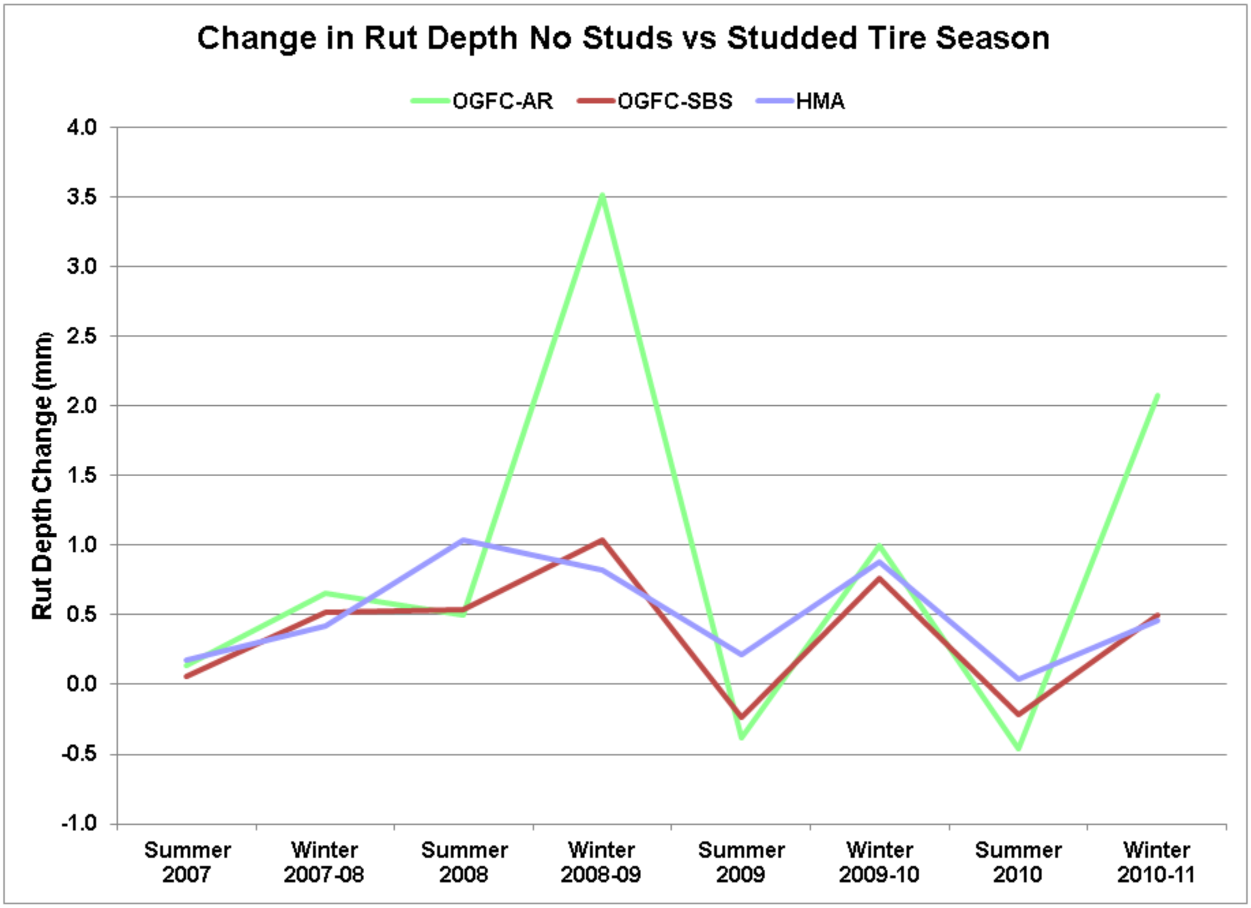


Figure 26. Change in the depth of the ruts in the wheel paths during the period when studded tires are legal versus the change during the remainder of the year.

The average change in rut depth for all lanes of each section is listed in Table 14 and shown graphically in Figure 27 for the four winter and summer time periods. The OGFC-AR had an average increase in rutting of 1.8 mm during each winter period as contrasted with the OGFC-SBS and HMA sections which showed smaller increases, 0.7 and 0.6 mm, respectively. The average increase for all of the sections during the summer period was between a negative 0.1 mm and 0.4 mm, therefore, the raveling and rutting on all of the sections is occurring primarily during the winter months. A negative rutting value 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 14. 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	OGFC-SBS	HMA
Summer 2007	0.1	0.1	0.2
Winter 2007-08	0.7	0.5	0.4
Summer 2008	0.5	0.5	1.0
Winter 2008-09	3.5	1.0	0.8
Summer 2009	-0.4	-0.2	0.2
Winter 2009-10	1.0	0.8	0.9
Summer 2010	-0.5	-0.2	0.0
Winter 2010-11	2.1	0.5	0.5
Summer Average	-0.1	0.0	0.4
Winter Average	1.8	0.7	0.6

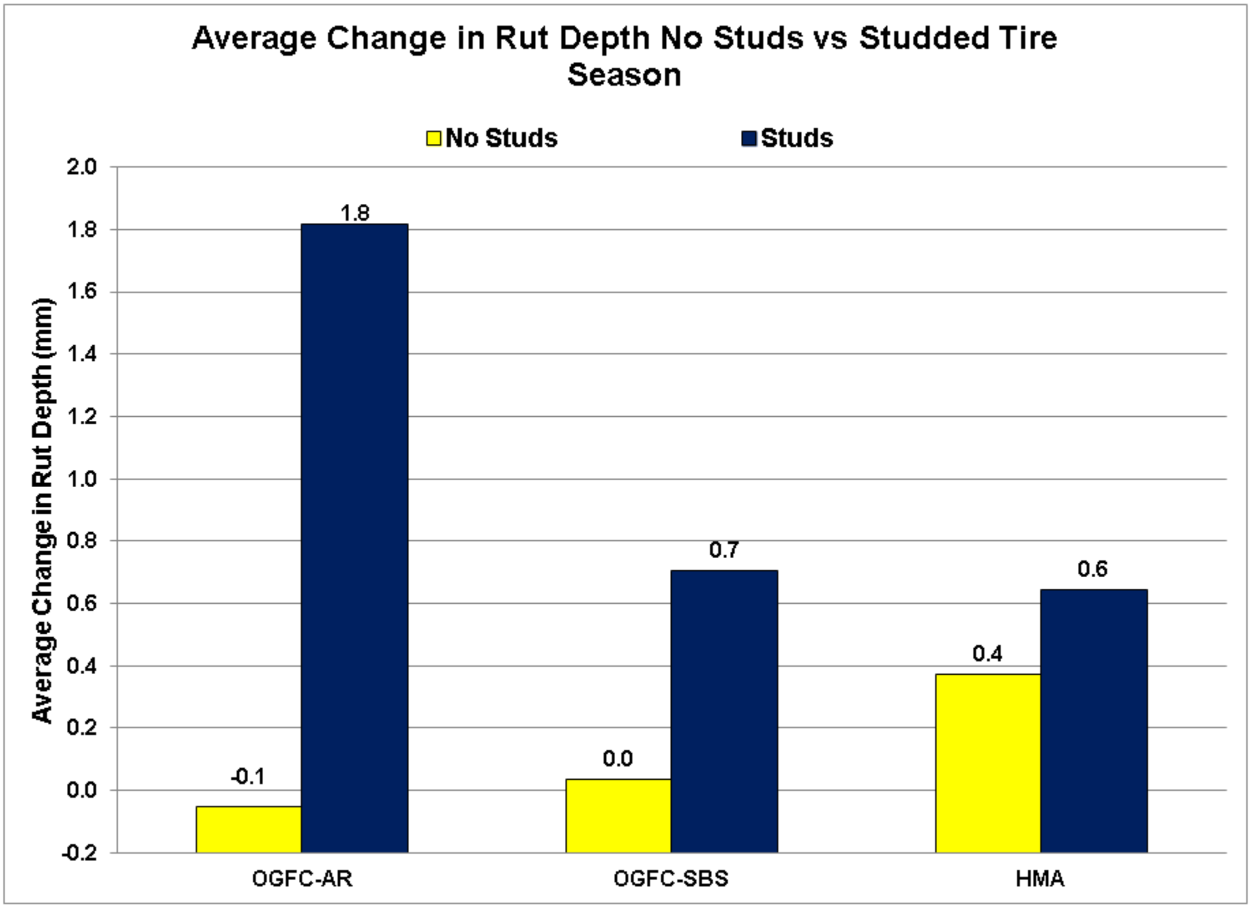


Figure 27. Average change in the depth of the rut during the legal studded tire season as compared to the rest of the year.

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 HMA and then the OGFC-SBS.
- The wear/rutting of the OGFC-AR increased dramatically following a severe winter storm that resulted in a higher use of studded tires and chains.
- The poor wear/rutting performance of the OGFC sections is consistent with previous experience with these types of pavements in Washington.
- 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 Table 15. 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. Figure 28 is a bar chart of the average friction number for each period of measurement for each pavement type. The readings were generally lower for the Fall measurement due to the accumulation of oils and other contaminants on the pavements during the summer months when there is less rain and higher in the Spring when the pavements have been cleaned by winter rains. Friction numbers below 30 require additional testing to assure that the pavement is safe.

Table 15. Friction resistance measurements SR 520, Eastside Quieter Pavement Evaluation.

Section	Lane	PC* 2007	F 2007	S 2008	F 2008	S 2009	F 2009	F 2010	S 2011
AR	EB1	37.4	41.6	49.6	41.5	54.7	48.3	48.7	51.7
AR	EB2	38.5	40.4	50.1	41.5	52.4	44.1	46.4	51.4
AR	WB3		41.1	48.0	42.8	52.7	48.4	48.3	49.9
AR	WB2	46.9	43.4	51.3	41.4	55.0	44.7	50.2	53.3
AR	HOV	40.3	41.1	51.4	41.6	52.2	46.7	47.0	50.6
Average		40.8	41.5	50.5	41.8	53.4	46.4	48.1	51.4
SBS	EB1	39.8	41.2	51.1	40.2	51.8	45.6	48.7	50.2
SBS	EB2	38.3	39.2	51.2	40.7	51.2	43.9	46.3	49.2
SBS	WB3		40.8	46.9	39.6	49.9	45.8	50.2	47.0
SBS	WB2	42.5	41.8	48.4	40.0	51.3	46.4	46.0	48.4
SBS	HOV	39.5	39.3	49.2	42.0	51.1	46.9	46.5	48.2
Average		40.0	40.5	49.4	40.5	51.1	45.7	47.5	48.5
HMA	EB1	50.4	49.8	53.2	41.8	51.7	46.0	48.1	49.2
HMA	EB2	52.6	48.6	53.0	42.9	51.3	46.9	45.8	48.5
HMA	WB3		47.7	52.6	44.4	51.2	44.0	49.6	48.5
HMA	WB2	50.6	44.7	48.7	39.3	48.2	44.5	47.7	46.4
HMA	HOV	52.6	45.0	50.0	41.3	49.4	47.8	47.8	46.4
Average		51.6	47.2	51.5	41.9	50.4	45.8	47.8	47.8

***PC = post-construction measurements taken in September after the July paving. F = Fall, S = Spring. Row colors in the table match the bars in Figure 28. No measurements were made in the Spring of 2010.**

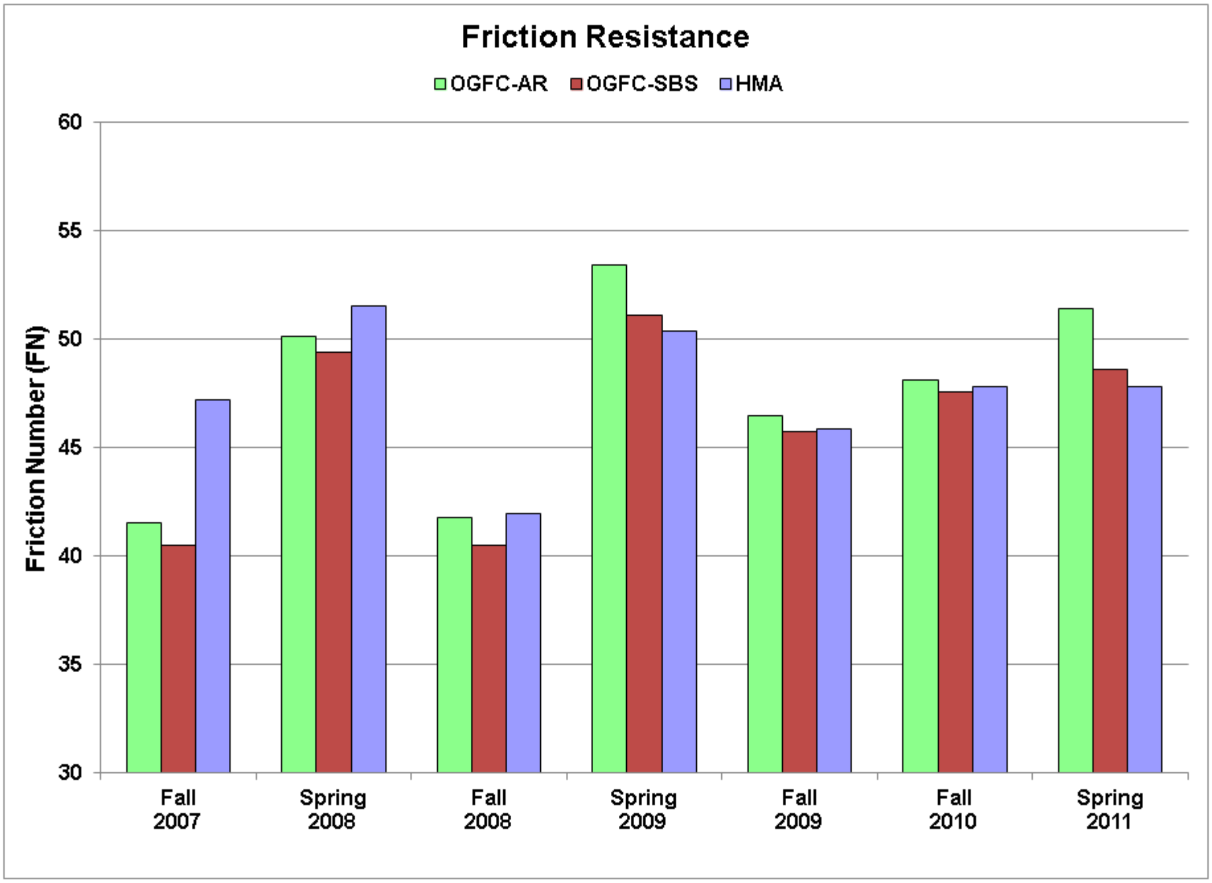


Figure 28. Average friction resistance for each pavement type.

Ride

Ride measurements for the OGFC-AR, OGFC-SBS and HMA are summarized in Table 16 and shown in the bar chart in Figure 29. 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 or lower is typical of good pavement construction. Initial ride scores after construction were excellent with the OGFC-AR lanes averaging an IRI of 57 with a range of 44-76. The OGFC-SBS lanes averaged 53 with a range of 43 to 78 and the HMA averaged 54 with a 46-66 range in IRI. The OGFC-AR ride shows a moderate jump in roughness following the Fall 2008 measurement because of the severe winter event in December of 2008.

Section	Lane	S 2007	F 2007	S 2008	F 2008	W 2009	S 2009	F 2009	S 2010	F 2010	S 2011
AR	EB1	60	58	61	61	81	89	81	87	87	98
AR	EB2	56	57	57	59	59	64	61	66	66	71
AR	WB3	44	43	43	44	46	49	47	54	51	58
AR	WB2	50	49	51	52	78	83	78	84	80	97
AR	HOV	76	79	78	79	90	96	95	94	102	111
Average		57	57	58	59	71	76	72	77	77	87
SBS	EB1	48	50	50	49	54	59	55	58	56	62
SBS	EB2	46	47	46	44	45	50	47	51	52	54
SBS	WB3	43	41	41	42	42	44	42	44	44	46
SBS	WB2	52	52	50	51	55	58	56	56	56	60
SBS	HOV	78	81	80	84	82	86	81	88	88	92
Average		53	54	53	54	56	59	56	60	59	63
HMA	EB1	58	63	61	59	60	65	61	62	61	63
HMA	EB2	56	60	60	56	56	58	56	58	57	59
HMA	WB3	46	51	49	50	50	51	56	61	65	67
HMA	WB2	46	51	49	50	50	53	56	59	60	64
HMA	HOV	66	68	71	71	69	75	75	74	77	79
Average		54	59	58	57	57	60	61	63	64	66

Table 16. Ride (IRI) measurements for the SR 520 project. Units are inches per mile.

Row colors in the table match the bars in Figure 29. F = Fall, S = Spring

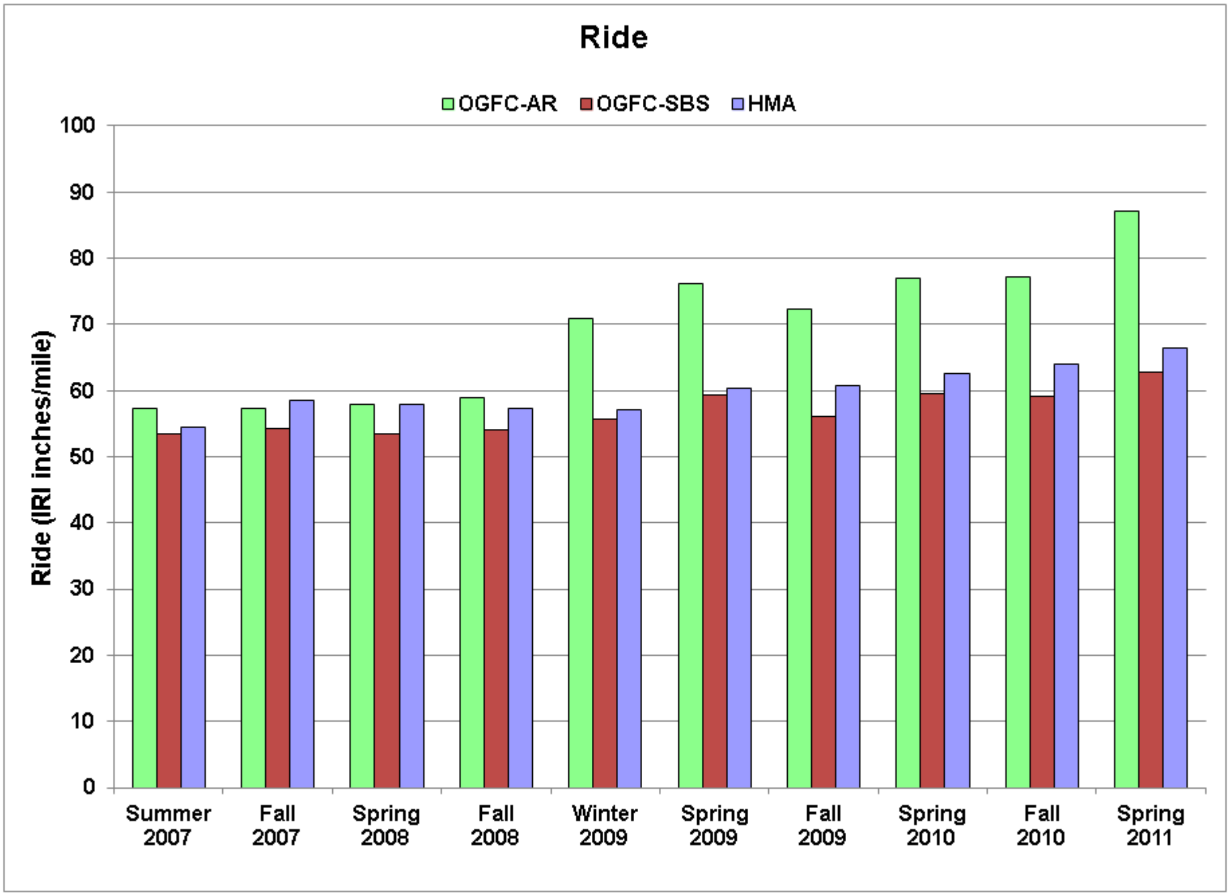


Figure 29. Average ride for each pavement.

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 as noted in the following excerpt:

> "…an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures."

In the case of the OGFC and the HMA control section, the future cost is the cost of repaving the roadway at the end of the pavements life. The life cycle cost is a function of how much it cost to pave the road and the time between each cycle of repaving.

The bar chart below (Figure 30) compares the OGFC-AR and OGFC-SBS if they were replaced as soon as they were no longer audibly quieter than the HMA control section. Cost has been converted to uniform annual cost in order to directly compare the different pavement types. Although the audible noise reduction capability of the OGFC's were less than six months, for simplicity, one year was used in the calculation as the OGFC's pavement life with respect to audible noise reduction. The LCCA for the HMA control section based on performance data is also included for comparison.

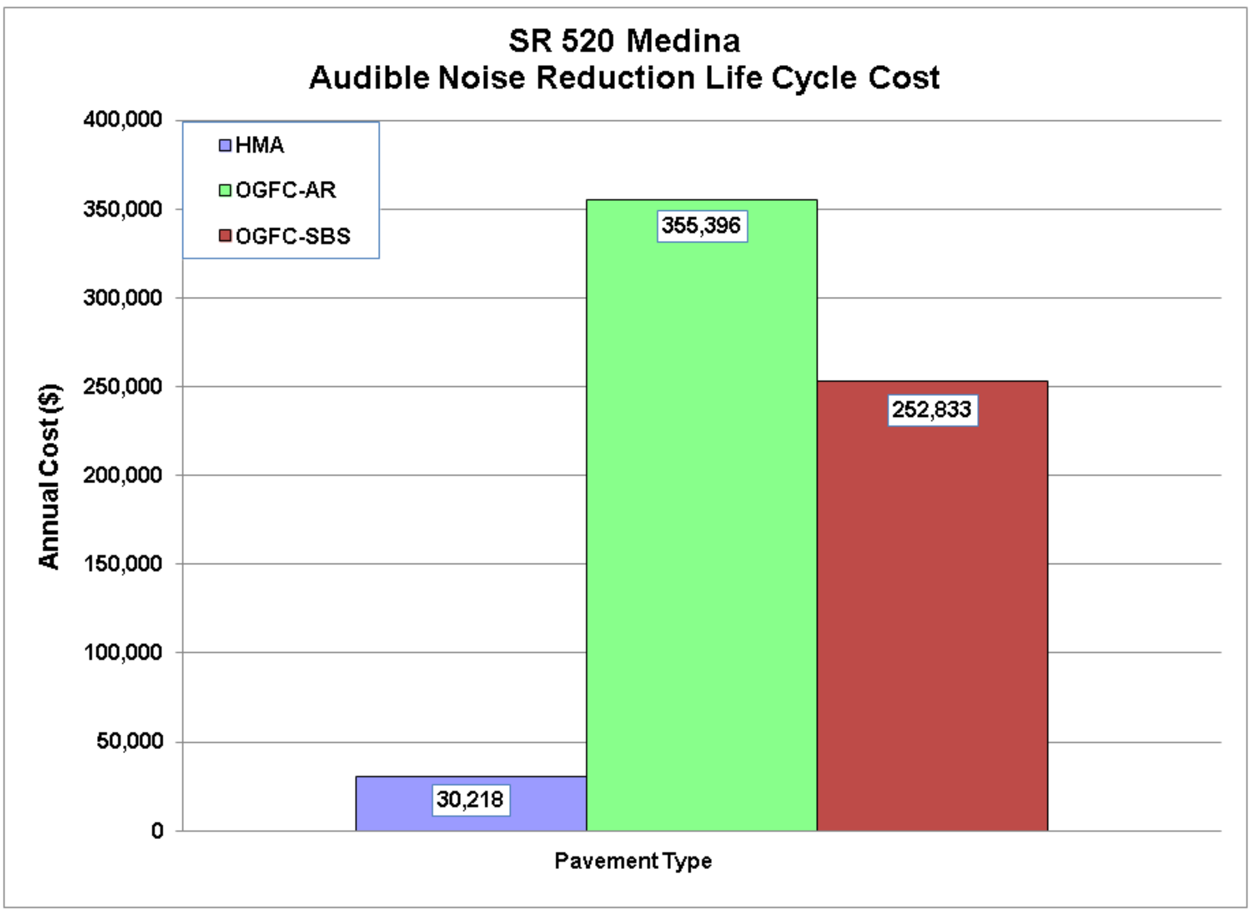


Figure 30. Life cycle cost based on audible noise reduction.

The short duration of audible noise reduction for the OGFC's leads to a high life cycle cost. Current performance data for the HMA control section indicates that it will need to be replaced at an age of about 11 years. The OGFC-AR life cycle cost is more than eleven times and the OGFC-SBS eight times the life cycle cost of the longer lasting HMA.

An LCCA analysis based on strictly pavement performance was also performed. Data from the Washington State Pavement Management System (WSPMS) indicates that the OGFC-AR would have needed replacement at five years due to rutting from studded tires. The OGFC-SBS would have lasted fourteen years with rutting also dragging down its performance. The bar chart below (Figure 31) shows the LCCA comparison of the OGFC sections and HMA control section.

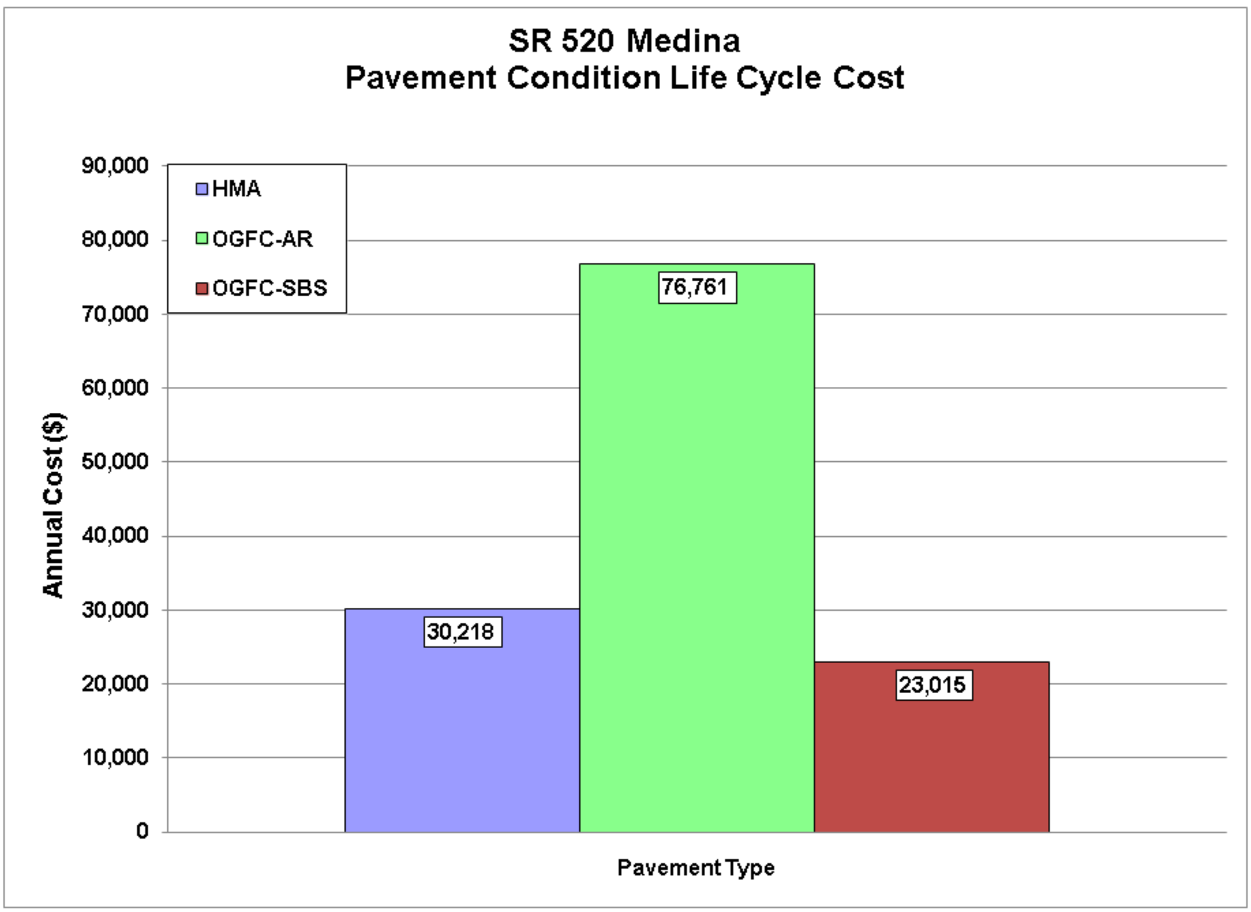


Figure 31. Life cycle cost passed on WSPMS performance data.

The annual cost of the OGFC-AR is over twice that of the HMA, but the annual cost of the OGFC-SBS is 24% lower than the HMA.

The data appears to indicate that the OGFC-SBS may be an alternative to dense graded HMA; however, this may not be the case. The HMA is under performing the average performance of this type of pavement which is 17 years in western Washington. If the SR-520 control section lasted the average life of a west side HMA, its life cycle cost would be much lower than the OGFC-SBS at $23,015

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 severe winter storm of December 2008 caused an acceleration of the wear in the OGFC-AR section which was accompanied by increases in the sound intensity level and rutting and a decrease in the smoothness of the ride over the pavement.

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 for only five months.
- The OGFC-SBS mix produced a pavement that was never audibly quieter than the conventional HMA for the entire four year monitoring period.
- 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 life cycle cost of the OGFC pavements is eight to more than eleven times higher than the HMA with respect to audible noise reduction.
- The life cycle cost of the OGFC-AR with respect to performance as a pavement is only double that of the HMA, however, this is with the caveat that the control section is under performing with respect to the average life for western Washington HMA pavements.
- The life cycle cost of the OGFC-SBS is twenty-four percent lower than the HMA based strictly on their performance as pavements, however, this is again with the caveat that the control section is underperforming with respect to the average life for western Washington HMA pavements.

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., Russell, M., Weston, J. (2012). *Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses.* Washington State Department of Transportation.

Scofield, Larry (2009) "Transportation Noise and Concrete Pavements – "Transportation Noise and Concrete Pavements – Using Concrete Pavements as Noise Solution", American Concrete Paving Association, May 2009.

Appendix A

Mix Designs
(Retyped from Originals)

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 COURSE (OGFC-AR)	WORK ORDER NO: 007353
DATE SAMPLED: 6/18/2007	LAB ID NO: 0000333961
DATE RECVD HQS: 6/19/2007	TRANSMITTAL NO: 333961
SR NO: 520	MIX ID NO: G71903
SECTION: EASTSIDE QUIETER PAVEMENT EVALUATION PROJECT	CONTRACTOR: WILDER

CONTRACTOR'S PROPOSAL

Mat'l:	3/8" CHIPS	#4-0	#4 - #8 SAND	COMBINED	SPECIFICATIONS
Source:	B-335	B-355	B-355		
Ratio:	70%	10%	20%		
3/8"	100.0	100.0	100.0	100	100
No. 4	7.0	94.5	80.5	31	30 – 45
No. 8	0.8	65.6	5.2	8	4 - 8 .
No. 200	0.6	11.5	0.3	1.6	0 - 2.5

LABORATORY ANALYSIS

		SPECIFICATIONS
L.A.ABRASON %@ 500 REVELOUTIONS*	16	40 MAX
SAND EQUIVALENT (AZ 242)	55	45 MAX
FRACTURE, % (AZ 212)	94	85 MAX
FLAKINESS INDEX, % (AZ 238)	3.8	25 MAX
CARBONATES, % (AX 210)	14	30 MAX
COMBINED SPECIFIC GRAVITY (AZ 210)	2.653	2.350 – 2.850
COMBINED WATER ABSORBTION, % (AZ 814)	1.28	2.50 MAX
PBA-ASPHALT ABSORBTION	0.49	1.00 MAX
Gsb – OF COARSE AGGREGATE BLEND	2.666	
Gsb – OF FINE AGGREGATE BLEND	2.507	
Gb – SPECIFIC GRAVITY OF BINDER	1.031	
Gmm – MAX S.G. FROM RICE @ 4.0% Pb	2.525	
Gmb – BULK S.G. OF MIX	122.5	

RECOMMENDATIONS

SUPPLIER	PARAMOUNT RB	CRUMB RUBBER MODIFIED TYPE B	
GRADE	PB64-22	RUBBER SOURCE	CRM
% ASPHALT (BY TOTAL MIX)	9.0	CRM SPECIFIC GRAVITY	1.156
% ANTI-STRIP (BY WT. ASPHALT)	0.25	% BY WT.OF ASPHALT CEMENT	23.5
TYPE OF ANTI-STRIP	ARR-MAZ 6500		
MIX ID NUMBER	G71903		
MIXING TEMPERATURE	325ºF		
COMPACTION TEMPERATURE	317ºF		

Headquarters T152 - 3
Construction Engineer------------X T153-
Materials File----------------------X T166 - 3
General File------------------------X T172 -
Bituminous Section---------------X T175 -
Region: Northwest T178 - 2
Construction Office - 41 -------X
Materials Eng--------- 41 -------X
P.E.: D. HAIGHT --X(2)

REMARKS: *L.A. ABRASION ONLY RUN @ 500 REVOLUTIONS
**THIS DESIGN IS ACCEPTABLE ON THE CONDITION THAT 3/8" CHIPS ARE SCALPED TO REMOVE MATERIAL ON 3/8" SIEVE.

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol ___________________
(360)709-5421
Date: 7 / 11 / 2007

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 COURSE (OGFC-SBS) WORK ORDER NO: 007353
DATE SAMPLED: 6/18/2007 LAB ID NO: 0000333958
DATE RECVD HQS: 6/21/2007 TRANSMITTAL NO: 333958
SR NO: 520 MIX ID NO: G71900
SECTION: EASTSIDE QUIETER PAVEMENT EVALUATION PROJECT CONTRACTOR: WILDER

CONTRACTOR'S PROPOSAL

Mat'l:	3/8" CHIPS	#4-0	#4 - #8 SAND	COMBINED	SPECIFICATIONS
Source:	B-335	B-355	B-355		
Ratio:	63%	16%	21%		
3/8"	100.0	100.0	100.0	100	100
No. 4	7.0	94.5	80.5	36	35 – 55
No. 8	0.8	65.6	5.2	12	9 - 14
No. 200	0.6	11.5	0.3	2.3	0 - 2.5

LABORATORY ANALYSIS / SPECIFICATIONS

ASPH% BY WT. OF MIX:	7.8	8.3	8.8	
% VOIDS @ Ndes: 50	23.2	20.8	19.5	15.0 Min.
% VMA @ Ndes: 50	35.1	34.4	34.1	24.0 Min.
% Gmm @ Ndes: 50	76.9	79.2	80.6	92.0 Min.
Draindown @ 339ºF	0.0	0.0	0.1	0.3 Max.
Stabilizing Additive	0.3	0.3	0.3	0.2 – 0.5
Gmm – MAX S.G. FROM RICE	2.432	2.402	2.384	
Gmb – BULK S.G. OF MIX	1.870	1.902	1.921	
Gsb – OF AGGREGATE BLEND	2.658	2.658	2.658	
Gsb – OF FINE AGGREGATE	2.615	2.615	2.615	
Gb – SPECIFIC GRAVITY OF BINDER	1.022	1.022	1.022	

LOTTMAN STRIPPING EVALUATON

% ANTI-STRIP	0.0%	¼%	½%	¾%	1.0%
Visual Appearance	MODERATE	NONE	NONE	NONE	NONE
% Retained Strength:	58	88	98	73	93

RECOMMENDATIONS / AGGREGATE TEST DATA

			VALUE	SPECIFICATIONS
SUPPLIER	U.S. OIL TEST			
GRADE	PG70-22			
% ASPHALT (BY TOTAL MIX)	8.8	FRACTURE	100	85 Min. (2 FACES)
% ANTI-STRIP (BY WT. ASPHALT)	0.25			
TYPE OF ANTI-STRIP	ARR-MAZ 6500	SAND EQUIVALENT	68	45 Min.
MIX ID NUMBER	G71900			
MIXING TEMPERATURE	346ºF			
COMPACTION TEMPERATURE	317ºF			

Headquarters T152 - 3
Construction Engineer------------X T153-
Materials File---------------------X T166 - 3
General File-----------------------X T172 -
Bituminous Section---------------X T175 -
Region: Northwest T178 - 2
Construction Office - 41 -------X
Materials Eng--------- 41 -------X
P.E.: D. HAIGHT --X(2)

REMARKS: *L.A. ABRASION ONLY RUN @ 500 REVOLUTIONS
**THIS DESIGN IS ACCEPTABLE ON THE CONDITION THAT 3/8" CHIPS ARE SCALPED TO REMOVE MATERIAL ON 3/8" SIEVE.

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol __________________
(360)709-5421
Date: 7 / 13 / 2007

Appendix B

Special Provisions

DIVISION 5
SURFACE TREATMENTS AND PAVEMENTS

HOT MIX ASPHALT

Description

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

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

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

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

Materials

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

(******)
The use of RAP shall not be permitted in the production of OGFC and OGFC-AR.

Asphalt binder material for the OGFC shall be PG 70-22. SBS modifier shall be added to a non air blown or oxidized PG 58-22 or PB 64-22 asphalt to produce a binder that complies with the requirements for PG 70-22.

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

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

Asphalt-Rubber

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.

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

Asphalt-Rubber Proportions

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

Asphalt-Rubber Properties

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

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

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

Asphalt-Rubber Binder Design

At least 10 working days to the use of asphalt-rubber, the Contractor shall submit an asphalt-rubber binder design prepared by one of the following laboratories who have experience in asphalt-rubber binder design:

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

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

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

Construction Requirements

Section 5-04.3 shall be supplemented with the following:

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

Mixing of Asphalt-Rubber

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

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

Handling of Asphalt-Rubber

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

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

1. The source, grade, amount and temperature of the asphalt binder prior to the addition of rubber.
2. The source and amount of rubber and the rubber content expressed as percent by the weight of the asphalt binder.
3. Times and dates of the rubber additions and resultant viscosity test.
4. A record of the temperature, with time and date reference for each load or batch. The record shall begin at the time of the addition of rubber and continue until the load or batch is completely used. Readings and recordings shall be made at every temperature change in excess of 20°F, and as needed to document other events which are significant to batch use and quality.

HMA Mixing Plant

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

Fiber Supply System

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

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

2) Provides interlock with the aggregate feed or weigh systems so as to maintain the correct proportions for all rates of production and batch sizes.

   a) Controls dosage rate accurately to within plus or minus 10 percent of the amount of fibers required.

   b) Automatically adjusts the feed rate to maintain the material within the 10 percent tolerance at all times.

   c) Provides flow indicators or sensing devices for the fiber system that are interlocked with plant controls so that mixture production will be interrupted if introduction of the fiber fails or if the output rate is not within the tolerances given above.

3) Provides in-process monitoring, consisting of either a digital display of output or a printout of feed rate, in pounds per minute to verify the feed rate.

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

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

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

Hot Mix Asphalt Pavers
Section 5-04.3(3) is supplemented with the following:

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

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

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

The wheels of the rollers used for OGFC or OGFC-AR shall be wetted with water, or if necessary soapy water, or a product approved by the Engineer to prevent sticking to the steel wheels during rolling. The soap shall not contain phosphates. The soap shall be biodegradable.

Vibratory rollers must be used in the static mode only.

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

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

Preparation Of Existing Surfaces

Section 5-04.3(5)A paragraph 1 sentence 1 is supplemented with the following:

After completion of planning bituminous pavement the existing paved surface shall be cleaned and swept.

Section 5.04.3(5) is supplemented with the following:

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

The Contractor shall limit the amount of tack coat placed to that amount that will be fully covered by the asphalt overlay at the end of each work shift.

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

Mix Design

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

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

   The Contractor shall also furnish representative samples of the following materials: a five-pound sample of the crumb rubber proposed for use, four 1-quart cans of asphalt binder from the intended supplier, twenty 1-quart cans of the proposed mixture of binder and rubber, and a one-gallon can of the mineral admixture to be used in the OGFC-AR.

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

The above materials and letter shall be shipped to the WSDOT State Materials Laboratory in Tumwater to ensure that they arrive by the time the final Asphalt Rubber Binder Design is received. Within 10 working days of receipt of all samples and the Contractor's letter 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 and mineral admixture gradation, and any special or limiting conditions for the use of the mix.

The Contracting Agency will determine the anti-strip requirements in accordance with WSDOT Test Method 718.

Mix Design (OGFC). 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 production of the OGFC. This material must be submitted to the WSDOT State Materials Laboratory in Tumwater to ensure that they arrive by the time the final Asphalt Rubber Binder Design is received.

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

The Contracting Agency will determine the anti-strip requirements in accordance with WSDOT Test Method 718.

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

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

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

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

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

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

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

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

1. Fiber length:	0.25 inch (6 mm) max.
2. Sieve Analysis	
a. Alpine Sieve Method	
Passing No. 100 sieve:	60-80%
b. Ro-Tap Sieve Method	
Passing No. 20 sieve:	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.

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

1. Pellet size:	1/4 in^3 (6 mm^3) max.
2. Asphalt:	25 - 80 pen.

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

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

Acceptance Sampling and Testing – HMA Mixture

Item 3 of Section 5-04.3(8)A is supplemented with the following:

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

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

The first paragraph is revised to read:

The Engineer will furnish the Contractor with a copy of the results of all acceptance testing performed in the field within either 24 hours of sampling or 40 hours after the beginning of the next paving shift, whichever is later. The Engineer will also provide the Composite Pay Factor (CPF) of the completed sublots after three sublots have been produced. The CPF will be provided by the midpoint of the next paving shift after sampling results are completed.

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

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

The third paragraph is revised to read:

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

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

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

Item 5 Section 5-04.3(8)A is supplemented with the following:

Mineral Aggregate Gradation - OGFC
For the OGFC a sample shall be taken in accordance with WSDOT T-2 on a random basis just prior to the addition of mineral admixture and bituminous materials. At least one sample shall be taken during the production of the OGFC. Samples will be tested for conformance with the mix design gradation. The gradation of the mineral aggregate shall be considered 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	Mixture Control Tolerance
3/8 inch	± 5.7
No. 4	± 5.5
No. 8	± 4.5
No. 200	± 2.0

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

Passing **Number of Tests**

Sieve	3 Consecutive	One
No. 4	± 4	± 4
No. 8	± 3	± 4
No. 200	± 1.0	± 1.5

Item 7 of Section 5-04.3(8) A is revised as follows:

The last sentence is revised to read:

The calculation of the CPF in a test section with a mix design that did not verify will include gradation, asphalt binder content, voids in mineral aggregate (VMA) and percent air voids (Va).

Item 7 of Section 5.04-3(8)A is supplemented with the following:

Prior to starting any OGFC or OGFC-AR paving operation, including test sections, the Contractor shall provide at least 14 days written notice to the Engineer so that the Engineer can provide notification to WSDOT Materials Laboratory staff.

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

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

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

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

Compaction

Control

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

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

Surface Smoothness

The second sentence of Section 5-04.3(13) is deleted and replaced with the following:

> The completed surface of the wearing course of the following sections of highway shall not vary more than 1/4–inch from the lower edge of a 10-foot straightedge place on the surface parallel to centerline:
>
> SR 520
>
> The completed surface of the wearing course of all other sections of highway shall not vary more than 1/8 inch from the lower edge of a 10-foot straightedge placed on the surface parallel to centerline.

Planing Bituminous Pavement

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

> The Contractor shall perform the planing operations no more than four calendar days ahead of the time the planed area is to be paved with OGFC, OGFC-AR, HMA, unless otherwise allowed by the Engineer in writing.

Weather Limitations

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

> The mixing and placing of OGFC and OGFC-AR shall not be performed when the existing pavement is wet or frozen. OGFC and OGFC-AR shall not be placed when the air temperature is less than 60°F.
>
> Once the OGFC and OGFC-AR pavement have been compacted, the pavement must cool to a surface temperature of 100°F of less prior to opening to construction or general traffic.
>
> The Contractor shall monitor the weather forecast and notify the Engineer in writing if the weather (and temperature) might affect the paving operation.

Measurement

Section 5-04.4 is supplemented with the following:

(******)

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

Payment

Section 5-04.5 is supplemented with the following:

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

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

Price Adjustment for Quality of HMA

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

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

Table of Price Adjustment Factors

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

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

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

Appendix C

Infrared Images and Construction Comments

Contract 7353
SR-520
Eastside Quieter Pavement Evaluation Project
Construction Comments

The content of this report reflect the views of the author, Jim Weston, who is responsible for the facts and the accuracy of the data presented herein. The content does not reflect necessarily the official views or policies of the Washington State Department of Transportation.

TACK APPLICATION

Tack coat for both the OGFC test sections was applied by an Etnyre distributor. The application of the CRS-2P tack was the item of concern because the snivies would plug quickly due to the tack material itself. The tack application was sporadic with streaking in the eastbound lanes of the OGFC-AR but the application was fairly uniform on the westbound lanes. The tack applied on the OGFC-Polymer was also erratic with streaking. Some tracking of the tack coat by the Shuttle Buggy and delivery trucks was observed in the wheelpaths but it was not as substantial as that which occurred on the OGFC project on I-5 near Lynnwood.

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

MATERIAL TRANSFER VEHICLE

The use of tarps on the HMA delivery trucks and trailers was seen throughout the paving operations for both the OGFC materials. Two ROADTEC Shuttle Buggy (SB) material transfer vehicles were used throughout the project. The SB has excellent remixing and storage capabilities and specifying it in the contract special provisions was a wise choice. The temperature of the mix as it was transferred from the SB into the paver hopper was typically around 290ºF. The insulating and remixing capability of this device resulted in consistent temperatures across the mat and behind the screed. The only exception to this consistent pattern of temperatures occurred because of problems with one of the pavers as detailed later.

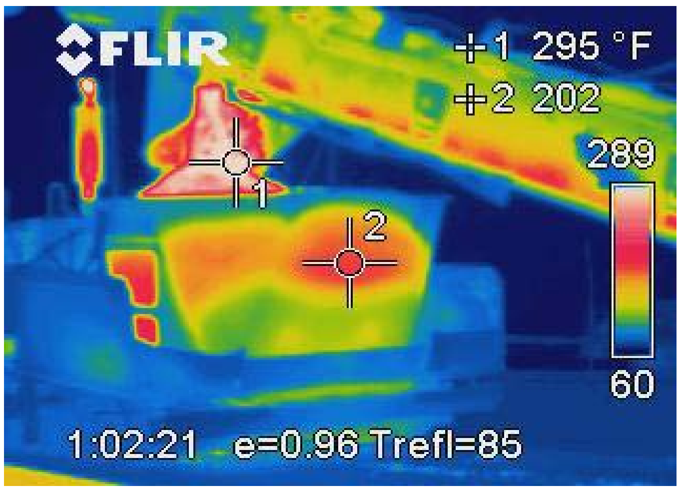


Figure 33. Thermal image of the mix as it leaves the SB and enters the paver hopper at 295°F.

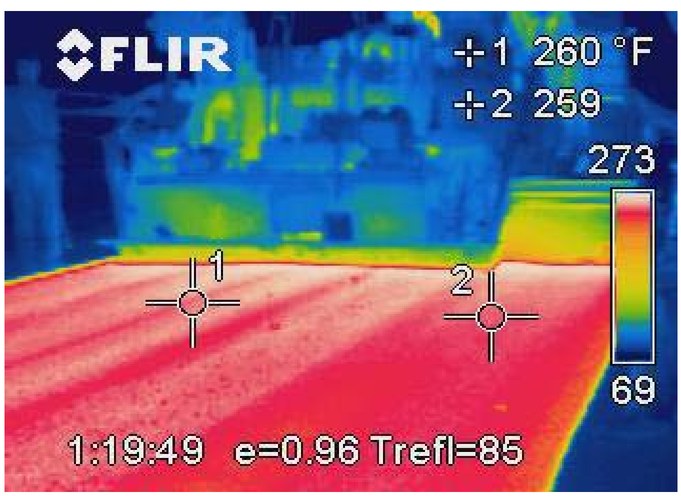


Figure 34. Image looking towards the paver from behind the screed.

PAVER

Two Blaw-Knox PF-5510 pavers equipped with paver hopper boxes were used throughout the project. The older was outfitted with a Carlson Easy Screed and the newer was set with a Carlson EZIV. Both pavers were equipped with paver retrofit kits to keep the screed from being starved at the gearbox; however, both were missing chains at the inner portion of the kit. The older paver appeared to leave more longitudinal streaks than the newer but this may have been caused by excessive speed. Streaking was also believed to have been caused by the buildup of cooler material at the front of the screed at the location of the auger extensions. Pieces of mix would dislodge from the paver at this location and travel under the screed and show up as a glob of cooler material in the mat. These globs were removed and replaced using material taken from in front of the screed with the result being that no surface defects were left after compaction.

Figure 35. Digital image looking at the paver screed from behind with chain seen near the tracks but not between.

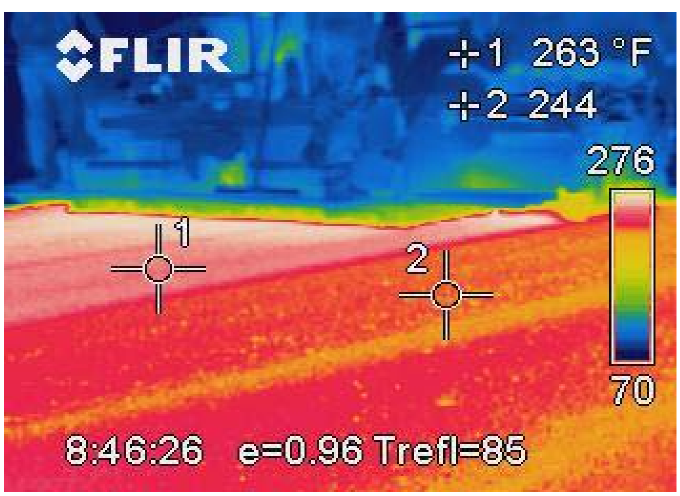


Figure 36. Streaking OGFC of first paver (spot 2) and the consistent mat behind second paver (spot 1).

Most of the problems with streaking and globs of material were eliminated once the speed of the paving operation stabilized. This was also true during the paving of the OGFC-Polymer. Paving was conducted in a side-by-side operation and longitudinal joints were eliminated by hot-lapping of the joint from the simultaneous paving operation.

Figure 37. View of trucks loading MTV's and pavers with view of breakdown rollers

ROLLERS

A total of four rollers were used for the paving of the OGFC-AR and OGFC-Polymer, two Ingersoll-Rand DD-130's and two Ingersoll-Rand DD-110's. All rollers operated solely in static mode as specified in the contract Special Provisions. One DD-130's was used as a breakdown roller followed by one DD-110 for finishing behind each paver.

Figure 38. Image of distance between rollers.

Generally, the rollers met the requirement to be within 300 feet of the paver; however, the operators had trouble knowing when to get off the mat after the surface temperature of the pavement reached the Special Provision requirement of 200ºF. This was not caused by excessively low temperatures of the OGFC at arrival but seemed to be caused by lack of checking surface temperature while rolling. This caused aggregate breakage to occur during OGFC placement.

Figure 39. Image of aggregate breakage in paved lanes (brown surface).

The roller operations could have more easily adhered to the 300-foot specification if the paver slowed down at the beginning of each new lane. Additionally, the rollers could have made fewer passes if the temperature of the pavement was being monitored and this would have eliminated the aggregate breakage. A closer monitoring of mat temperatures might also have indicated how many passes and what roller speed was optimal for the speed of the paving operation.

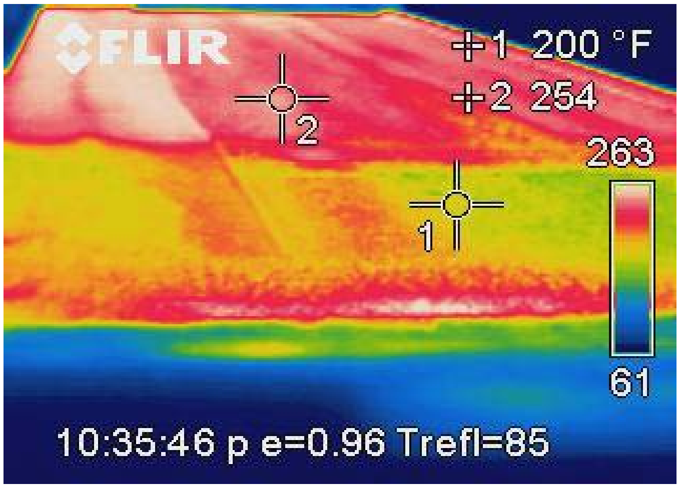


Figure 40. Thermal image of construction joint at startup

OGFC-AR

The OGFC-AR mix was sticky and adhered to the paving equipment (i.e. rakes, truck beds, SB tires, etc.). The temperatures recorded directly behind the paver where generally between 250 and 265ºF. These temperatures were nearly 50ºF cooler than those recorded at the Lynnwood test section (I-5) and those reported by the Arizona Department of Transportation when paving with the same mix. This could account for the stickiness.

OGFC-POLYMER

The OGFC-Polymer mix was not as sticky as the OGFC-AR mix and was not as difficult to work with when compared to the Lynnwood test section. The problem on the Lynnwood project, which was globules of tack coat bubbled up through the mat, did not occur and may have been the result of using less tack on this project.

OTHER PROBLEMS

Other problems occurred that were but not related to the use of either OGFC-AR or OGFC-Polymer. During the paving of the OGFC-AR, a substantial amount of material was accidentally dumped on the roadway as the dump truck approached the Shuttle Buggy. The mix was removed although some residual material remained. The Shuttle Buggy did not track through this material so fat spots were not seen in the mat as was the case on the Lynnwood project.

RECOMMENDATIONS

- It may be of benefit on future projects that use CRS-2P as a tack coat to modify the tack specifications to ensure an even application of the material. This might require a test of the tack coat truck prior to beginning paving to ensure that all of the snivies are clean and operating properly.

- Specify that tarps be used on all trucks and trailers to ensure maximum heat retention in the mix between the plant and the paving operation.
- Specify a material transfer vehicle be used on all thin lift open-graded friction course projects.
- Specify that a paver retrofit kit be used on all applicable models and that the kit is in working order as recommended by the manufacture.
- Specify that auger extensions be used when the screed is extended a certain specified distance or that the contractor will take necessary measures to minimize longitudinal streaking at the screed extensions.

COMMENTS

- The temperature of the screed should be as close as possible to the temperature of the mix prior to starting the paving operation.
- All of the paving operations need to be coordinated in order to adhere to the requirement that rollers are kept within 300 feet of the paver.
    - Slow down mix production at the plant at the end of the completion of one lane so that the material does not build up while the paver is being moved.
    - Allow for time for the rollers to work at the construction joint by not loading too many trucks.
    - Move the paver at a consistently slow speed.
    - Slow the speed of the paver until rollers have completed the work at a construction joint.
- Mat surface temperature should be monitored regularly so that aggregate breakage is minimized. Aggregate breakage may be the link to wearing of the OGFC (note where the aggregate breakage is occurring…in the wheelpaths).
- Minimize handwork as much as possible.
- Keep delivery trucks and MTV tires as clean as possible to avoid bringing debris into the work area.
- Keep the work area as clean as possible at all times. Material dumped onto the roadway should be removed before the paver runs over it and material that builds up on tires should be removed as soon as it is noticed.
- Remember that this is a thin surface and defects will reflect through.

Appendix D

Sound Intensity Level Measurements

Tables 17-19 list the sound intensity level for each lane and the average for all lanes for the monthly measurements of the OGFC-AR, the OGFC-SBS and HMA test sections.

Table 17. OGFC-AR sound intensity readings (dBA).

Date	EB1	EB2	WB3	WB2	WBHOV	Average
7/25/07	96.5	97.0	95.0	95.2	97.0	96.1
8/9/07	96.3	97.0	95.4	95.3	97.8	96.3
9/19/07	98.3	97.7	96.4	97.6	98.1	97.6
10/26/07	98.2	97.7	97.3	97.7	98.4	97.9
12/7/07	98.3	97.9	97.5	97.1	100.3	98.2
1/17/08	100.0	99.5	98.0	99.2	99.9	99.3
2/8/08	100.0	99.7	97.7	99.8	99.1	99.3
4/8/08	101.0	100.7	99.4	100.8	100.1	100.4
5/8/08	99.2	100.6	99.4	100.3	99.2	99.7
7/8/08	98.1	97.3	96.3	97.5	97.1	97.2
8/8/08	98.1	97.5	98.1	98.1	98.6	98.1
12/3/08	101.8	100.5	99.8	101. 2	100.6	100.8
1/7/09	106.6	100.9	100.7	105.3	104.8	103.7
2/9/09	106.0	99.9	99.8	104.4	104.4	102.9
3/12/09	105.9	101.0	101.6	105.2	103.1	103.4
4/20/09	104.3	100.0	101.1	103.8	102.1	102.3
5/27/09	103.4	99.8	103.2	100.7	103.3	102.1
8/13/09	104.7	100.8	101.3	104.0	104.3	103.0
9/2/09	103.4	100.4	100.5	103.3	103.2	102.2
10/6/09	104.8	101.2	101.8	104.6	103.1	103.1
12/22/09	106.9	103.6	105.0	104.0	104.2	104.7
1/7/10	106.6	103.5	104.8	105.9	106.0	105.4
2/10/10	105.9	103.2	104.0	104.6	105.1	104.6
3/10/10	104.9	103.2	102.3	104.2	103.2	103.6
4/10/10	105.0	103.3	103.5	104.4	102.5	103.7
6/10/10	105.3	103.4	102.4	104.2	103.9	103.8
7/13/10	104.6	102.7	102.0	104.2	103.4	103.4
8/16/10	104.1	102.4	102.7	103.0	101.3	102.7
9/30/10	104.4	103.2	103.4	104.2	103.2	103.7
11/8/10	105.7	104.3	104.5	105.3	104.8	104.9
12/7/10	105.3	103.9	103.9	104.5	104.9	104.5
2/1/11	106.7	105.5	104.2	105.4	105.9	105.5
3/17/11	106.2	104.4	104.6	104.1	103.9	104.8
4/19/11	105.6	105.6	104.7	105.1	104.9	105.2
7/20/11	-	-	-	-	-	104.7

Table 18. OGFC-SBS sound intensity readings (dBA).						
Date	EB1	EB2	WB3	WB2	WBHOV	Average
7/25/07	97.6	96.7	96.9	98.2	99.5	97.8
8/9/07	98.6	98.4	98.6	100.0	99.7	99.1
9/19/07	100.8	100.4	99.8	100.5	100.6	100.4
10/26/07	98.6	98.4	98.6	100.0	99.7	99.1
12/7/07	100.2	97.8	97.8	99.1	100.6	99.1
1/17/08	100.5	99.0	99.1	101.0	101.6	100.2
2/8/08	100.4	98.4	98.3	100.1	98.8	99.2
4/8/08	101.5	99.4	99.8	101.0	100.2	100.4
5/8/08	100.0	99.3	99.8	101.2	98.7	99.8
7/8/08	101.6	96.4	97.7	98.4	98.5	98.5
8/8/08	99.1	97.5	98.8	99.5	99.7	98.9
12/3/08	101.9	100.3	101.8	102.3	102.1	101.7
1/7/09	104.4	101.3	102.0	104.4	103.1	103.0
2/9/09	103.7	100.9	102.1	103.8	102.5	102.6
3/12/09	104.1	101.2	102.2	104.2	102.8	102.9
4/20/09	103.7	100.6	100.3	102.9	102.0	101.9
5/27/09	100.9	100.9	102.1	100.9	100.9	101.1
8/13/09	103.1	101.3	101.6	103.0	102.2	102.2
9/2/09	102.1	100.3	100.6	101.4	101.2	101.1
10/6/09	103.2	101.1	101.9	103.0	101.8	102.2
12/22/09	105.0	103.7	103.4	103.8	104.1	104.0
1/7/10	105.1	103.2	104.0	104.6	103.8	104.1
2/10/10	104.1	103.7	103.3	104.1	103.0	103.6
3/10/10	103.9	102.4	102.2	103.2	102.1	102.8
4/10/10	103.9	102.3	102.6	103.7	102.6	103.0
6/10/10	103.8	102.6	102.8		102.6	103.0
7/13/10	103.3	102.0	102.4	103.2	102.0	102.6
8/16/10	101.3	100.9	100.1	102.1	101.0	101.1
9/30/10	104.1	101.8	102.4	102.8	102.0	102.6
11/8/10	104.5	103.0	103.5	104.4	102.7	103.6
12/7/10	103.9	102.6	102.8	103.3	102.3	103.0
2/1/11	105.4	104.7	104.1	105.2	103.7	104.6
3/17/11	105.2	103.2	102.9	104.5	103.1	103.8
4/19/11	105.2	103.9	104.1	104.6	103.6	104.3
4/20/11	-	-	-	-	-	103.7

Table 19. HMA sound intensity readings (dBA).						
Date	EB1	EB2	WB3	WB2	WBHOV	Average
7/25/07	99.5	99.4		100.1	100.0	99.8
8/9/07	99.2	99.1	100.5	101.0	100.7	100.1
9/19/07	101.4	101.1	102.3	102.5	102.3	101.9
10/26/07	101.4	101.0	102.1	102.7	102.6	102.0
12/7/07	101.2	100.7	101.3	102.0	102.3	101.5
1/17/08	101.9	101.4	102.0	103.0	102.6	102.2
2/8/08	101.1	100.5	101.5	101.7	101.6	101.3
4/8/08	102.1	101.8	102.8	103.2	102.6	102.5
5/8/08	101.4	102.0		102.5	101.9	101.9
7/8/08	100.1	100.0	100.6	101.1	100.0	100.3
8/8/08	100.4	100.4	101.2	98.6	100.4	100.2
12/3/08	102.6	102.4	103.0	103.2	102.3	102.7
1/7/09	104.7	103.0	103.5	104.8	103.3	103.8
2/9/09	104.4	102.4	103.2	104.2	103.1	103.5
3/12/09	104.8	102.7	102.9	104.5	103.0	103.6
4/20/09	103.8	101.3	103.4	103.3	102.0	102.8
5/27/09	103.4	101.9	103.4	101.8	101.6	102.4
8/13/09	103.4	102.2	102.6	103.6	102.4	102.8
9/2/09	102.7	101.9	101.9	102.8	101.8	102.2
10/6/09	103.1	102.7	102.6	103.6	101.5	102.7
12/22/09	104.5	103.2	103.6	104.6	105.3	104.2
1/7/10	105.4	103.9	104.7	104.7	103.7	104.5
2/10/10	104.7	103.7	103.6	104.8	102.6	103.9
3/10/10	104.4	102.8	102.7	104.0	102.4	103.3
4/10/10	104.5	103.3	103.6	104.4	102.6	103.7
6/10/10	104.4	103.9	103.7	104.1	102.5	103.7
7/13/10	103.1	103.4	102.3	103.1	101.9	102.8
8/16/10	103.3	102.1	102.9	102.8	101.3	102.5
9/30/10	103.9	103.3	103.0	103.8	102.5	103.3
11/8/10	104.5	103.7	104.0	104.7	103.4	104.1
12/7/10	104.0	103.5	102.9	104.0	103.0	103.5
2/1/11	105.3	104.6	104.9	105.5	103.6	104.8
3/17/11	105.1	103.8	103.9	104.3	103.0	104.0
4/19/11	105.2	105.0	104.4	105.3	103.7	104.7
4/20/11	-	-	-	-	-	104.7

Appendix E

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

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

SR 520
Eastside Quieter Pavement Evaluation Project
Milepost 4.24 to Milepost 5.82

Linda M. Pierce, PE
State Pavement Engineer
Washington State Department of Transportation

Introduction

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

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

Plan of Study

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

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

Scope

This project will construct three types of pavement on its approximately 1.5 mile length. Two OGFC test sections, each ½-mile in length, one with asphalt-rubber and the other with PG70-22 (polymer) will be placed on either side end of a ½-mile middle section of Superpave 1/2 inch that will serve as a control section. This section of SR 520 consists of two 12-foot lanes in the eastbound direction and two 11-foot lanes and a 12-foot HOV lane in the westbound direction.

In addition there are variable width shoulders and flyer stops that will also be paved with the type of mix that is being placed on the adjacent mainline.

All sections of the OGFC and Superpave ½-inch will be placed full roadway, including shoulders and flyer stops, to a depth of 0.06 feet.

WSDOT will be designing the mixes in accordance with the Arizona DOT specifications for OGFC with asphalt-rubber and OGFC with a modified asphalt binder.

Layout

The first test section of OGFC, polymer, will begin at MP 4.24 and end at MP 4.78 and the second, asphalt-rubber, will begin at MP 5.31 and end at MP 5.82. The control section of Superpave ½-inch will begin at MP 4.78 and end at MP 5.31.

Staffing

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

Contacts and Report Author

Linda Pierce, PE
WSDOT State Pavement Engineer
(360) 709-5470
FAX (360) 709-5588
piercel@wsdot.wa.gov

Testing

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

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

Reporting

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

Cost Estimate

Construction Costs

Description	Quantity	Unit Cost	Unit	Total Cost
OGFC – asphalt rubber	980	$62.00	Ton	$60,760
OGFC – PG70-22	890	$55.00	Ton	$48,950
Total				**$109,710**

Testing Costs

The pavement condition survey will be conducted as part of the statewide annual survey (all lanes will be tested). Noise intensity measurements will be conducted on a periodic basis by Environmental Services.

Report Writing Costs

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

Total Cost = $124,110

Schedule

Estimated Project Ad Date – March 2007
Estimated Construction – August 2007

Date	Pavement Condition Survey	Sound Intensity Measurement	End of Construction Report	Annual Report	Final Report
September 2007	X	X			
January 2008			X		
July 2008	X	X			
October 2008		X		X	
July 2009	X	X			
October 2009		X		X	
July 2010	X	X			
October 2010		X		X	
July 2011	X	X			
October 2011		X		X	
July 2012	X	X			
October 2012		X		X	
June 2013					X