Post-Construction and Performance 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

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16. ABSTRACT

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

Sound intensity measurements were conducted using the On Board Sound Intensity (OBSI) method immediately after construction and monthly since the end of construction.

OBSI readings immediately after construction indicated that the open-graded asphalt rubber and SBS modified sections were 3.7 to 2.0 decibels, respectively, quieter than the Class ½ inch HMA control section. The most recent readings, taken in December of 2007, show the asphalt rubber section to be 3.3 dBA quieter than the ½ inch HMA control section and the SBS modified to be 2.4 dBA quieter.

Pavement wear/rutting and roughness data indicates that there has been virtually no increase in the measured rutting and only a slight increase in the roughness for both of the open-graded sections and the control section.

This experimental evaluation will continue for a minimum of five years.

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Introduction

This is the second in a series of three experimental feature projects involving the construction of open-graded friction course (OGFC) pavements to mitigate tire/pavement noise. The first, on Interstate 5 near the town of Lynnwood, was constructed in August of 2006 using asphalt rubber and 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 surface voids (around 20 percent air voids) which absorbs some of the noise generated at the tire/pavement interface. The OGFC pavements are thus "quieter" than densely-graded pavements which have between four and eight 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 very extensively in the state in the early to middle 1980's. Their use was discontinued in 1995 due to problems with excessive rutting caused by studded tire wear. The renewed interest in open-graded pavements is prompted by successful use of this type of pavement in other states, principally Arizona. The Arizona Department of Transportation (ADOT) has been a leading advocate of rubberized open-graded pavements as one solution to making pavements quieter. Intense interest regarding rubberized open-graded pavement as the answer to making pavements quieter has reached the public sector who are now asking for this type of pavement to be used on the highways that bisect their neighborhoods.

Background

There are downsides with the use of open-graded pavements. Open-graded pavements are very susceptible to excessive wear from studded tires. This excessive wear produces ruts in the pavements that fill with water during rainy periods and pose the additional hazard of hydroplaning. The other downside is pavement life. The life of open-graded pavements is cut short by the studded tire wear mentioned previously. Pavement lives of less than 10 years, and as short as three to four years were experienced with these types of pavement in the 1980's in Washington State. 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 minimum surface temperature at the time of placement. Washington State urban pavements, placed at night to avoid traffic impacts, rarely reach this temperature during the available nighttime hours for paving (10:00 p.m. to 5:00 a.m.), even in summer. Other pavements and bridge decks reach such temperatures at night only on rare occasions, making successful placement of this type of pavement a challenge. A more complete discussion of the performance history of open-graded pavements in Washington State is found in the report on the first quieter pavement experimental project (Anderson et al., 2008).

Project Description

The site selected for the second experiment is located on SR-520 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, consisted of paving all lanes of SR-520 from MP 4.18 to MP 5.82. 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.

Figure 1. Location map for Contract 7353.

The open-graded sections were placed 0.06 feet thick 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 place 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.

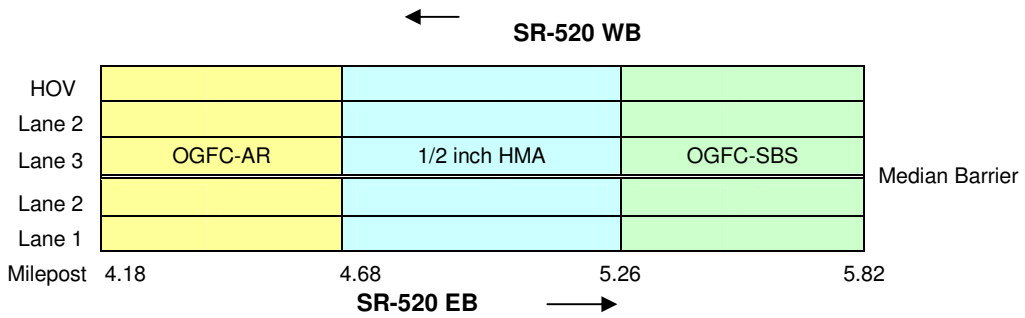

Figure 2. Plan map of section layout.

The pavement section 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 predated 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. It involved reacting the granulated rubber 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-Asphalt Rubber

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 identical with 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**		
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**
Processed recycled paper	0.30		Hi-Tech Asphalt Solutions

Construction

The Special Provisions for the contract contains several items pertaining to the construction of the two special OGFC pavements. A brief description of these items is included in this section of the report as a guide to understanding the circumstances under which the sections were constructed. The 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. The crumb rubber was required to have a specific gravity of 1.15 ± 0.05 and be free of wire or other contaminating materials. The rubber could also not contain more than 0.5 percent fabric. Calcium carbonate could be added to prevent the particles from sticking together. The minimum amount of crumb rubber required in the mix was 20 percent by weight of the asphalt binder.

Table 3. Gradation requirement for crumb rubber.

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

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

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

OGFC-SBS Special Provisions

The asphalt binder for the OGFC-SBS was required to be a PG70-22 produced by adding SBS modifier to a 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 Limitations

Paving of the open-graded mixes could not occur unless air temperature was above 60°F. This is in contract 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

In order to pave the section as rapidly as possible with the shortest disruption to traffic, the entire roadway was closed off 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 beginning 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
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	1:00 pm		277, 280, 290
OGFC-AR	7/14/07	2:00 pm	Finished AR paving	
Class ½ Inch HMA	7/14/07	2:30 pm	Begin HMA paving	
Class ½ 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	2:30 am		287, 290, 292
OGFC-SBS	7/15/07	7:00 am	Finished SBS paving	

The paving operation is capture 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 report of the construction that includes infrared images is included as Appendix C.

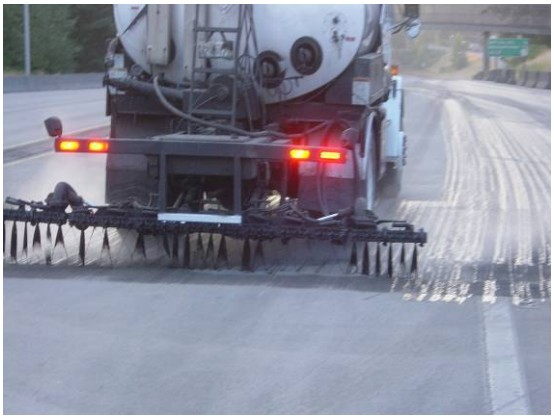

Figure 3. Distributor applying tack coat.

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.

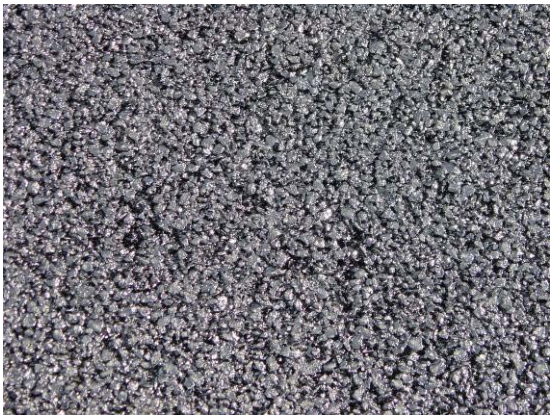

Figure 12. Close-up of OGFC-AR.

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 Eastside 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

Post-Construction Testing

Post-construction evaluation of the two sections of open-graded pavement and the control section of Class ½ inch HMA included measurements of friction, smoothness, rutting/wear and noise. This data will be collected throughout the life of the experiment as noted in the experimental feature work plan found in Appendix D.

Friction

Friction tests were performed with a ribbed tire using a locked-wheel friction tester meeting ASTM E-274 requirements. The friction number (FN) results are listed in Table 6 and plotted in Figure 15. The friction numbers are all in the acceptable category with the Class ½ inch HMA having the highest average for all lanes of 47.2. The average for all lanes of the OGFC-AR was 41.9 while the average for all lanes of the OGFC-SBS was slightly lower at 40.5.

Table 6. FN results from October 31, 2007

Section	Direction/Lane	Average FN	FN Range
OGFC-AR	EB/1	41.6	38.9 – 47.2
OGFC-AR	EB/2	40.4	36.7 – 48.0
OGFC-AR	WB/HOV	41.1	39.8 – 42.7
OGFC-AR	WB/2	43.4	43.1 – 43.7
OGFC-AR	WB/3	41.1	40.3 – 41.7
OGFC-AR Average and Range		**41.9**	**36.7 – 48.0**
Class ½ inch HMA	EB/1	49.8	47.6 – 50.6
Class ½ inch HMA	EB/2	48.6	45.5 – 51.0
Class ½ inch HMA	WB/HOV	47.7	44.6 – 49.7
Class ½ inch HMA	WB/2	44.7	42.1 – 46.4
Class ½ inch HMA	WB/3	45.0	42.0 – 47.1
Class ½ inch HMA Average and Range		**47.2**	**42.0 – 51.0**
OGFC-SBS	EB/1	41.2	40.5 – 42.8
OGFC-SBS	EB/2	39.2	37.8 – 40.2
OGFC-SBS	WB/HOV	40.8	38.4 – 42.0
OGFC-SBS	WB/2	41.8	41.4 – 43.1
OGFC-SBS	WB/3	39.3	38.9 – 39.9
OGFC-SBS Average and Range		**40.5**	**37.8 – 43.1**

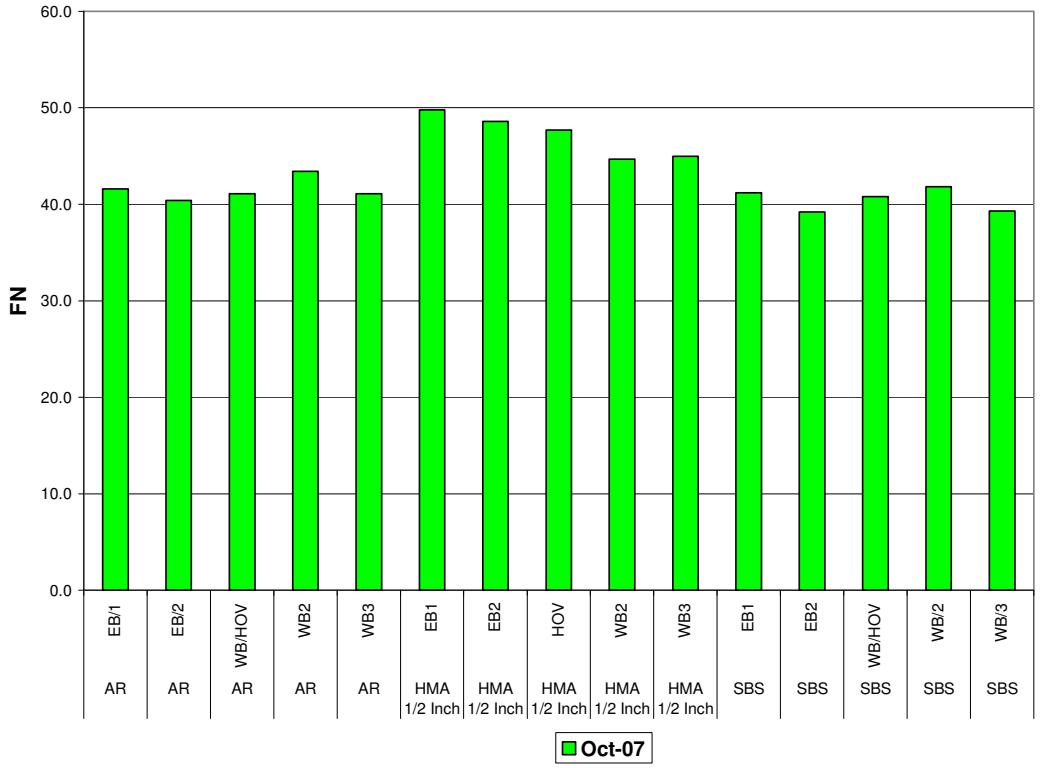

Figure 15. FN values from October 31, 2007.

Ride

Ride measurements were made prior to construction of the new surfaces on May 24 and immediately after construction on August 6 and again on October 23, 2007. Table 7 lists the ride measurements, International Roughness Index (IRI), for each lane in each direction. All measurements were made with WSDOT's Pathway Pavement Condition Collection Van.

Table 7. IRI measurements.

Pavement Type	Direction/Lane	IRI (inches/mile)		
		May 24, 2007	August 6, 2007	October 23, 2007
OGFC-AR	EB/1	76	60	58
OGFC-AR	EB/2	65	56	57
OGFC-AR	WB/HOV	86	76	79
OGFC-AR	WB/2	49	50	49
OGFC-AR	WB/3	57	44	43
Class ½ inch HMA	EB/1	64	58	63
Class ½ inch HMA	EB/2	55	56	60
Class ½ inch HMA	WB/HOV	83	66	68
Class ½ inch HMA	WB/2	55	46	51
Class ½ inch HMA	WB/3	51	46	51
OGFC-SBS	EB/1	66	48	50
OGFC-SBS	EB/2	60	46	47
OGFC-SBS	WB/HOV	63	78	81
OGFC-SBS	WB/2	56	52	52
OGFC-SBS	WB/3	47	43	41

The ride improved on most of the lanes with the new overlays. In some cases it remained the same and in two cases it got slightly worse. The trend of the ride readings can be seen in Figure 16 which plots the three sets of readings listed in Table 7.

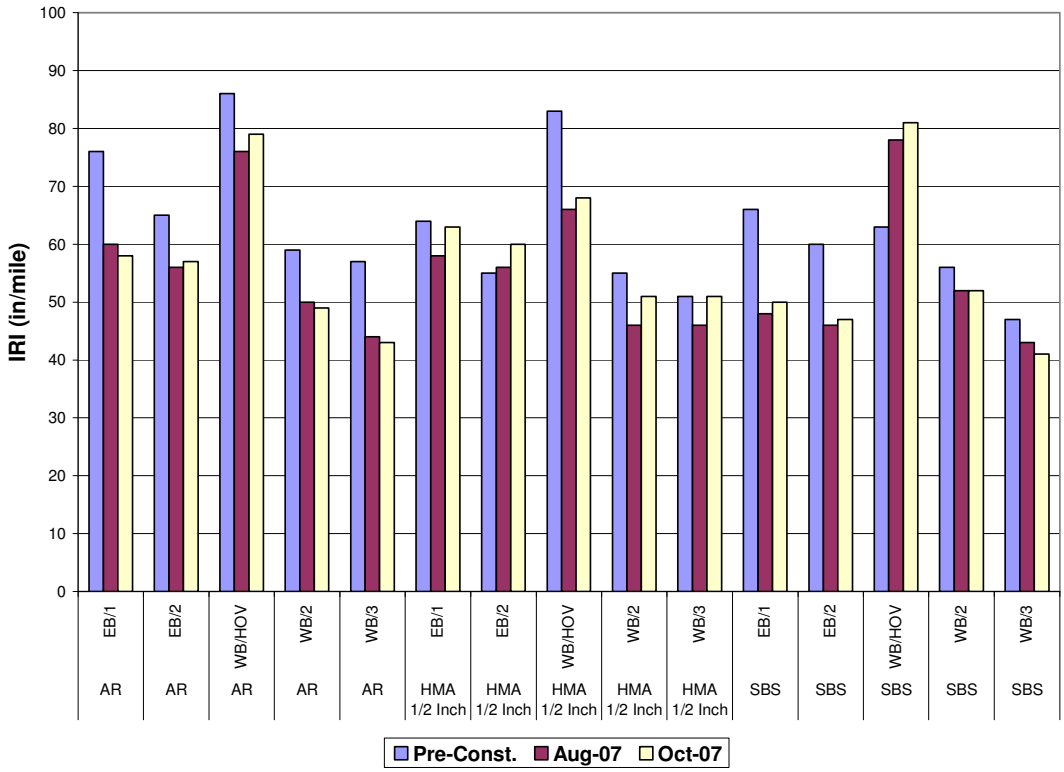

Figure 16. IRI measurements pre-construction, August and October 2007.

Wear/Rutting

The transverse profile measurements, which indicate the wear or rutting in the wheel paths, are listed in Table 8 and shown graphically in Figure 17. The decrease in wear/rutting provided by the new surface is quite evident as the average for all lanes decreased from 5.8 mm prior to construction to 1.6 mm in the most recent measurement. The wear/rutting in the westbound Lane 2 for all three sections is greater than any of the other lanes which may indicate that the wear/rutting of the existing pavement may be reflecting through the overlay. The data was collected using the WSDOT's Pathway Pavement Condition Collection Van at the same time that the ride data was collected.

Table 8. Wear/rutting measurements.

Pavement Type	Direction/Lane	IRI (inches/mile)		
		May 24, 2007	August 6, 2007	October 23, 2007
OGFC-AR	EB/1	4.9	1.4	1.4
OGFC-AR	EB/2	7.1	1.6	1.6
OGFC-AR	WB/HOV	7.8	1.1	1.3
OGFC-AR	WB/2	7.4	1.6	1.9
OGFC-AR	WB/3	3.0	1.3	1.5
Class ½ inch HMA	EB/1	4.6	1.1	1.1
Class ½ inch HMA	EB/2	6.2	1.2	1.3
Class ½ inch HMA	WB/HOV	7.1	1.2	1.4
Class ½ inch HMA	WB/2	7.0	1.9	2.3
Class ½ inch HMA	WB/3	2.8	1.7	1.9
OGFC-SBS	EB/1	4.6	1.4	1.4
OGFC-SBS	EB/2	6.8	1.7	1.8
OGFC-SBS	WB/HOV	7.1	1.4	1.5
OGFC-SBS	WB/2	8.2	2.5	2.5
OGFC-SBS	WB/3	2.8	1.5	1.6

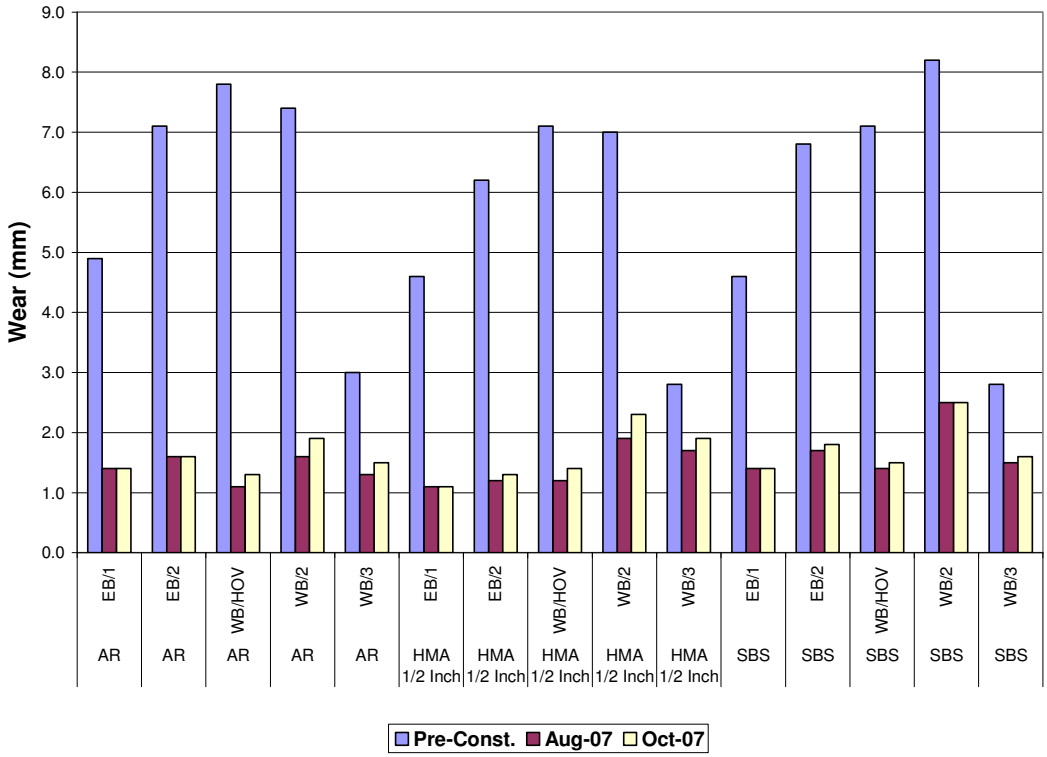

Figure 17. Wear/rutting measurements.

Noise

Sound intensity measurements were made using the On Board Sound Intensity method. Table 9 lists the measurements made on the OGFC-AR section and Figure 18 plots them on a bar chart. The noise level on the OGFC-AR has gradually increased since completion of the paving.

Table 9. Sound intensity measurements (dBA) for the OGFC-AR.

Date	L1 EB	L2 EB	HOV WB	L2 WB	L3 WB	Average
July 25, 2007	96.5	97.0	97.0	95.2	95.0	96.1
August 9, 2007	96.3	97.0	97.8	95.3	95.4	96.3
September 18, 2007	98.3	97.7	98.1	97.6	96.4	97.6
October 26, 2007	98.2	97.7	98.4	97.7	97.3	97.9
December 7, 2007	98.3	97.9	100.3	97.1	97.5	98.2

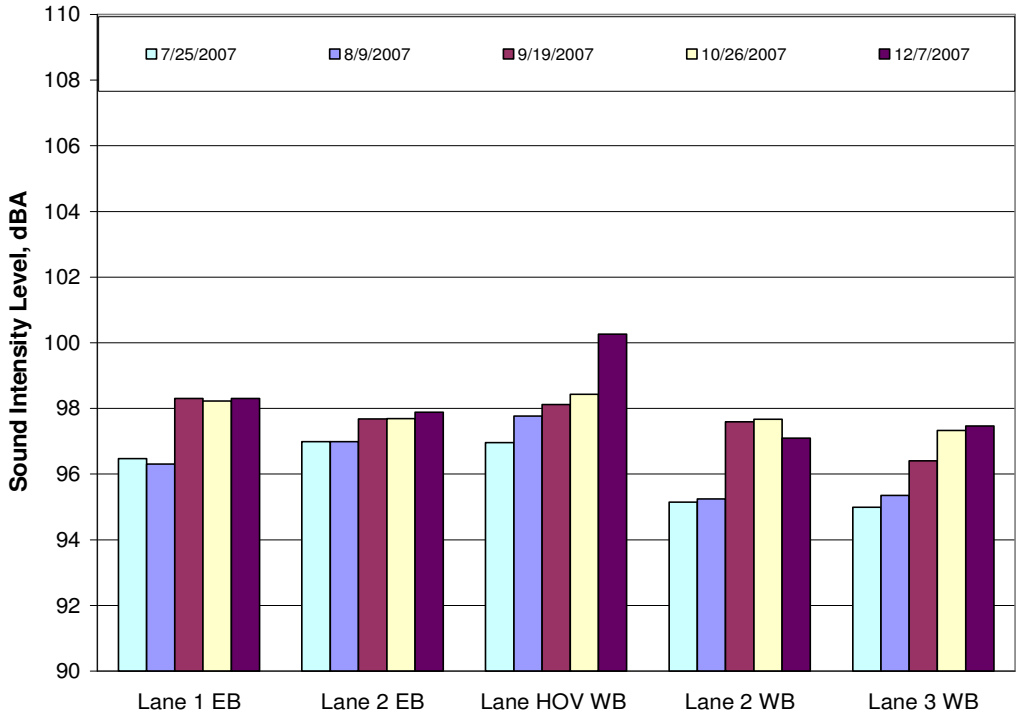

Figure 18. Sound intensity level (dBA) measurements for OGFC-AR section.

Table 10 lists the sound intensity measurements for the OGFC-SBS section. Figure 19 shows that the noise level of the OGFC-SBS section has increased and then decreased over time as contrasted with the OGFC-AR section which has shown only a gradual increase over time.

Table 10. Sound intensity measurements (dBA) for the OGFC-SBS

Date	L1 EB	L2 EB	HOV WB	L2 WB	L3 WB	Average
July 25, 2007	97.6	96.7	99.5	98.2	96.9	97.8
August 9, 2007	98.6	98.4	99.7	100.0	98.6	99.1
September 18, 2007	100.8	100.4	100.6	100.5	99.8	100.4
October 26, 2007	100.5	99.0	101.4	101.1	99.2	100.2
December 7, 2007	100.2	97.8	100.6	99.1	97.8	99.1

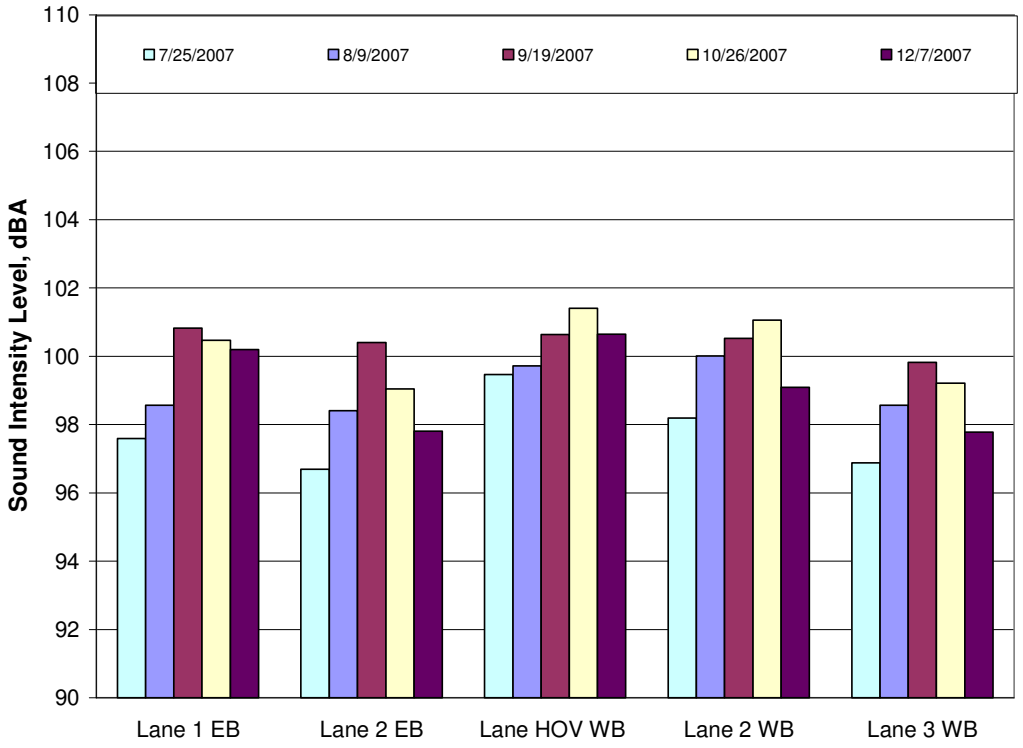

Figure 19. Sound intensity level (dBA) measurements for the OGFC-SBS section.

Table 11 lists the sound intensity level measurement for the control section of Class ½ inch HMA. Figure 20 shows that the levels are mimicking the pattern of the OGFC-SBS with and increase and then a decrease over time for each lane.

Table 11. Sound intensity measurements for Class ½ inch HMA.

Date	L1 EB	L2 EB	HOV WB	L2 WB	L3 WB	Average
July 25, 2007	99.5	99.4	100.0	100.1	N/A	99.8
August 9, 2007	99.2	99.1	100.7	101.0	100.5	100.1
September 18, 2007	101.4	101.1	102.3	102.5	102.3	101.9
October 26, 2007	101.4	101.0	102.6	102.7	102.1	102.0
December 7, 2007	101.2	100.7	102.3	102.0	101.3	101.5

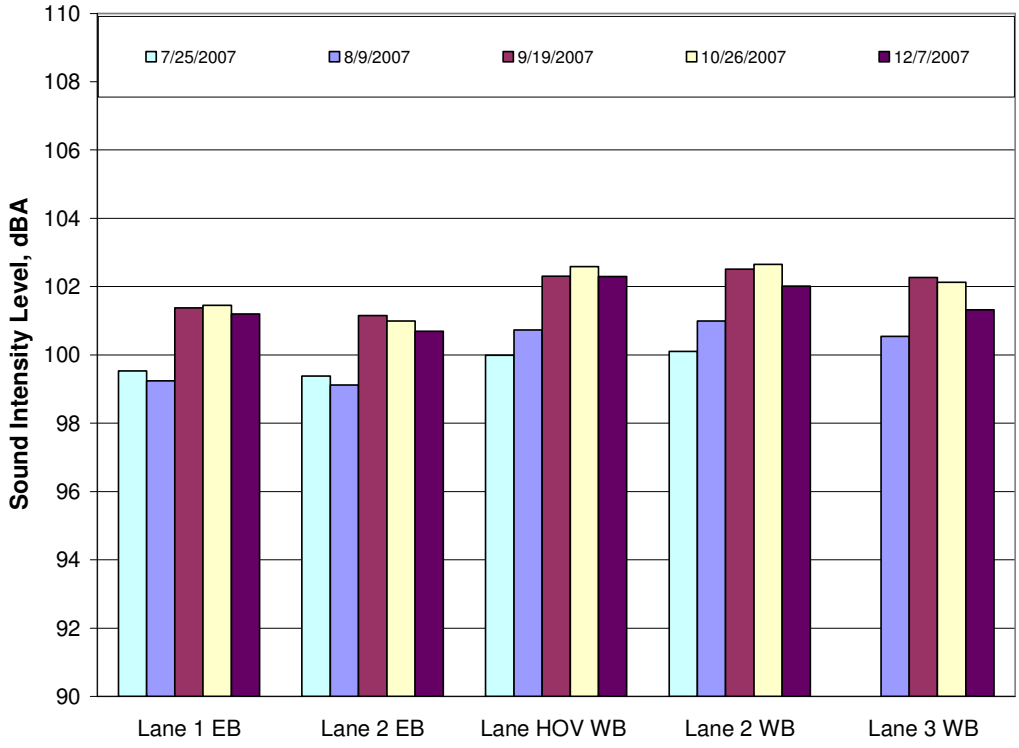

Figure 20. Sound intensity level (dBA) measurements for the Class ½ inch HMA section.

A comparison of the December OBSI readings is shown in Table 12. It reveals that the asphalt rubber section is currently doing the best job of mitigating noise. The average sound intensity reading on the OGFC-AR section for the most current set of measurements (98.2 dBA) is 3.3 dBA lower than the average for the control section (101.5 dBA) and 0.9 dBA lower than the average for the SBS section (99.1 dBA).

Table 12. December 2007 OBSI readings for each section.

Section	L1 EB	L2 EB	HOV WB	L2 WB	L3 WB	Average
OGFC-AR	98.3	97.9	100.3	97.1	97.5	98.2
OGFC-SBS	100.2	97.8	100.6	99.1	97.8	99.1
Class ½ inch HMA	101.2	100.7	102.3	102.0	101.3	101.5

The sound intensity levels measured immediately after construction are higher for all three types of pavement on this project than on the Lynnwood project as can be seen in Table 13 and Figure 21. A discussion of the probable causes for the higher readings is contained in the following section of the report.

Table 13. Comparison of average sound intensity levels immediately after construction.

Pavement Type	I-5, Lynnwood	SR-520, Eastside	Difference
OGFC-AR	95.0	96.1	+1.1
OGFC-SBS	96.0	97.8	+1.8
Class ½ inch HMA	98.8	99.8	+1.0

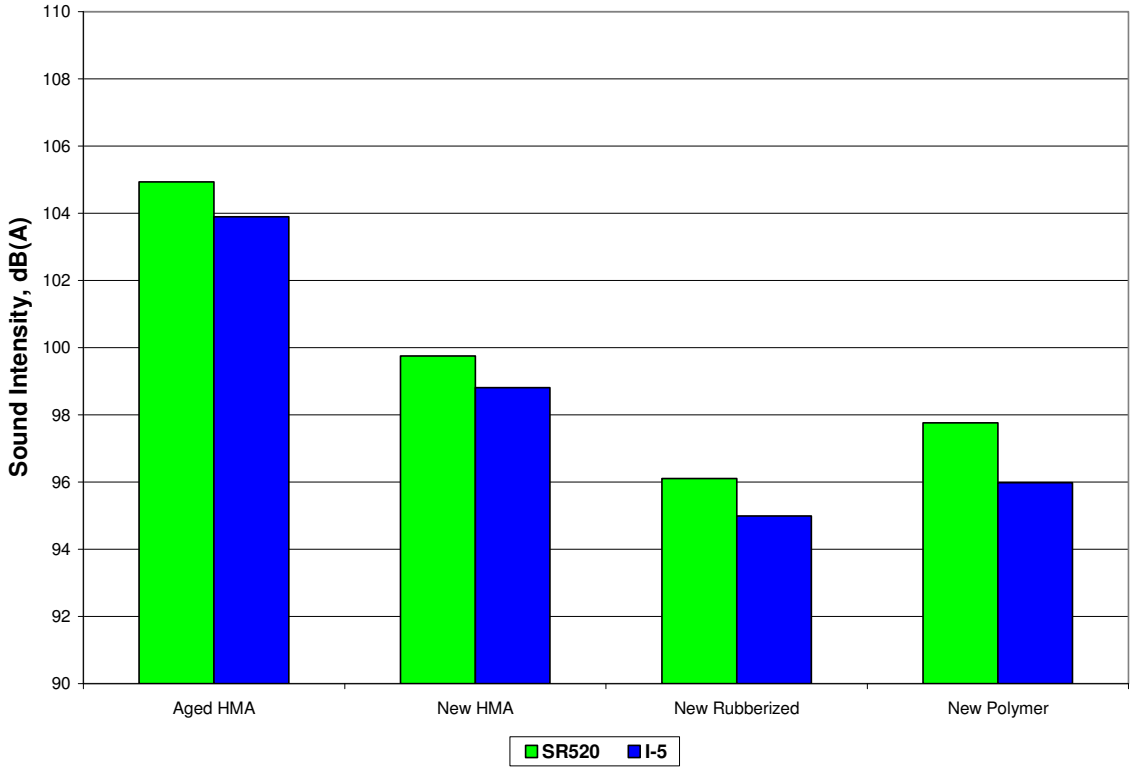

Figure 21. Comparison of sound intensity levels immediately after construction.

Discussion of Results

Several observations can be made in comparing the results from this project to the previous open-graded project done in 2006 on I-5 near Lynnwood, Washington (Anderson et al., 2008). The initial sound intensity level measurements for this project follow the same pattern as the Lynnwood project with the AR section having the lowest OBSI readings, the SBS next and the HMA the highest (note that on the Lynnwood project the SBS section has seen less deterioration over time and is, as of the publication date of this report, quieter than the AR section). It should be noted that the SR-520 readings are between one and almost two dBA higher than the Lynnwood project with the largest difference occurred on the SBS section with a difference of 1.8 dBA between initial readings on the two projects.

There were minor differences between the two projects even though the same contractor was used and essentially used the same equipment to produce the mix and pave each of the sections. The OGRC-SBS had the largest difference in the mix design asphalt content (8.3 percent for I-5 versus 8.8 percent for SR-520). Perhaps the higher asphalt content resulted in a pavement surface that was lower in voids than the I-5 project, or perhaps the over rolling noted by those observing the construction of the SR-520 project worked in concert with the higher asphalt content to decrease surface voids. It is probably not profitable to spend a great deal of time or energy trying to find the cause or causes for the difference noted in the sound intensity levels between the two projects. It is sufficient to state that there was a difference in the initial readings following construction.

Conclusions

The special test sections of OGFC-AR and OGFC-SBS were constructed, from all indications, according to the specifications. The use of an MTV insured that the mix going into the paving machine was uniform in temperature and as a result no significant temperature differentials were observed in the mat behind the paver. Post-construction testing confirmed that the pavement placed was up to standards and suitable for the long-term evaluation of the noise mitigating properties of the two types of open-graded pavements placed.

The primary observations that can be made from the data currently available are:

- The sound intensity levels for the OGFC-AR, OGFC-SBS and Class ½ inch HMA have increased with time since construction.
- The sound intensity levels for the OGFC-AR have been consistently lower than the readings for the OGFC-SBS and Class ½ inch HMA.
- The sound intensity level readings immediately after construction for all of the sections on SR-520 were higher than the initial readings on the I-5 Lynnwood project.

Future Research

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

References

Anderson, K., Pierce, L., Uhlmeyer, J., Weston, J. (2008). *Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses.* Washington State Department of Transportation. Available at: http://www.wsdot.wa.gov/biz/mats/pavement/LongTermPavementPerformance.pdf

Appendix A

Mix Designs

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

TEST OF: OPEN GRADED FRICTION COARSE (OGFC)
DATE SAMPLED: 6/18/2007
DATE RECVD HQS: 6/21/2007
SR NO: 520
SECTION: EASTSIDE QUIETER PAVEMENT EVALUATION PROJECT

WORK ORDER NO: 007353
LAB ID NO 0000333958
TRANSMITTAL NO: 333958
MIX ID NO: G71900
CONTRACTOR: WILDER

CONTRACTOR'S PROPOSAL

Mat'l:	3/8" CHIPS	#4-0	#4 - #8 SAND	COMBINED	SPECIFICATIONS
Source:	B-335	B-335	B-335		
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

VALID FOR 2007

LABORATORY ANALYSIS — SPECIFICATIONS

ASPH% BY TOTAL 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	82.0 Max.
Draindown @ 339°F	0.0	0.0	0.1	0.3 Max.
Stabilizing Additive	0.3	0.3	0.3	0.2 – 0.5
Gmm – MAX S. G. FROM RICE	2.432	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	

CONTRACT 7353 ONLY

LOTTMAN STRIPPING EVALUATION

% ANTI-STRIP	0.0%	1/4 %	1/2 %	3/4 %	1.0%
Visual Appearance:	MODERATE	NONE	NONE	NONE	NONE
% Retained Strength:	58	88	98	73	83

RECOMMENDATIONS

SUPPLIER	U.S. OIL
GRADE	PG70-22
% ASPHALT (BY TOTAL MIX)	8.8
% ANTI-STRIP (BY WT. ASPHALT)	0.25
TYPE OF ANTI-STRIP	ARR-MAZ 6500
MIX ID NUMBER	G71900
MIXING TEMPERATURE	346°F
COMPACTION TEMPERATURE	317°F

AGGREGATE TEST DATA

TEST	VALUE	SPECIFICATIONS
FRACTURE	100	85 Min. (2 FACES)
SAND EQUIVALENT	68	45 Min.

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

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

REMARKS:

THOMAS E. BAKER, P.E.
Materials Engineer
By: Joseph R. DeVol
(360)709-5421
Date: 7 / 13 / 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 COARSE AR (OGFC-AR)
DATE SAMPLED: 6/18/2007
DATE RECVD HQS: 6/19/2007
SR NO: 520
SECTION: EASTSIDE QUIETER PAVEMENT EVALUATION PROJECT

WORK ORDER NO: 007353
LAB ID NO 0000333961
TRANSMITTAL NO: 333961
MIX ID NO: G71903
CONTRACTOR: WILDER

CONTRACTOR'S PROPOSAL

Mat'l:	3/8" CHIPS	#4-0	#4 - #8 SAND	COMBINED	SPECIFICATIONS
Source:	B-335	B-335	B-335		
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

VALID FOR 2007

LABORATORY ANALYSIS

		SPECIFICATIONS
L.A. ABRASION % @ 500 REVOLUTIONS*	16	40 MAX
SAND EQUIVALENT (AZ 242)	55	45 MIN.
FRACTURE, % (2 FACES) (AZ 212)	94	85 MIN.
FLAKINESS INDEX, % (AZ 238)	3.8	25 MAX
CARBONATES, % (AZ 238)	14	30 MAX
COMBNED SPECIFIC GRAVITY (AZ 210)	2.653	2.350 – 2.850
COMBINED WATER ABSORPTION, % (AZ 814)	1.28	2.50 MAX
Pba-ASPHALT ABSORPTION	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	

CONTRACT 7353 ONLY

RECOMMENDATIONS

SUPPLIER	PARAMOUNT RB	CRUMB RUBBER MODIFIER TYPE	B
GRADE	PG64-22	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	325°F		
COMPACTION TEMPERATURE	317°F		

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

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

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

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 °F; pascal seconds	1.5 - 4.0
Penetration: 39.2 °F, 200 g, 60 sec. (ASTM D 5); minimum	15
Softening Point: (ASTM D 36); °F, minimum	130
Resilience: 77 °F (ASTM D 5329); %, minimum	25

The viscotester used must be correlated to a Rion (formerly Haake) Model VT-04 viscotester using the No. 1 Rotor. The Rion viscotester rotor, while in the off position, shall be completely immersed in the binder at a temperature from 350 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 in³ (6 mm³) max.
2.	Asphalt:	25 - 80 pen.

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

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

Acceptance Sampling and Testing – HMA Mixture

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

Comments on Construction of Open-Graded Pavements

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.

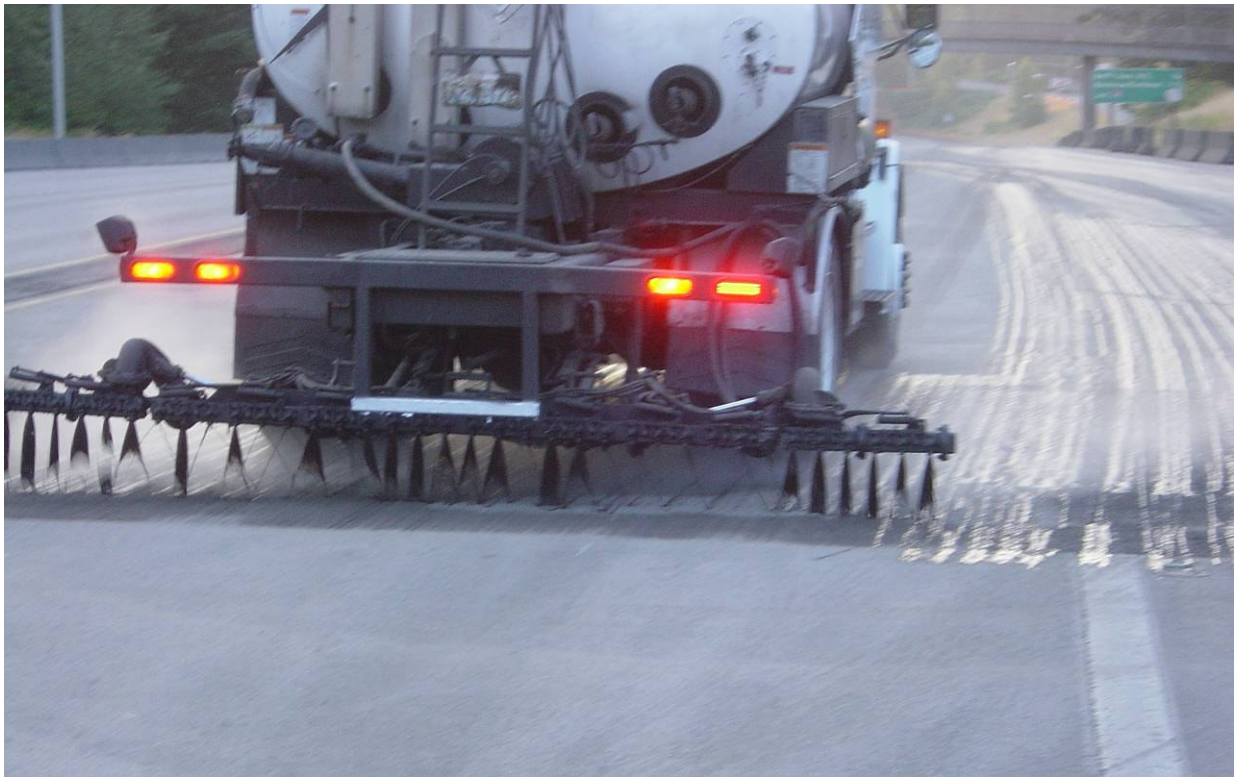

Figure 22. Image of typical tack application with some pickup visible in the wheelpaths.

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.

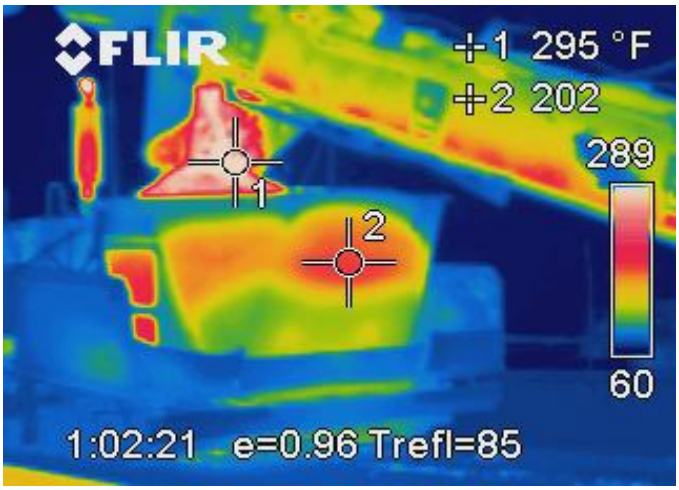

Figure 23. Thermal image of the mix as it leaves the SB and enters the paver hopper at 295 ° F.

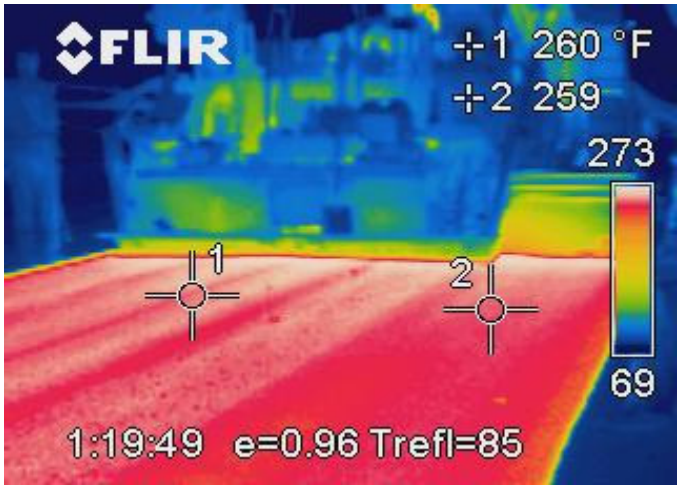

Figure 24. Image looking towards the paver from behind the screed.

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

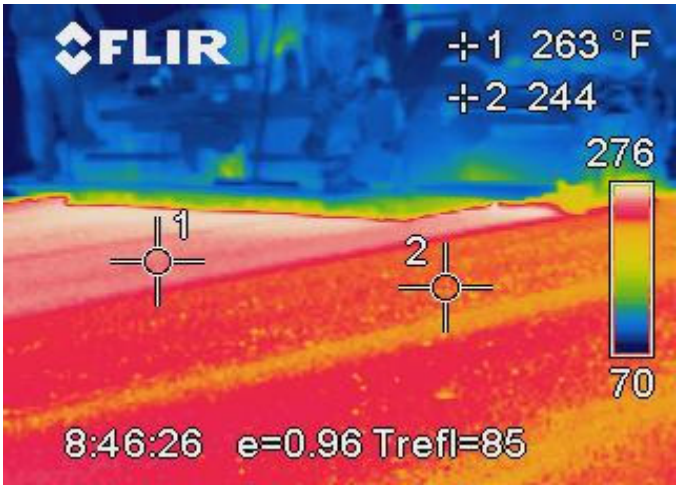

Figure 26. Streaking OGFC of first paver (spot 2) and the consistent mat behind second paver (spot 1).

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 27. 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 28. 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 29. 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.

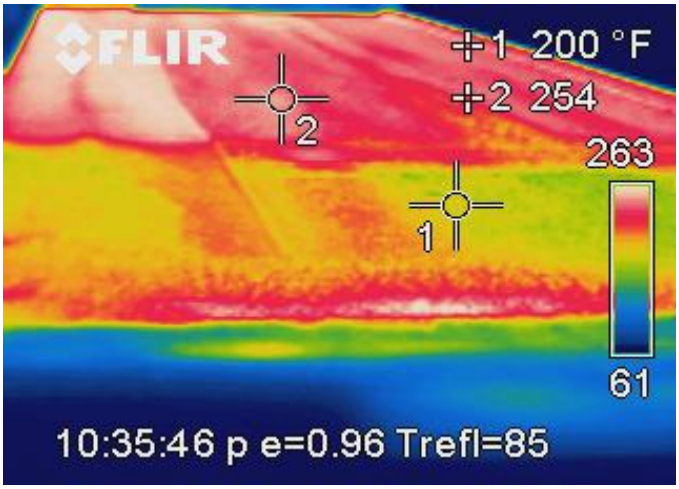

Figure 30. Thermal image of construction joint at startup

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 265º F. 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

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