2022 Summary of Special Pavement Test Sections

WA-RD 919.1

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September 2022

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Special Project Report

2022 Summary of Special Pavement Test Sections

Various Projects Statewide

Washington State Department of Transportation

Construction Division - Pavement Office

September 2022

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2022 Summary of Special Pavement Test Sections

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The State of Washington
Department of Transportation

Roger Millar, Secretary

September 2022

Special Project Report

. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 919.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
2022 Summary of Special Pavement Test Sections	September 2022
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Jeff Uhlmeyer, Mark Russell, Keith Anderson, Kim Schofield, Joe Mahoney, Kyler Carlson, Jianhua Li, Kevin Littleton	
. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Washington State Department of Transportation Materials Laboratory, MS-47365 Olympia, WA 98504-7365	11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Research Office	Special Report 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

WSDOT continued to collect rutting/wear and smoothness information on a number of completed studies. This report summarizes those studies.

- **Open Graded Friction Courses:** OGFC-AR on I-405 was more susceptible to wear than either OGFC-SBS or HMA matching the pattern seen in the I-5 and SR-520 quieter pavement test sections.
- **Concrete Performance and Wear**
  - The I-82 next generation concrete surface (NGCS) sections are showing slightly more wear than the adjacent diamond ground PCC pavement after nine years of traffic.
  - The longitudinal tining section on I-90 is currently showing slightly more wear than the adjacent diamond ground concrete; however, the difference is insignificant given the higher traffic on the longitudinal tined section.
  - The wear on the I-90 polyester polymer concrete is similar but slightly higher than wear in the adjacent diamond ground concrete after seven years of traffic.
  - The higher design flexural strength mixes for the SR-395 SPS-2 rigid pavement sections were the most resistant to studded tire wear. PCC paved on permeable asphalt treated base or dense graded aggregate base exhibited the best performance over lean concrete base.
  - The I-90 Argonne to Sullivan Road project results have some similarities to the sections on SR-395. The I-90 Lanes 1 and 3 (which had lower traffic) results are similar but a bit higher than the wear rates associated with the lower strength sections on SR-395. For the high traffic I-90 Lane 2, the range is higher due to the higher studded tire traffic.

The findings in this report continue to influence policy decisions that are documented in WSDOT's Pavement Policy.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Rutting, wear, smoothness, pavement, concrete pavement, surface tining, polyester polymer, flexural strength, studded tire, performance, open graded friction course, Washington state	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	55	

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I-405 Quieter Pavements Test Section Performance

The quieter pavement projects were built to determine the noise levels associated with open-graded friction course (OGFC) pavements and their longevity. The OGFC pavements project included test sections on I-5, SR-520 and I-405. Each project consisted of a test section constructed with an asphalt rubber binder (OGFC-AR) and another constructed with a styrene butadiene styrene modified binder (OGFC-SBS). The OGFC-AR and OGFC-SBS sections were initially audibly quieter than control sections of dense-graded HMA, but that benefit lasted less than one year on all three of the project locations.

The OGFC-AR section was more susceptible to rutting/wear than either the OGFC-SBS or HMA matching the pattern on the I-5 and SR-520 test sections. The I-405 quieter pavements lasted four years longer than the I-5 and SR-520 before the underlying pavement was exposed (due to greater initial pavement thickness and the absence of significant adverse winter weather that shortened the life of the I-5 and SR-520 sections). The smoothness measurements mimic the wear measurements with the OGFC-AR having the highest Mean Roughness Index (MRI, inches/mile) followed by the OGFC-SBS and the HMA with the lowest due to the raveling that took place.

I-82 Next Generation Concrete Surface Test Section Performance

A 0.30-mile section of I-82 was converted to the next generation concrete surface (NGCS) profile by diamond grinding in October of 2010 as part of efforts to produce quieter pavements. The concrete pavement west of the NGCS was conventional diamond ground (CDG) and serves as the control section for the NGCS. The noise levels on the NGCS were initially quieter, but within 7 months increased to match the levels of the adjacent CDG pavement.

Wheel path wear is the primary concern of the ongoing study. The NGCS has slightly more than 6.5 mm of wear after eight and a half years of traffic. The wear on the conventional diamond grinding is similar at 5.9 mm. The smoothness measurements have remained consistent for the CDG section but took a dramatic drop in 2014 for the NGCS section due to WSDOT implementing the use of a transverse line laser in lieu of the previous single point laser.

I-90 Cle Elum Longitudinal Tining and Conventional Diamond Grinding Performance

Following seven years of measurements, the purpose of this I-90 study was to compare the wear and smoothness measurements of longitudinal tining to conventional diamond grinding. The outside travel lane of I-90 near Cle Elum was rebuilt and finished with longitudinal tining. The inside passing lane received dowel bar retrofitting and conventional diamond grinding to remove stud wear and faulting. The wear on the longitudinal tining is slightly higher than the diamond ground section after seven years of traffic at 5.6 mm (0.80 mm/year) and 4.8 mm (0.68 mm/year), respectively (these wear rates are similar to those reported for I-90 in Spokane). The higher amount of wear on the longitudinal tining section is likely due to the higher traffic volumes on the outside travel lane. The smoothness on the diamond ground section was generally smoother than the longitudinal tined section.

I-90 Polyester Concrete Rut Fill Test Section Performance

Polyester polymer concrete (PPC) was used in a trial application to determine its possible use as a rut filling solution for studded tire wear on concrete pavements. In July of 2012 the polyester polymer concrete was used to fill the wheel path ruts on 180 feet of the west bound lanes of I-90 west of Spokane. The adjacent section of concrete was diamond ground to remove wear at the same time as the application of the PPC.

Similar wear was measured in the PPC section as compared to the adjacent conventional diamond ground concrete (CDG) with 7.8 mm in Lane 1 of the PPC and 7.3 mm in Lane 1 for the diamond ground concrete after 85 months. Wear rates were also calculated using linear regression resulted in estimated wear rates of 0.94 mm/year for Lane 1 of the PPC and 0.58 mm/year for the CDG. Several years of data collection and analysis will be necessary to determine if current trends continue.

The footprint of the three polyester polymer concrete sections has not changed since they were placed with no spalling noted at joints or along edges. The MRI on the polyester polymer concrete (95 inches per mile) is about double that of the adjacent diamond ground concrete (58 inches per mile).

SR-395 LTPP Special Pavement Study Performance (SPS-2)

The primary purpose of this experiment was to study the structural factors of rigid pavement and pavement wear. The SPS-2 PCC test sections were paved during September of 1995 from northbound MP 91.70 to 93.50. Three PCC mix designs were used for the 13 sections, each 500 feet in length. The sections were built with three design flexural strengths, 550, 650 and 900 psi. The pavement thickness and the depth and type of base were also varied. All sections received a transverse tined finish. The tined finish is completely worn off in the sections with the lower flexural strength (550 and 650). All the sections with the lean concrete base, regardless of pavement thickness or flexural strength, have the highest amount of cracking. Two of the sections with the least concrete and base depths (8” PCC and 6” dense graded aggregate base (DGAB)) have transverse cracking (530202 and 530201). The one section with WSDOT’s standard 650 psi flexural strength concrete and the thinnest total section thickness outperformed the other sections with respect to cracking. The sections with 900 psi flexural strength had the least amount of wear after 24 years of traffic. The maximum average wear measured in 2019 is 9.1 mm on test section 530201 with 550 psi flexural strength design. A rate of wear of 0.38 mm per year wear for the 550 psi flexural strength section suggests that it will be 12.5 mm following 33 years of service.

I-90, Argonne Road to Sullivan Road, Studded Tire Resistant Concrete Pavement

The project located on I-90 between Argonne Road and Sullivan Road was built with a number of different concrete mix designs and texturing methods to test if any of these designs or texturing methods could produce a studded tire resistant pavement. The findings of this study showed that except for the transverse tined surface texture, the type of mix design (650 psi flexural strength, 800 psi flexural strength, and 925 lbs. cement/cubic yard of concrete) and other features such as carpet drag texture or use of a concrete hardener did not make a significant difference in the studded tire wear for the test sections. Broadly speaking, the long-term trends for the lower traffic lanes (Lanes 1 and 3) wear rates are about 0.40 mm/year and for the Lane 2 (the high traffic lane) the rates range between 0.72 to 1.17 mm/year. Based on the 12.5 mm limit for WSDOT rehabilitation practices, wear-related lives of about 30 years can be expected for Lanes 1 and 3 and 11 to 17 years for the Lane 2.

Study Findings and Support of WSDOT Pavement Design Policies

The relationship between the current WSDOT Pavement Policy used for pavement design and the long-term studies documented in this report are noted below:

- While past WSDOT studies have helped to identify studded tire wear rates and, broadly some best practices, an effective approach to reduce studded tire wear has not been found. All WSDOT pavements exposed to studded tires will exhibit wear.
- WSDOT can expect poor performance and high life cycle cost of open graded pavements used to provide quieter hot mix asphalt pavements. OGFC mixes should not be used by WSDOT on state highways as long as studded tires are allowed in the State of Washington.
- While the NGCS was initially quieter, within 7 months the noise quality rose to match that of the adjacent CDG section. With the same noise quality and associated lower construction costs, WSDOT's primary pavement texturing technique should remain as longitudinally tined pavement.
- Polyester polymer concrete (PPC) is an acceptable alternative to fill wheel path wear from concrete pavements when diamond grinding is not feasible. PPC has a high cost and must be diamond ground following placement to achieve an acceptable smoothness.
- The SR-395 SPS-2 study supports WSDOT's policy of requiring HMA base under all new concrete pavements and not allowing lean concrete for that purpose.
- Observations from the I-90 (Spokane) and SR 395 SPS-2 test sections do not support high strength concrete as a solution to studded tire wear. The current, standard specified strength for PCC is 650 psi. Consideration of constructability and increased strength versus cost is warranted going forward.
- Due to the concrete wear rate associated with the use of transverse tined concrete pavement, WSDOT should continue the agency's practice of utilizing longitudinally tined pavements.

Introduction

The purpose of this study is to report on the pavement wear and mean roughness index (MRI) for various Washington State Department of Transportation (WSDOT) experimental test sections across the state of Washington. Many of these test sections were built in the mid to late 2000's at a time when decisions were made to proceed with construction projects yet the actual pavement performance for those sections was not clear or known. The intent of this study is to report on pavement performance and validate WSDOT design decisions that have been accepted over the years for pavement design/pavement management practices particularly noted in WSDOT Pavement Policy (1).

Data Collection Methods

The wear and smoothness data analyzed in this study was collected using a Pathway Survey Van owned and operated by WSDOT. These data were automatically produced based on standardized calculations from longitudinal and transverse profiles collected from the van. For smoothness, WSDOT reports International Roughness Index (IRI) as Mean Roughness Index (MRI) which is the average value from both wheel paths. For wear, WSDOT used a single point laser before 2014 then switched to a transverse line laser which, in some instances, explains the offset in some of the collected data.

WSDOT calibrates its Pathway Survey Van every year per AASHTO R56 protocols to provide consistent data year after year. However, with variables such as different drivers, different tracking in the wheel paths, new equipment and differences with local calibrations, inconsistencies in data are sometimes observed.

While only six statewide test locations were studied, the data collected year after year and the results that followed are invaluable for WSDOT to understand smoothness and wear rates to make data driven decisions in the future.

I-405, Open Graded Friction Course Quieter Pavement

Study Design

The quieter pavement projects were built to determine if OGFC pavements could produce a quieter pavement than a conventional dense-graded HMA, and how long they would remain quieter. These pavements included test sections on I-5, SR-520 and I-405 (2).

Each project included test sections constructed with an asphalt rubber binder (OGFC-AR) and another constructed with a styrene butadiene styrene modified binder (OGFC-SBS). The OGFC-AR and OGFC-SBS sections were initially noticeably quieter than measurements on control sections of dense-graded HMA, but the reduced noise benefit only lasted for less than one year on all three of the projects.

The OGFC-AR and OGFC-SBS pavements were placed 3/4 inch thick on the I-5 and SR-520 test sections, but this was increased to 1 inch on the I-405 project. The I-5 and SR-520 sections were terminated due to excessive wear and raveling after only four years of service. A winter storm in 2009, with the use of studs, chains and snowplows, was a major contributor to the excessive raveling and wear noted on these two projects.

The 2009 I-405 project (3) was constructed after the winter of the severe storm and has survived to a current age of 114 months (9.5 years). Two test sections consisting of both OGFC-AR and OGFC-SBS; one south of I-90 (Figure 1) and one north (Figure 2). The control section of HMA was located south of the open-graded sections.

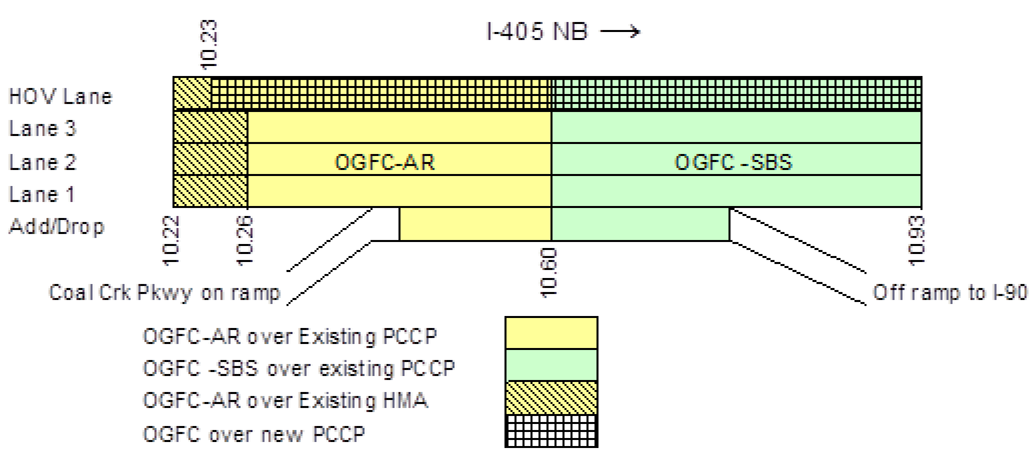


Figure 1. Location of open graded friction course sections on the south section.

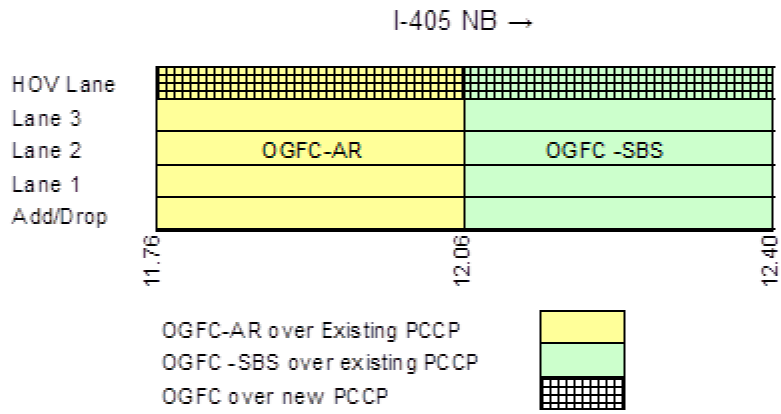


Figure 2. Location of open graded friction course sections on the north section.

Wear

The maximum average wear depth is in Lane 2 of the OGFC-AR pavement was 12.4 mm (1.24 mm/year), see Table 1. Not far behind at 12.1 mm (1.21 mm/year) is Lane 1 of the OGFC-AR. The maximum average wear depth in the OGFC-SBS section is 9.6 mm (0.96 mm/year) in Lane 2. The maximum average wear depth in the HMA is 8.1 mm (0.81 mm/year) for Lane 3. Video records show that the underlying concrete pavement is visible due to the wear in the wheel paths of Lane 2 of the OGFC-AR section. The underlying concrete is visible as small spots at the joints and in strips extending for several feet in either the left or right wheel path.

Table 1. Wear in millimeters for the I 405 OGFC AR, OGFC SBS and HMA sections

Section	Fall 2009	Spring 2010	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013	Fall 2013	Fall 2014	Spring 2016	Fall 2017	Winter 2019
AR HOV	1.8	1.8	2.5	2.1	2.2	6.8	2.2	3.0	3.6	3.4	3.8	4.4	5.5
AR L3	1.6	2.3	2.2	3.1	3.5	4.5	4.3	5.3	6.5	6.0	7.2	8.7	10.6
AR L2	1.8	2.6	2.7	4.1	4.4	6.0	5.2	7.0	7.5	7.4	8.9	10.0	12.4
AR L1	1.9	2.6	3.7	4.3	4.6	6.5	6.1	7.5	8.0	8.1	10.1	10.4	12.1
SBS HOV	1.5	1.6	2.3	1.9	2.0	2.4	2.0	2.8	3.2	3.1	3.2	3.2	4.7
SBS L3	1.5	2.2	2.1	2.8	3.3	4.2	3.9	4.4	5.4	5.1	6.3	7.1	8.6
SBS L2	1.6	2.3	2.1	3.3	3.6	4.9	4.6	5.5	6.0	5.9	6.9	8.0	9.6
SBS L1	1.9	2.3	2.9	3.5	3.3	4.6	4.6	5.4	5.7	5.6	6.6	7.5	8.6
HMA HOV	1.8	1.8	1.6	2.2	2.2	2.7	2.3	3.0	3.4	3.9	3.8	4.2	5.0
HMA L3	2.1	2.4	2.9	3.8	3.8	4.5	4.2	4.8	5.5	5.3	6.0	6.8	8.1
HMA L2	2.2	2.7	3.0	3.8	3.4	4.8	4.4	5.2	5.3	5.3	6.1	6.4	7.8
HMA L1	2.1	2.5	2.8	3.2	2.9	3.7	3.4	4.0	4.1	4.1	5.0	4.7	5.7
Age (mos.)	**3**	**9**	**14**	**20**	**26**	**33**	**39**	**45**	**58**	**76**	**83**	**96**	**114**

Table 2 lists the averages and wheel path maximum readings for the north and south sections of each lane. The highest average and maximums are in Lanes 1 and 2 of the north section of the OGFC-AR and OGFC-SBS. This does not line up with the WSPMS photos that show wear down to the underlying concrete in the south section of the OGFC-AR. The wear data indicates that either the overlay on the south section of the OGFC-AR was not 1 inch in depth or that excessive wear has occurred over the entire lane which would reduce the maximum wear readings.

Table 2. Average and maximum wear measurements for the I 405 OGFC AR, OGFC SBS and HMA sections

Section	Lane	Lane Average (mm)	LWP Maximum (mm)	RWP Maximum (mm)
OGFC-AR	1S	9.1	21.4	13.2
	2S	9.6	11.8	22.3
	3S	10.4	14.2	10.5
	HOVS	5.0	8.5	9.7
	1N	15.0	19.6	19.5
	2N	15.2	20.2	21.6
	3N	10.8	15.0	10.6
	HOVN	5.9	10.8	6.6
OGFC-SBS	1S	4.3	8.5	7.0
	2S	7.4	11.1	9.0
	3S	8.8	13.7	8.8
	HOVS	4.2	7.6	6.4
	1N	12.8	25.1	17.8
	2N	11.7	20.5	21.0
	3N	8.4	15.0	10.6
	HOVN	5.1	14.1	8.2
HMA	1	5.7	8.0	8.3
	2	7.8	11.8	8.8
	3	8.1	11.9	9.5
	HOV	5.0	7.3	7.7

Smoothness

The smoothness measurements expressed by Mean Roughness Index (MRI) are listed in Table 3. The smoothest surface was found to be HMA followed by the OGFC-SBS and then the OGFC-AR. The smoothness measurements on the OGFC-AR and OGFC-SBS increased gradually until 2013 and then dropped in 2015 when the new Pathway van came into service. From 2015 on, results from all three pavement types are fairly consistent.

Table 3. Smoothness measurements in MRI, inches per mile, for the I 405 OGFC AR, OGFC SBS and HMA sections.

Section	Fall 2009	Spr. 2010	Fall 2010	Spr. 2011	Fall 2011	Spr. 2012	Fall 2012	Spr. 2013	Fall 2015	Spr. 2016	Spr. 2017	Win. 2019
OGFC-AR	61	63	63	72	68	77	72	79	72	74	79	78
OGFC-SBS	55	58	58	63	59	63	64	67	61	63	60	65
HMA	45	47	47	49	48	49	48	50	48	49	49	49
Age (months)	**3**	**9**	**14**	**20**	**26**	**33**	**39**	**45**	**76**	**83**	**96**	**114**

I-82 Next Generation Concrete Surface

Study Design

In October 2010, a next generation concrete surface (NGCS) was constructed on a 0.30-mile section of I-82 as part of an effort to evaluate the NGCS as a quieter pavement (4). The concrete pavement west of the NGCS was given a conventional diamond ground (CDG) surface and serves as the control section for the NGCS (Figure 3). The noise levels on the NGCS were initially quieter than most concrete pavements, but within 7 months increased to the levels of the adjacent CDG pavement.

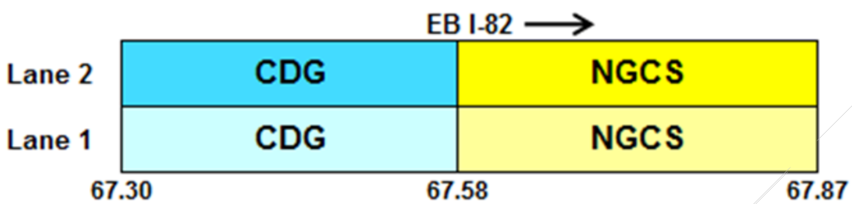


Figure 3. Location of diamond grinding and NGCS texturing on I-82.

Wear

The wear measurements in the travel lane (East Bound Lane 1) show an increase during the nine year study period for both the NGCS and CDG sections (see Table 4 and Figures 4 to 6). The amount of wear (Spring 2019 minus the Fall 2010 reading) on the travel lanes is minimal with 3.3 mm on Lane 1 of the NGCS and 1.7 mm on Lane 1 of the CDG. The Lane 2 wear is also minimal at 2.6 mm and 1.7 for the NGCS and CDG, respectively.

Table 4. Wear depths in millimeters for the I 82 NGCS and CDG.

Section	Dir./Lane	Fall 2010	Spr. 2011	Spr. 2012	Fall 2012	Spr. 2013	Spr. 2015	Fall 2016	Spr. 2017	Fall 2018	Spr. 2019
NGCS	EB1	3.2	3.7	4.9	3.9	4.5	4.5	5.6	5.7	6.8	6.5
NGCS	EB2	1.9	1.9	2.1	1.9	2.0	2.2	2.1	3.8	4.5	3.7
CDG*	EB1	4.2	4.5	4.4	4.4	4.7	4.4	5.4	5.6	6.1	5.9
CDG*	EB2	2.2	2.3	2.4	2.2	2.3	2.9	2.4	3.9	3.8	3.6
Age (months)		1	6	18	24	30	55	71	79	95	103

* Grinding took place in October 2010.

Figure 4. Transition between CDG foreground and NGCS background. Note slight spalling at the transverse joints. October 2017.

Figure 5. Note erosion of the edges of the land areas on the NGCS. October 2017.

Figure 6. Note erosion of the edges of the land areas on the NGCS and the greater wear on the dowel bar retrofit fill material. October 2017.

Smoothness

The smoothness measurements were very consistent from 2010 to 2013 and then took a dramatic drop in 2015 on the NGCS with the use of the new Pathway van (Table 5). The effect of the new van is clearly evident on the NGCS section with the change in WSDOT's line laser measurement technology, but not as much on the diamond ground section.

Table 5. Smoothness measurements in MRI, inches for mile, for the I 82 NGCS and CDG.

Section	Dir./Lane	Fall 2010	Spring 2011	Spring 2012	Fall 2012	Spring 2013	Spring 2015	Fall 2016	Spring 2017	Fall 2018	Spring 2019
NGCS	EB1	164	161	161	130	145	56	63	82	66	66
NGCS	EB2	110	112	121	116	129	42	41	46	39	38
CDG	EB1	97	71	66	67	72	67	63	74	73	73
CDG	EB2	76	53	51	52	49	46	44	47	45	51
Age (months)		1	6	18	24	30	55	71	79	95	103

I-90 Cle Elum Longitudinal Tining and Conventional Diamond Grinding

Study Design

The purpose of this study is to compare the wear and smoothness measurements of longitudinal tining to conventional diamond grinding. The west bound outside travel lane (Lane 1) of I-90 near Cle Elum was rebuilt and finished with longitudinal tining. The inside passing lane (Lane 2) received dowel bar retrofitting and conventional diamond grinding to remove rutting and faulting (Figure 7).

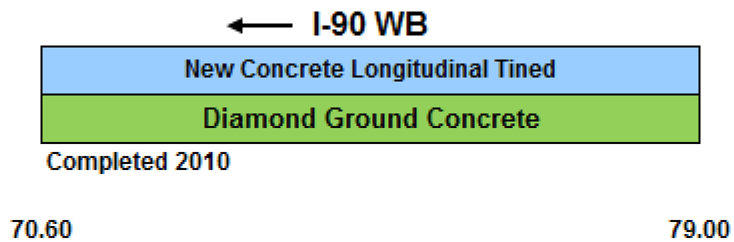


Figure 7. Location of new concrete with longitudinal tining on the outside travel lane and DBR concrete with diamond grinding on the inside passing lane.

Wear

The wear depth on the longitudinal tined sections remained fairly constant until the 2016 measurement when it increased 0.8 mm to 3.7 mm and then jumps again in 2019 to the current 5.6 mm depth see Table 6. The wear depth on the diamond ground sections remained fairly constant from 2013 to 2017 and then increased 0.8 mm in July 2018 to 5.0 mm and then decreases slightly in 2019 to the current reading of 4.8 mm.

Table 6. Wear depth measurements in millimeters for the I 90 Cle Elum diamond ground and longitudinal tined lanes.

Section	June 2013	Oct. 2013	Oct. 2015	Sept. 2016	May 2017	July 2018	June 2019
Longitudinal Tining Lane 1	2.8	2.8	2.9	3.7	4.1	4.2	5.6
Diamond Grinding Lane 2	4.0	3.9	3.8	4.1	4.2	5.0	4.8
Age (months)	9	14	38	49	57	71	82

Smoothness

The smoothness on the longitudinal tining section improved for three years and then became rougher in 2017 but remained the same in 2019 (Table 7). The smoothness on both sections has been fairly consistent in the 60's for the longitudinal tined section (except for the jump in 2017) and increased from the low 80's to the low 90's for the diamond ground section over 6 years.

Table 7. Smoothness measurements in MRI, inches per mile, for I 90 Cle Elum CDG and Longitudinal tining lanes.

Section	June 2013	Oct. 2013	Oct. 2015	Sept. 2016	May 2017	July 2018	June 2019
Longitudinal Tining Lane 1	82	68	65	62	79	63	63
Diamond Grinding Lane 2	91	81	79	81	89	88	90
Age (months)	9	14	38	49	57	71	82

I-90, Polyester Polymer Concrete Rut Fill and Diamond Ground Rigid Pavement

Study Design

Polyester polymer concrete was used in the trial application (5) to determine its possible use as a rut filling solution for studded tire wear on concrete pavements. In July of 2012 the polyester polymer concrete was used to fill the wheel path ruts on 180 feet of the west bound lanes of I-90 west of Spokane. The section is located at the end of the concrete pavement before it changes to HMA. The experimental use of the polyester rut fill was part of a project that did panel replacement and diamond grinding on all east bound and west bound lanes between the end of the concrete (Geiger Road vicinity to the Spokane Viaduct Bridge). A one-mile section east of the polyester concrete is being measured to represent the diamond grinding.

The polyester concrete was applied using three methods; (1) as a one inch inlay after grinding the existing concrete to a level profile, (2) as a one inch inlay of the ruts after the existing concrete was ground to a level profile, (3) as a patch just in the existing ruts using a hand screed (see Figure 8). The 60-foot length of the sections make them too short to separate into individual readings, therefore only one wear and one smoothness measurement are provided.

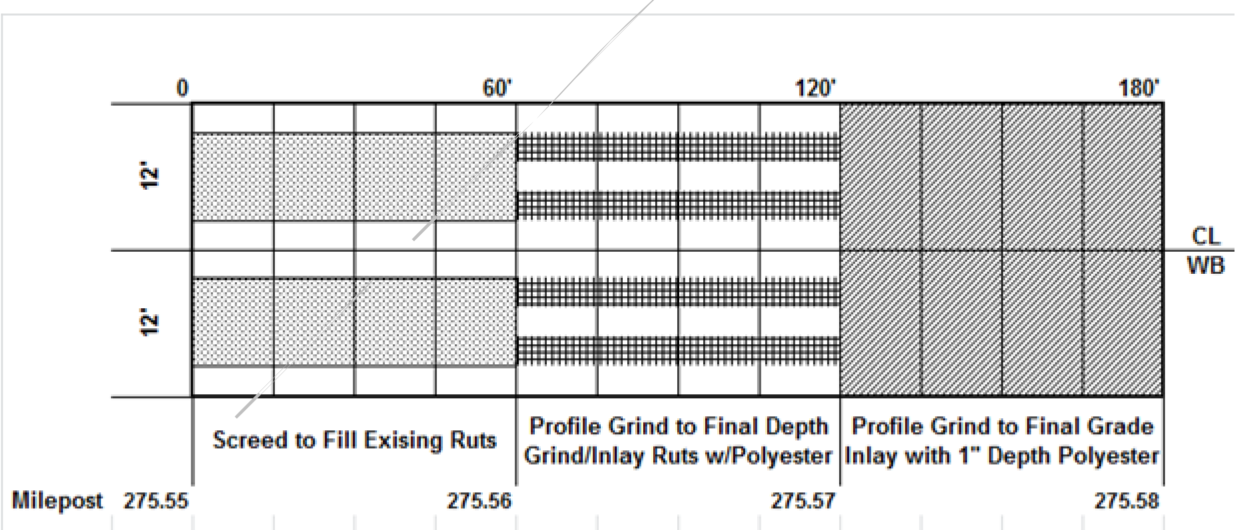


Figure 8. Plan map of the polyester test section.

Wear

The rut depths measured by WSDOT's ride van on the travel lane for both the polyester polymer and the diamond ground concrete were very similar for the 2019 measurements at 7.8 and 7.3 mm, respectively (see Table 8). The rut depth on the passing lane of the polyester polymer concrete was also higher at 6.3 mm as compared to the diamond ground concrete at 5.2 mm in 2019.

Table 8. Wear measurements in millimeters for the I 90 Spokane polyester concrete and diamond grinding sections. Project constructed in July of 2012.								
Section/Lane	**Spring 2013**	**Fall 2013**	**Fall 2014**	**Spring 2015**	**Fall 2016**	**Fall 2017**	**Fall 2018**	**Fall 2019**
Polyester Lane 1	3.0	2.8	2.9	3.6	6.4	7.4	7.4	7.8
Polyester Lane 2	2.0	2.5	2.6	3.0	2.4	5.1	5.1	6.3
Diamond Grinding Lane 1	4.0	4.3	4.0	4.7	5.8	6.2	7.2	7.3
Diamond Grinding Lane 2	3.0	3.2	3.6	3.3	3.4	4.3	4.4	5.2
Age (months)	9	15	26	33	50	62	73	85

Wear Rate

Wear rates for the PPC and Diamond Ground sections were estimated using the linear trendline of the wear depth versus time for the PPC and Diamond Ground sections (see Table 9). Figures 9 and 10 shows the plots for the average of both wheel paths in each lane for the PPC and Diamond Ground sections.

Table 9. Alternative method of calculating wear rates using the slope of the linear regression line.	
Section/Lane	**Wear Rate (mm/year)**
PPC Lane 1	0.94
PPC Lane 2	0.64
Diamond Ground Lane 1	0.58
Diamond Ground Lane 2	0.32

Based on the measurements taken the wear rates for each lane on the PPC test section are approximately 1.5 to 2 times that of the Diamond Ground test section. While the rate of wear is greater in the PPC, additional testing will determine whether the trend found in the first seven years remains the same.

Figure 9. Lane 1 wear measurements for the PPC and Diamond Ground sections. Wear rate per year is equal to 12 times the slope of the line.

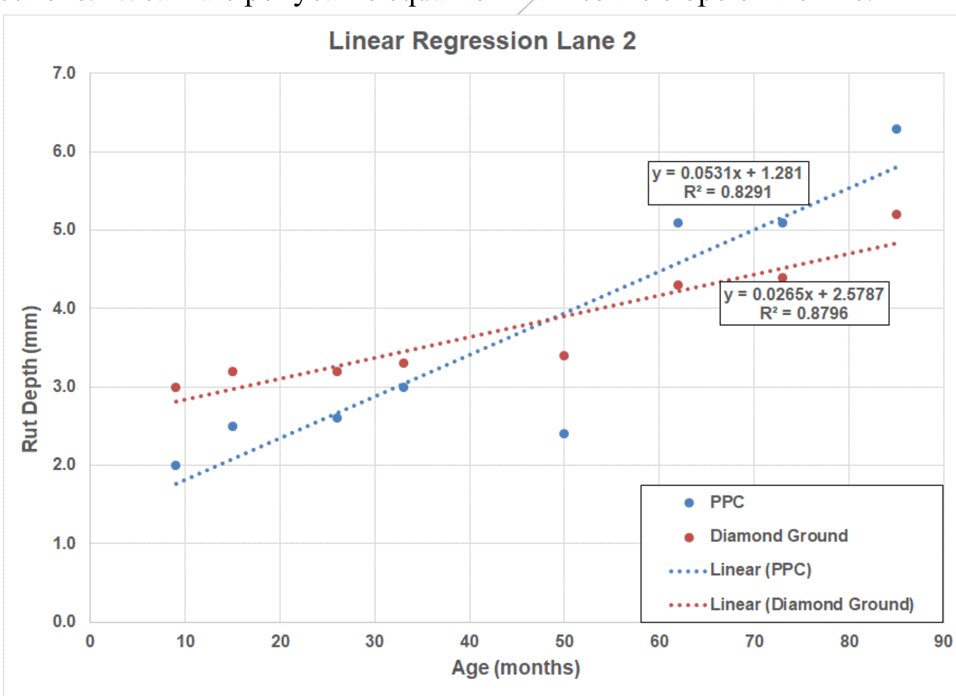


Figure 10. Lane 2 wear measurements for the PPC and Diamond Ground sections. Wear rate per year is equal to 12 times the slope of the line.

Pavement Condition Observations

Figure 11 contains photos from the WSPMS video taken in 2014 that show the three sections of the polyester concrete. Figure 12 shows the same three photos from the 2016 video and Figure 13 the 2018 video. The photos show no change in the footprints of the three sections with no spalling or erosion at the edges of the polyester concrete.

Figure 11. 2014 WSPMS views of the three polyester concrete sections. Top photo is of the screed to fill existing ruts, middle photo is the grind and inlay the wheel paths, and bottom photo is the grind and inlay entire lane.

Figure 12. 2016 WSPMS views of the three polyester concrete sections. Top photo is of the screed to fill existing ruts, middle photo is the grind and inlay the wheel paths, and bottom photo is the grind and inlay entire lane.

Figure 13. 2018 WSPMS views of the three polyester concrete sections. Top photo is of the screed to fill existing ruts, middle photo is the grind and inlay the wheel paths, and bottom photo is the grind and inlay entire lane.

Photos of the section were taken on September 27, 2017 (Figures 14-19). They show very little change in the condition of the polyester concrete with no delamination or cracking noted.

Figure 14. The full lane one inch inlay section of polyester concrete on I-90. (Sept. 2017)

Figure 15. The total lane, one inch inlay section of polyester concrete. (Sept. 2017)

Figure 16. The wheel path one inch inlay section of polyester concrete. (Sept. 2017)

Figure 17. The wheel path one inch inlay section. (September 2017)

Figure 18. The screed to fill section of polyester concrete. (September 2017)

Figure 19. The screed to fill section of polyester concrete. (September 2017)

Smoothness

The smoothness measurements are listed in Table 10. The smoothness on the polyester concrete section is erratic due to its short length which allows for only three measurements but is in general about twice as rough as the diamond ground concrete. The smoothness on the diamond ground concrete is reasonably smooth and has changed little over the study period.

Table 10. Smoothness measurements in MRI, inches per mile, for the I 90 Spokane polyester concrete and diamond grinding sections.

Section/Lane	Spring 2013	Fall 2013	Fall 2014	Spring 2015	Fall 2016	Fall 2017	Fall 2018	Fall 2019
Polyester Lane 1	72	68	84	101	126	124	120	95
Polyester Lane 2	58	54	120	64	119	124	60	78
Diamond Grinding Lane 1	59	54	41	57	47	52	53	58
Diamond Grinding Lane 2	47	44	45	49	43	48	49	55
Age (months)	9	15	26	34	50	62	73	85

SR-395, LTPP Specific Pavement Studies (SPS-2)

Study Design

The primary purpose of this experiment was to study the structural factors of rigid pavement and provide additional insight to concrete wear by studded tires. The SPS-2 test sections were paved during September of 1995 on northbound SR-395 between MP 91.70 and 93.50. The experiment consisted of 13 test sections that were each 500 feet in length. A total of three concrete mix designs were used with varying combinations of thickness, subbase, and panel width. The flexural strength and water cement ratios for the three designs follow:

- 550 psi flexural strength: 0.46 W/C
- 650 psi flexural strength: 0.36 W/C
- 900 psi flexural strength: 0.29 W/C

All mixes were air entrained and incorporated a water reducing admixture. Type II cement was used with the crushed basalt aggregate obtained near the job site. The fine aggregate was natural sand and crushed fines. White pigmented curing compound was used to cure the concrete. All sections received a transverse tined finished (WSDOT tining practice is now done longitudinally). The average flexural strengths for the three mixes follow:

- “550 psi mix” – 485 psi at 14 days and 709 psi at 28 days
- “650 psi mix” – 612 psi at 14 days and 663 psi at 28 days
- “900 psi mix” – 831 psi at 14 days and 945 psi at 28 days

Wear

Wear measurements were initiated in 1998 (three years after construction) using a straight edge and tape measure. Additional wear measurements were made in 2005, 2006, 2007, 2008, 2015, 2016, 2017, 2018 and 2019 using the Pathway Van. Figure 20 graphs the measurements from 1998 to 2019. The average daily traffic count for SR-395 was 8,725 with 27 percent trucks.

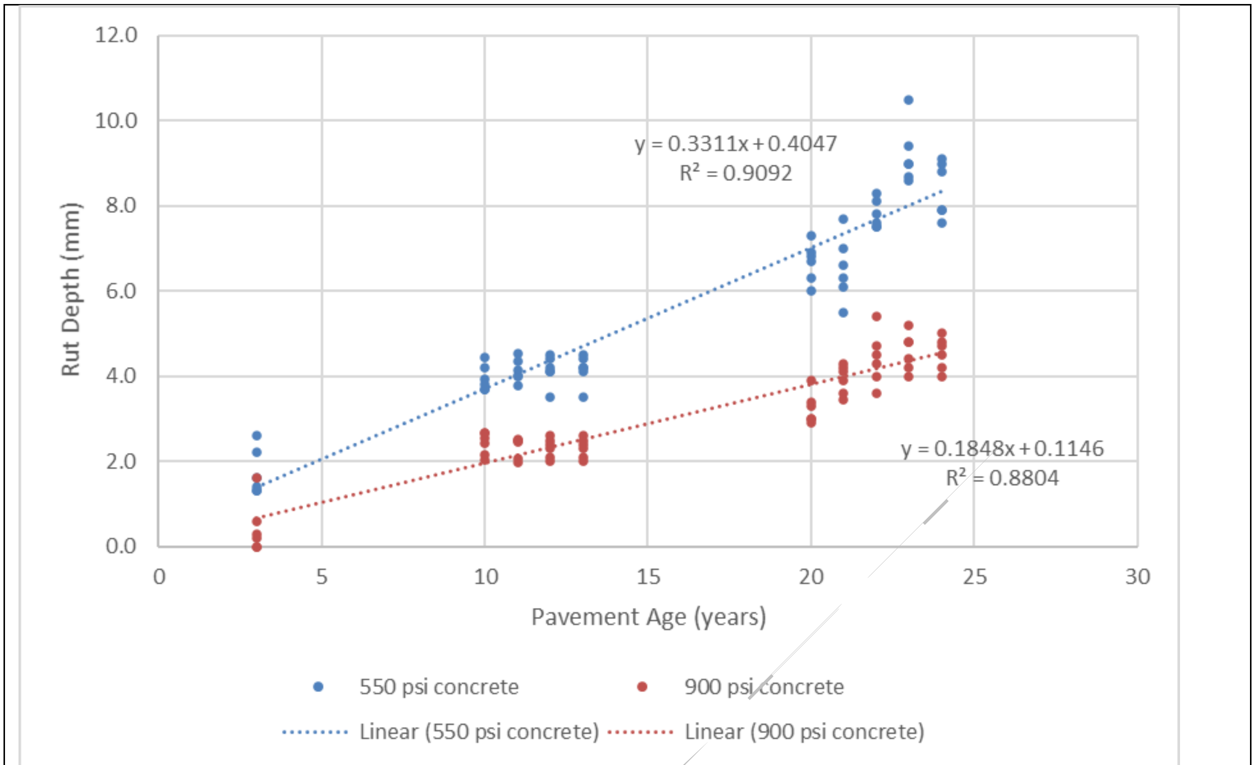


Figure 20. Comparison of wear for 550 psi and 900 psi flexural strength for all SR-395 test sections.

Figure 20 and Table 11 shows that there is a significant difference in the wear due to studded tires in the high flexural strength sections (900 psi) as compared to the lower flexural strength sections (550 psi). The average wear for the 550/650 psi mix design sections is 8.4 mm as compared to 4.5 mm for the 900 psi sections. The wear rate indicated by the trendline in Figure 20 for the 550 psi sections is almost twice that of the 900 psi sections at 0.33 mm/year versus 0.18 mm/year, respectively. Based on the wear rates, the 550 psi sections are forecasted to reach WSDOT's threshold for diamond grinding of 12.5 mm of wear after 36 years and the 900 psi sections after 66 years.

Table 11. Historical wear measurements for the SR 395 SPS sections.

Section Number	Section Design (psi)	Comp. Strength (psi)	Wear in Millimeters										Wear Rate (mm/yr.)	Year Reaching 12.5 mm of Wear
			1998	2005	2006	2007	2008	2015	2016	2017	2018	2019		
530259	650	4,239	1.4	3.8	4.0	4.0	4.0	6.4	7.9	7.6	8.8	8.3	0.35	2034
530203	550	3,399	1.3	4.2	4.4	4.1	4.2	6.9	7.7	7.8	9.4	9.0	0.38	2031
530202	900	7,398	0.0	2.5	2.5	2.6	2.6	3.4	4.3	4.5	4.8	4.7	0.20	2062
530210	900	8,078	1.6	2.7	2.5	2.3	2.3	3.0	4.2	4.0	4.4	4.2	0.18	2069
530211	550	3,107	2.2	3.9	4.0	3.5	3.5	6.7	7.0	8.1	8.6	7.9	0.33	2036
530209	550	3,426	1.6	3.8	4.1	4.2	4.2	6.3	5.5	7.5	9.0	7.9	0.33	2036
530212	900	7,496	0.2	2.0	2.1	2.0	2.0	2.9	3.4	3.6	4.0	4.0	0.17	2073
530204	900	6,681	0.3	2.2	2.0	2.1	2.1	3.3	3.9	4.7	4.2	4.5	0.19	2065
530201	550	3,088	1.4	3.7	3.8	4.4	4.4	6.8	6.6	7.5	8.7	9.1	0.38	2031
530205	550	3,515	2.6	4.4	4.5	4.5	4.5	7.3	6.1	8.3	10.5	8.8	0.37	2032
530208	900	6,705	0.0	2.7	2.5	2.5	2.5	3.0	3.6	4.3	4.8	4.8	0.20	2061
530206	900	7,158	0.6	2.4	2.5	2.4	2.4	3.9	4.1	5.4	5.2	5.0	0.21	2058
530207	550	3,613	1.3	3.7	4.0	4.1	4.1	6.0	6.3	7.6	9.0	7.6	0.32	2037
2019 Average for 650 and 550 psi Sections												8.4	0.35	2034
2019 Average for 900 psi Sections												4.5	0.19	2064

Figure 21 shows photos of three of the sections in November of 2002 and compares them with photos taken in August of 2017 in Figure 22. Note the complete absence of tining marks in 550 and 650 sections in the 2017 photos. There were tining marks on many of the 900 psi sections at the outer edge and centerline edge of the lanes. The 2017 photos show some remnant of the tining at the centerline in the 900 psi section.

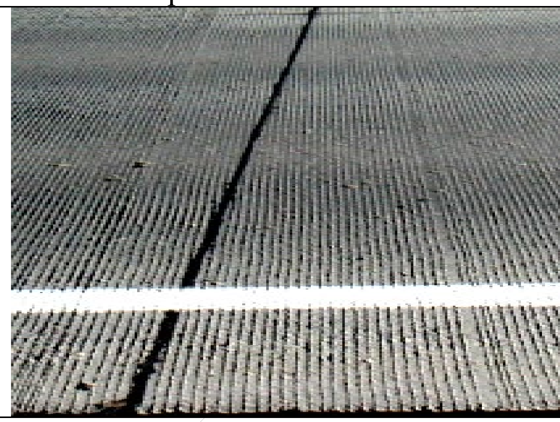
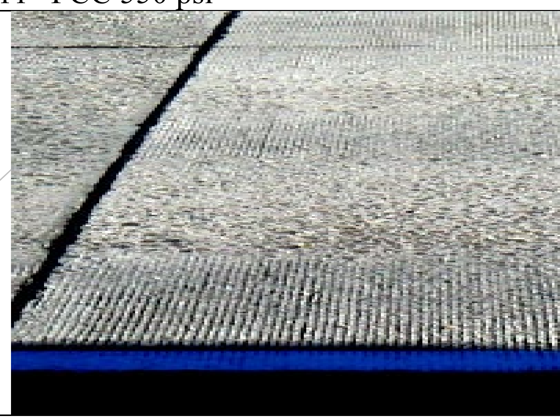
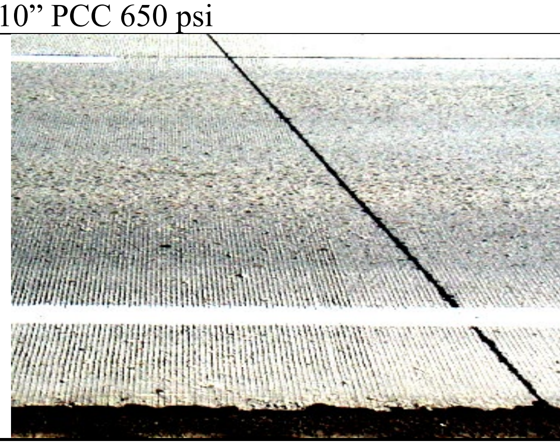
<table>
<tr><th>SPS Identification No.</th><th colspan="2">Section PCC Slab and Mix Design Features
(Photographs taken November 24, 2002)</th></tr>
<tr><td rowspan="2">530202</td><td colspan="2">8” PCC 900 psi</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td rowspan="2">530203</td><td colspan="2">11” PCC 550 psi</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td rowspan="2">530259
(WSDOT Standard Section)</td><td colspan="2">10” PCC 650 psi</td></tr>
<tr><td>
</td><td></td></tr>
</table>

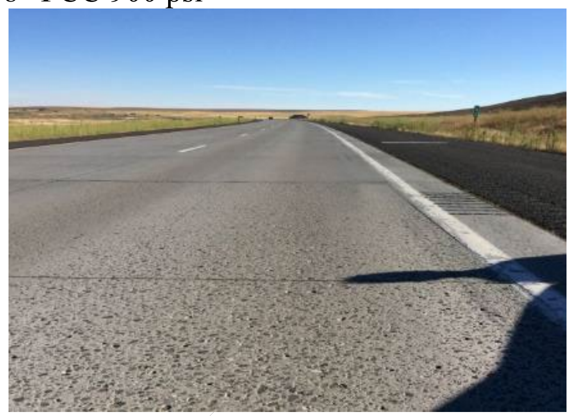
Figure 21. Condition of three of the special pavement sections on SR-395 in November of 2002.

SPS Identification No.

Section PCC Slab and Mix Design Features
(Photographs taken August 24, 2002)

530202

8” PCC 900 psi



530203

11” PCC 550 psi

530259
(WSDOT Standard Section)

10” PCC 650 psi

Figure 22. Condition of three of the special pavement sections on SR-395 in August 2017.

Pavement Condition

Table 12 summarizes the information on each section including the flexural strength, pavement section, total depth of surfacing and condition comments. The condition comments in Table 12 are based on reviews of the 2018 WSPMS video log. Figures 23-39 are photos of each section taken in August of 2017.

Section	Test Section Flexural Strength (psi)	Pavement Section	Total Depth (in.)	Condition Comments
530259	650	10” PCC, 3” ATB	13	Some tining, no cracks or spalls
530203	550	11” PCC, 6” DGAB	17	Some tining, one transverse crack, no spalls
530202	900	8” PCC, 6” DGAB	14	Tining, three transverse cracks
530210	900	8” PCC, 4” PATB, 4” DGAB	16	Tining, no cracks
530211	550	11” PCC, 4” PATB, 4” DGAB	19	No tining, no cracks or spalls
530209	550	8” PCC, 4” PATB, 4” DGAB	16	No tining, no cracks or spalls
530212	900	11” PCC, 4” PATB, 4” DGAB	19	Tining, no cracks or spalls
530204	900	11” PCC, 6” DGAB	17	Tining, no cracks or spalls
530201	550	8” PCC, 6” DGAB	14	No tining, two transverse cracks, spalling
530205	550	8” PCC, 6” LCB	14	No tining, three transverse cracks, longitudinal cracks right wheel path
530208	900	11” PCC, 6” LCB	17	Transverse cracks, longitudinal cracks RWP, some tining
530206	900	8” PCC, 6” LCB	14	Some tining visible, longitudinal cracks in both wheel paths that are spalling, five transverse cracks, appearance of stress induced multi cracks.
530207	550	11” PCC, 6” LCB	17	Three HMA filled potholes in left wheel path

Figure 23. Section 530259, 650 psi, 10" PCC, 3" ATB. August 2017. Some tining visible, no cracks or spalls.

Figure 24. Section 530203, 550 psi, 11" PCC, 6" DGAB. August 2017. Some tining visible, one transverse crack, no spalls.

Figure 25. Section 530202, 900 psi, 8" PCC, 6" DGAB. August 2017. Some tining visible, three transverse cracks.

Figure 26. Section 530210, 900 psi, 8" PCC, 4" PATB, 4" DGAB. August 2017. Some tining visible, no cracks.

Figure 27. Section 530211, 550 psi, 11" PCC, 4" PATB, 4" DGAB. August 2017. No tining visible, no cracks or spalls.

Figure 28. Section 530209, 550 psi, 8" PCC, 4" PATB, 4" DGAB. August 2017. No tining visible, no cracks or spalls.

Figure 29. Section 530212, 900 psi, 11" PCC, 4" PATB, 4" DGAB. August 2017. Tining visible, no cracks or spalls.

Figure 30. Section 530212, 900 psi, 11" PCC, 4" PATB, 4" DGAB. August 2017. Tining visible, no cracks or spalls.

Figure 31. Section 530201, 550 psi, 8” PCC, 6” DGAB. August 2017. No tining visible, two transverse cracks with spalling.

Figure 32. Section 530205, 550 psi, 8” PCC, 6” LCB. August 2017. No tining visible, three transverse cracks with spalling.

Figure 33. Section 530205, 550 psi, 8” PCC, 6” LCB. August 2017. No tining visible, three transverse cracks with spalling.

Figure 34. Section 530205, 550 psi, 8” PCC, 6” LCB. August 2017. No tining visible, three transverse cracks with spalling. Some asphalt patching of spalled cracks.

Figure 35. Section 530208, 900 psi, 11” PCC, 6” LCB. August 2017. Some tining visible, transverse cracks and longitudinal cracks in right wheel path.

Figure 36. Section 530206, 900 psi, 8” PCC, 6” LCB. August 2017. Some tining visible, longitudinal cracks in both wheel paths that are spalling, appearance of stress inducted multi-cracks similar to cracking on bridge decks.

Figure 37. Section 530206, 900 psi, 8” PCC, 6” LCB. August 2017.

Figure 38. Section 530206, 900 psi, 8” PCC, 6” LCB. August 2017. See Figure 33 for summary of condition statement.

Figure 39. Section 530207, 550 psi, 11” PCC, 6” LCB. August 2017. No visible tining, three HMA filled potholes in the left wheel path. See Table 11 for summary of condition information for each section.

I-90, Argonne Road to Sullivan Road, Studded Tire Resistant Concrete Pavement Study

Study Design

The purpose of the study (6) was to assess different concrete mix designs and texturing methods to study their resistance to studded tire wear. The project is located on I-90 between Argonne Road and Sullivan Road within the city limits of Spokane Valley. The 2019 average daily traffic in the eastbound direction was 96,407 and 95,259 westbound. The truck percentage was 6.8 percent. The east bound lanes were open to traffic in October of 2004 and the west bound in November of 2005. Several mix designs were used on very short sections of the project. The remainder of the experimental section was paved with 800 psi flexural strength mix with a carpet drag finish. The mix designs used for the shorter sections were developed using flexural strength requirements of 650 psi (WSDOT's Standard Specification requirement), 800 psi and a section with 925 lbs. of cement per cubic yard. The 650 psi sections included one with carpet drag finish, one with transverse tined finish, and one with Hard-Cem additive and carpet drag finish. The 800 psi section had a transverse tined finish and the section with 925 lbs. of cement per cubic yard had a carpet drag finish. Figure 40 shows where the various mix designs and finishing textures were used. Traffic levels in Lanes 1 and 3 were less than traffic levels in Lane 2.

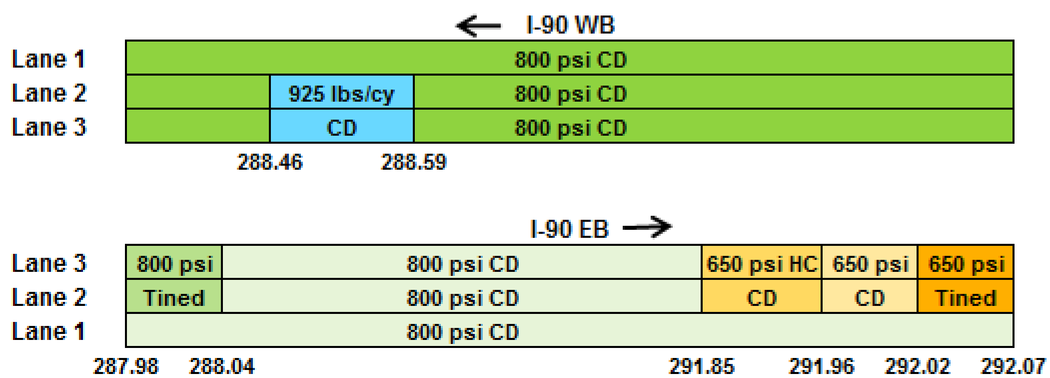


Figure 40. Location of mix designs and texturing types. CD stands for carpet drag, HC for Hard-Cem additive.

Wear

This project has been monitored for wear and smoothness since 2006. Table 13 shows the average wear for each of the mix design and texturing methods for each measurement interval. The average studded tire wear over the 15 year study period for Lane 2 east bound (highest traffic) ranged from 10.8 mm to 17.6 mm for all mix design types. The 800 psi transverse tined east bound section had the highest average wear. The average studded tire wear for Lane 2 in the west bound direction ranged from 12.9 to 14.4 mm. The average wear in Lanes 1 and 3 with less traffic for east bound and west bound followed the same trend as Lane 2 but had less average wear.

The wear rates for the lower traffic lanes (Lanes 1 and 3) for both directions range between 0.31 to 0.76 mm/year and for the Lane 2 (the high traffic lane) the rates range between 0.72 to 1.17 mm/year. By calculating pavement age with these ranges and based on the 12.5 mm limit for WSDOT rehabilitation practices, wear-related lives of about 16 to 40 years can be expected for Lanes 1 and 3 and 11 to 17 years for the Lane 2. This finding is supported in that the 800 psi transverse tined section now exceeds the WSDOT wear depth criterion of 12.5 mm.

None of the mix factors associated with the I-90 sections resulted in significantly different studded tire wear over the 15 year period; although, the mix/texturing type with the highest wear (17.6 mm) was the 800 psi mix (eastbound Lane 2) with transverse tining and, as noted earlier, WSDOT no longer uses that type of tining. The 650 psi mix (eastbound Lane 2) exhibited lower wear (11.4 mm) with the same tining process. The difference in wear rates between the 800 psi mix and 650 psi mix is not a trivial difference but both are high and only the “design” strength is known.

The next highest wear section was the 925 psi mix placed with a carpet drag finish. The 925 psi mix had a rut wear of 14.4 mm. All eastbound Lane 2 and westbound Lane 2 PCC sections experienced the highest wear with presumably the most traffic.

Table 13. Average wear in millimeters for each mix design/texture section.

Section	Lane	Spr. 2006	Spr. 2008	Spr. 2009	Spr. 2010	Spr. 2011	Spr. 2012	Spr. 2013	Spr. 2015	Fall 2016	Fall 2017	Fall 2018	Fall 2019
650 psi CD	EB2	2.0	3.6	5.0	5.5	6.4	6.3	7.2	7.8	8.9	9.9	11.7	11.4
650 psi CD	EB3	2.7	1.7	2.8	3.2	3.2	4.0	4.3	4.2	3.3	6.1	5.5	4.6
650 psi Hard-Cem CD	EB2	2.1	3.4	5.0	5.8	6.1	6.8	7.5	7.7	8.2	9.8	10.6	10.8
650 psi Hard-Cem CD	EB3	2.7	1.7	2.6	2.9	3.4	4.0	3.7	4.2	4.3	6.1	6.3	5.7
650 psi Tined	EB2	2.4	3.6	4.2	5.5	6.3	6.5	7.1	7.5	7.5	9.5	11.1	11.4
650 psi Tined	EB3	3.7	2.2	2.6	2.9	3.3	4.1	4.2	4.2	3.9	3.5	6.9	6.0
800 psi CD	EB1	2.3	2.5	3.5	3.7	4.1	4.7	4.7	5.1	6.0	6.5	7.9	7.2
800 psi CD	EB2	2.3	4.0	5.3	5.9	6.8	7.5	8.1	8.9	8.8	10.6	11.7	12.0
800 psi CD	EB3	2.1	2.1	2.8	2.8	3.1	3.7	3.8	4.2	4.5	5.7	6.4	5.5
800 psi Tined	EB2	2.8	4.4	6.2	6.8	7.8	8.2	9.1	10.0	12.7	14.8	17.1	17.6
800 psi Tined	EB3	2.9	2.9	4.1	4.5	3.8	6.6	8.4	9.4	10.4	9.3	11.7	11.4
Age (months)		18	42	54	67	78	91	103	127	143	156	166	179
800 psi CD WB*	WB1	2.6	3.1	3.9	4.5	4.7	5.5	6.2	6.4	7.4	7.9	8.7	8.7
800 psi CD WB*	WB2	2.6	4.1	5.5	6.4	6.9	7.8	8.7	8.9	9.9	11.4	12.4	12.9
800 psi CD WB*	WB3	3.3	3.1	3.8	4.0	4.2	5.1	5.1	5.8	6.8	7.4	7.7	8.4
925 lbs/CY CD WB*	WB2	2.6	3.0	5.0	5.8	7.8	8.5	9.2	9.9	11.9	12.1	12.4	14.4
925 lbs/CY CD WB*	WB3	2.6	4.0	4.1	4.4	2.7	5.8	6.3	6.8	7.8	8.3	9.9	9.3
Age (months)		5	29	41	54	65	78	90	114	130	143	153	166

*** Open to traffic 13 months after the other sections, thus the two age notations. CD = carpet drag finish**

Smoothness

The MRI readings for all the sections were between 80 and 104 inches per mile except for the 800-psi transverse tined section at 148 inches per mile (Table 14). It is not clear if the transverse tining was responsible for the roughness, however, the texture applied during construction was very light and the studded tire wear removed any texture within 2 to 3 years. The MRI of these sections changed little over 14 to 15 years of traffic. Other than the exceptions due to the 800 psi tined mix and levels of traffic in the three lanes, all MRI values fall within a tight range suggesting no significant difference.

Table 14. Smoothness measurements in MRI (inches per mile) for each mix design/texture.

Section	Spr. 2006	Spr. 2007	Spr. 2008	Spr. 2009	Spr. 2010	Spr. 2011	Spr. 2012	Spr. 2013	Spr. 2015	Fall 2016	Fall 2017	Fall 2018	Fall 2019
650 psi CD	92	82	89	84	88	90	95	89	84	88	91	88	102
650 psi Hard-Cem CD	90	90	98	96	96	83	95	94	94	95	98	88	90
650 psi Tined	82	82	92	88	85	100	86	89	77	81	80	75	80
800 psi CD	94	91	97	93	93	95	93	93	94	96	97	93	96
800 psi Tined	128	125	132	129	132	141	132	134	96	129	132	127	148
Age (months)	18	30	42	54	67	78	91	103	127	143	156	166	179
800 psi CD*	107	98	109	93	99	102	103	101	100	100	103	99	104
925 lbs/CY CD*	104	100	112	101	97	106	104	99	101	101	104	94	99
Age (months)	5	17	29	41	54	65	78	90	114	130	143	153	166

*** Open to traffic 13 months after the other sections, thus the two age notations.**

Comparison of I-90, Argonne to Sullivan to SR-395 SPS-2 Test Sections

The overall picture that emerges from the SR-395 sections is that increased flexural strength of the PCC can reduce studded tire wear rates but not eliminate it. Further, the SR-395 sections, built in 1995 with two lanes in each direction, used transverse tining which was standard practice at that time. Transverse tining appears to be more susceptible to accelerated surface wear. The fact remains that the high strength flexural sections (900 psi) exhibited 50% less wear depth than observed on the lower strength sections (550 and 650 psi) and, importantly, all sections had the same amount of traffic over a 24 year period.

The I-90 section results differ due to approximately 11 times more traffic than SR-395 accounting for both directional ADT and lane factors (and by assumption the number of studded tire applications). Given the wear trends and the limited differences in estimated concrete strength, the I-90 Lane 1 and 3 results are similar to the wear rates associated with the lower strength sections on SR-395. The SR-395 wear rates fall within a range of 0.32 to 0.38 mm/year for the lower strength mixes. For I-90, the Lane 1 and 3 wear rates, east bound, range between 0.31 to 0.48 mm/year or marginally higher than SR 395 if the transverse tined section is not included. For the high traffic I-90 Lane 2, the range for measured wear is substantially higher than SR 395: 0.72 to 1.17 mm/year for I-90 verses 0.17 to 0.38 mm/year for SR 395 (range includes all mix types). Direct comparisons with I-90 Lane 3 traffic and SR 395 results are limited since Spokane traffic is far higher than SR 395 as noted earlier. The range of wear rates are about three to four times higher for I-90.

The PCC sections associated with these two locations are complimentary in that WSDOT now has an improved picture of wear rates for low to high flexural strengths under a range of traffic levels. Higher strength PCC can reduce wear rates by 50 percent for rural US and Interstate highways but will not eliminate it. For high volume pavements in urban areas with high stud use, higher strength mixes will reduce wear, but the wear rates will be higher than rural locations.

From a policy view, these observations do not suggest higher strength concrete is a solution to studded tire wear, but it can be a positive mix factor. The current, standard specified strength for PCC is 650 psi. Consideration of constructability and increased strength versus cost is warranted going forward.

Pavement Test Section Performance Observations

Observations for wear and smoothness performance based on the data presented in this study for each of the Special Pavement Test Sections include the following.

I-405 Quieter Pavements

After 8 years of traffic on the I-405 section:

- The OGFC-AR is more susceptible to wear than either the OGFC-SBS or HMA matching the pattern seen in the I-5 and SR-520 test sections.
- The smoothness measurements mimic the wear measurements with the OGFC-AR having the highest MRI followed by the OGFC-SBS and the HMA with the lowest.

I-82 Next Generation Concrete Surface

Following almost nine years of measurements, the I-82 experiment compared NGCS with CDG and we find:

- The wear on the NGCS is slightly higher than on the CDG after 8.6 years of traffic.
- The smoothness measurements have remained very consistent for the CDG section but took a dramatic drop for the NGCS due to a change in the measurement methodology, making them similar in smoothness.

I-90 Cle Elum Longitudinal Tining and Conventional Diamond Grinding

Following seven years of measurements, the following observations are made on the performance of the longitudinal tining and the diamond grinding on I-90 near Cle Elum.

- The wear on the longitudinal tining is slightly higher than the diamond ground which is largely due to the higher traffic volumes over the longitudinal tining (Lane 1 or the outside travel lane). The CDG was done in Lane 2.
- The measured smoothness for this experiment varies due to equipment changes.

I-90 Polyester Concrete Rut Fill Test Section

- Higher wear rates are noted for the PPC section as compared to the diamond ground pavement adjacent to the PPC; however, the difference in wear is less than 0.03 mm after eight years.
- There has been no spalling of the three polyester polymer concrete sections.

- The MRI on the polyester polymer concrete is about double that of the adjacent diamond ground concrete.

SR-395 LTPP Special Pavement Study (SPS-2)

The following are observations based on the condition of the sections.

- Tining is completely worn off in the sections with the lower flexural strength (550 and 650 psi).
- All the sections with lean concrete base, regardless of pavement thickness or flexural strength, have the most cracking due to the higher strength of the base.
- Two of the sections with the thinnest concrete and base depth (8” PCC and 6” DGAB) have transverse cracking (530202 and 530201).
- The one section with WSDOT’s standard specification 650 psi flexural strength and the thinnest total section depth outperformed the other sections with respect to cracking.
- The sections with 900 psi flexural strength had the least amount of wear after 24 years of traffic. For the nine sections with that flexural strength, the average wear was 0.19 mm/year.
- The maximum average wear measured is 9.1 mm on test section 530201 (550 psi). A rate of wear of 0.38 mm per year wear (double the rate for 900 psi mix) would translate into that section reaching 12.5 mm of wear in 33 years (this assumes wear rates will remain constant given the data shown in Figure 20 and Table 11).
- All SR-395 sections have served traffic for 24 years as of 2019.

I-90, Argonne Road to Sullivan Road, Studded Tire Resistant Concrete Pavement

The following observations are made concerning the wear measurements after 15 years (14 for the westbound lanes) of traffic. The eastbound lanes were opened to traffic in 2004 and westbound in 2005.

- Except for the transverse tined 800 psi flexural strength concrete mix placed on east bound Lane 2, the strength of mix used did not make a difference in the average wear ranging from 10.8 mm to 12.0 mm.
- The tined 800 psi flexural strength concrete mix design in the east bound direction on Lane 2 has the highest average wear at 17.6 mm which exceeds the threshold where some type of rehabilitation is recommended.
- West bound Lane 2 has an average wear of 13.6 mm which exceeds the threshold where some type of rehabilitation is recommended.
- Increasing the flexural strength of the concrete mix to 800 psi or increasing the cement content to 925 lbs/cubic yard did not increase the pavements resistance to studded tire

wear for these experimental sections. However, actual compressive and flexural strength data is limited and that type of data would aid such comparisons.

- The addition of Hard-Cem additive to a 650 psi flexural strength mix did not increase the wear resistance over other 650 psi flexural strength sections.
- Comparison of transverse vs longitudinal tining. WSDOT surface texture construction methods have changed from transverse to longitudinal tining but it is yet unclear how studded tire wear rates will change. Wear rates for longitudinal tining from I-90 near Cle Elum (Lane 1) are similar to those observed for transverse tining on I-90 Spokane.
- Flexural strengths converted from compressive strengths for all test sections ranged from 709 psi to 775 psi. Flexural strength values likely had little to do with studded tire wear measurements as the converted flexural strengths do not appear to reflect the expected individual test section strength values. The compressive strength of all mixes in the experiment were within about 1,000 psi of each other.

Summary and Conclusions

The conclusions drawn from this study influences WSDOT pavement design and pavement management practices as follows:

- While this and past WSDOT studies have helped to identify studded tire rutting and wear rates, an effective approach to eliminate studded tire wear for new construction is not apparent based on section performance summarized in this and prior reports. Some of the maximum PCC wear depths that in recent years have been measured on I-90 Sunset Hill (just west of downtown Spokane and not associated with the sections summarized in this report) were 38 to 44 mm of wear after 14 years of traffic or wear rates of 2.7 to 3.3 mm/year (7). These can be put into perspective by viewing the rates shown shortly.
- WSDOT can expect poor performance and high life cycle cost of open graded asphalt pavements used to provide quieter hot mix asphalt pavements. Open graded asphalt paving should not be used for that purpose on state routes.
- WSDOT's change to longitudinal tining. It is unclear that longitudinal tining performs better than transverse tining based on the I-90 sections near Cle Elum. The wear for the longitudinal tining is similar to that via diamond grinding but the ride was smoother. The NGCS sections on I-82 had slightly higher wear than diamond grinding.
- Polyester polymer concrete (PPC) is an acceptable alternative to remove rutting from concrete pavements when diamond grinding is not feasible. PPC has a high cost and must be diamond ground following placement to achieve an acceptable smoothness.
- The SR-395 SPS-2 study supports WSDOT's policy of requiring HMA base under all new concrete pavements and not allowing lean concrete for that purpose.
- Observations from the I-90 (Spokane) and SR 395 SPS-2 test sections show that higher strength concrete does not eliminate studded tire wear; although higher strength mixes reduce the rutting rate by about 50 percent based on SR 395 results and its relatively low traffic levels. The current, standard specified flexural strength for PCC is 650 psi.

Consideration of constructability and increased strength versus cost is warranted going forward.

- Wear rates can be broadly summarized for these sections (all concrete strengths are design flexural strengths):
  - PCC wear SR 395 (SPS 2 sections measured over 24 years)
    - 550 psi: average depth = 8.4 mm, average wear rate = 0.35 mm/year.
    - 650 psi: average depth = 8.3 mm, average wear rate = 0.35 mm/year
    - 900 psi: average depth = 4.6 mm, average wear rate = 0.19 mm/year
  - PCC wear I-90 (Argonne Road to Sullivan Road, sections measured over either 14 to 15 years)
    - East Bound Lane 2
      - 650 psi carpet drag: average depth = 11.4 mm, average wear rate = 0.76 mm/year
      - 650 psi Hard Cem: average depth = 10.8 mm, average wear rate = 0.72 mm/year
      - 650 psi transverse tining: average depth = 11.4 mm, average wear rate = 0.76 mm/year
      - 800 psi carpet drag: average depth = 12.0 mm, average wear rate = 0.80 mm/year
      - 800 psi transverse tining: average depth = 17.6 mm, average wear rate = 1.17 mm/year
    - West Bound Lane 2
      - 800 psi carpet drag: average depth = 12.9 mm, average wear rate = 0.92 mm/year
      - 950 lb/CY carpet drag: average depth = 14.4 mm, average wear rate = 1.03 mm/year
- The wear rates listed above suggest:
  - The sections associated with I-90 Spokane Lane 2 collectively will reach a critical depth of 12.5 mm following 11 to 17 years of service. One transversely tined section has already exceeded the criterion.
  - The sections on SR 395, with about 11 times lower annual traffic rates than I-90 Spokane, will reach the 12.5 mm criterion based on wear alone at about 35 years for the lower flexural strength sections (550 and 650 psi) and 65 years for the higher flexural strength sections (900 psi). Though the time to the 12.5 mm criterion is two to four times higher than the I-90 sections, the tining that aids tire traction was largely worn away early in the life of these SR 395 pavements.
- This report focuses largely, but not exclusively, on PCC wear due to studded tires. The deficiency is the lack of measured studded tire applications on the various test sections. Traffic levels were used to understand the observed results, but these estimates are approximate. In spite of this limitation, the performance of these test sections provides significant insight about this process.

References

1. WSDOT Pavement Policy. Washington State Department of Transportation, Olympia, WA. September 2018.

2. Anderson, Keith; Uhlmeyer, Jeff; Sexton, Tim; Russell, Mark; Weston, Jim. Summary "Report on the Performance of Open-Graded Friction Course Quieter Pavements," WA-RD 817.1. Washington State Department of Transportation, Olympia, WA. September 2013

3. Anderson, Keith; Uhlmeyer, Jeff; Sexton, Tim; Russell, Mark; Weston, Jim. "Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses Project 3 – Final Report." WA-RD 749.2. Washington State Department of Transportation, Olympia, WA. July 2013

4. Keith W. Anderson, Jeff S. Uhlmeyer, Tim Sexton, Mark Russell, and Jim Weston. "Evaluation of Long-Term Pavement Performance and Noise Characteristics of the Next Generation Concrete Surface : Final Report," WA-RD 767.2. Washington State Department of Transportation, Olympia, WA. January 2014

5. Keith W. Anderson, Jeff S. Uhlmeyer, Mark Russell, Chad Simonson, Kevin Littleton, Dan McKernan, and Jim Weston. "Polyester Polymer Concrete Overlay Final Report," WA-RD 797.2 Washington State Department of Transportation, Olympia, WA. January 2019

6. Keith W. Anderson, Jeff Uhlmeyer, Mark Russell, and Jim Weston. "Studded Tire Resistance of PCC Pavements with Special Mix Designs," WA-RD 658.2. Washington State Department of Transportation, Olympia, WA. February 2011

7. Jeff S. Uhlmeyer and Cam Gilmour, Studded Tire Update, Washington State Transportation Commission Meeting, Olympia, WA. February 18, 2015