Evaluation of Portland Cement Concrete Pavement with High Slag Content Cement

WA-RD 728.2

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WSDOT Research Report

Experimental Feature Report

Final Report
Experimental Feature 07-03

Evaluation of Portland Cement Concrete Pavement With High Slag Content Cement

Contract 7064
SR-543
I-5 To International Boundary Widening
MP 0.20 to MP 1.09

Washington State Department of Transportation

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16. ABSTRACT

The performance of a section of concrete pavement built with 30 percent Ground Granulated Blast Furnace Slag (GGBFS) is compared to a control section of concrete pavement built with 25 percent GGBFS to determine if the higher slag content pavement is more resistant to wear from studded tires. The wear measurements made over a period of six years showed minimal amount of wear on both the higher slag content section and the control section. It was impossible to conclude that the higher slag content was more resistant to studded tire wear than conventional concrete mixes normally used on Washington roadways. The low speed of vehicles (40 mph speed limit) is a possible contributing factor to the lower amounts of wear noted on this project.

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Introduction

This experimental feature will investigate the performance of high slag concrete mixes and their affect on the pavements ability to resist studded tire wear. Concrete mixes with higher slag content produce higher strength pavements which may be more resistant to studded tire damage.

Class F fly ash has been used by WSDOT for many years in portland cement concrete pavement (PCCP). WSDOT has experienced shortages of fly ash at various times when the main supplier in Washington State, the TransAlta coal fired power plant in Centralia, shuts down in the spring due to hydroelectric power being cheaper than power produced by coal. Ground Granulated Blast Furnace Slag (GGBFS) is being imported into Washington State and can be substituted for portland cement because it has cementitious properties similar to fly ash.

Background

GGBFS is a by-product of iron manufacturing. Slag is what is left after the molten iron is poured out of a blast furnace. The slag is formed from a combination of the limestone and/or dolomite used as a flux in the making of iron and the siliceous and aluminous residues from the iron ore and the coke ash. Slag with cementitious properties is made by rapidly cooling the molten slag to produce a glassy, granular product that is then dried and ground into a fine powder.

Properties of Concrete with Slag Cement

Concrete with slag cement will have a slower rate of strength gain than concrete made with 100 percent portland cement; however, the long-term strength of slag cement is comparable to or higher than the same concrete with all portland cement. The optimum amount of slag to achieve the highest strength development appears to be between 40 and 60 percent (Richardson, 2006). While other sources note the optimum blend of GGBFS and portland cement that produces the greatest 28 day compressive strength to be between 40 and 70 percent, this proportion is dependent on the grade of slag used (ACI 233R-03). As the replacement level of slag increases the 28 day compressive strength of the concrete generally increases, up to approximately 50 percent slag as a percent of the cementitious materials (SCA No. 14, 2003). Scaling can be a problem when higher percentages of slag cement are used in paving concrete mixes, however, at the 35 percent level designed to be used on this project, there are no problems reported in the literature. Note that the 35 percent level was not achieved due to problems placing the mix due to the long haul distance between the plant and the project location.

Project Description

Contract 7064, SR 543, I-5 to International Boundary Widening and Border Crossing Improvements, is located at the northern limits of I-5 near the Canadian border as shown in Figure 1. The project converted the existing two lane facility into a four lane roadway to provide a separate truck route to address congestion and safety issues. In addition, a new interchange at "D" Street was constructed. The total length of the project is 0.89 miles.

Figure 1. Project vicinity map.

Construction

Construction of the concrete pavement began on June 13 and was completed on October 19, 2007. Four mix designs were used, one with 25 percent slag cement, one with 30 percent slag cement, one with 35 percent slag cement, and two with conventional Type I/II portland cement without slag. The latter two mix designs were 24 hour and 48 hour mixes used for special situations that required quicker set times. The components for each mix design are summarized in Tables 1-5 and provided in greater detail in Appendix A.

Table 1. Mix design SS6012P25 with 25 percent slag cement.

Item	Source	Type	Lbs/cy	Specific Gravity
Cement	Lafarge	I-II	423	3.15
Slag	Lafarge	NewCem	141	2.87
Agg. Source 1	F-34	ASTM C33 No. 4	624	2.68
Agg. Source 2	F-34	ASTM C33 No. 67	1014	2.68
Agg. Source 3	F-34	ASTM C-33 No. 8	481	2.68
Agg. Source 4	F-194	WSDOT Class II Sand	1,053	2.57
Water			238	1.00
W/C Ratio			0.42	
Air Entrainment	Master Builders	AE 90	5-10 oz/cy	
Water Reducer	Master Builders	Polyheed 997	23-30 oz/cy	

Table 2. Mix design SS6012P30 with 30 percent slag cement.

Item	Source	Type	Lbs/cy	Specific Gravity
Cement	Lafarge	I-II	395	3.15
Slag	Lafarge	NewCem	169	2.87
Agg. Source 1	F-34	ASTM C33 No. 4	624	2.68
Agg. Source 2	F-34	ASTM C33 No. 67	1014	2.68
Agg. Source 3	F-34	ASTM C-33 No. 8	481	2.68
Agg. Source 4	F-194	WSDOT Class II Sand	1,050	2.57
Water			217	1.00
W/C Ratio			0.38	
Air Entrainment	Master Builders	AE 90	5-10 oz/cy	
Water Reducer	Master Builders	Polyheed 997	23-30 oz/cy	
High-Range Water Reducer	BASF/Master Builders	Delvo	20 oz/cy	

Table 3. Mix design SSP012635 with 35 percent slag cement.				
Item	**Source**	**Type**	**Lbs/cy**	**Specific Gravity**
Cement	**Lafarge**	**I-II**	**369**	**3.15**
Slag	**Lafarge**	**NewCem**	**195**	**2.87**
Agg. Source 1	**F-34**	**ASTM C33 No. 4**	**624**	**2.68**
Agg. Source 2	**F-34**	**ASTM C33 No. 67**	**1014**	**2.68**
Agg. Source 3	**F-34**	**ASTM C-33 No. 8**	**481**	**2.68**
Agg. Source 4	**F-194**	**WSDOT Class II Sand**	**1,048**	**2.57**
Water			**217**	**1.00**
W/C Ratio			**0.38**	
Air Entrainment	**Master Builders**	**AE-90**	**5-10 oz/cy**	
Water Reducer	**Master Builders**	**Polyheed 997**	**23-30 oz/cy**	

The 25, 30 and 35 percent slag mix designs were similar except for the higher quantities of slag and lower quantities of water and resultant lower water/cement ratios in the 30 and 35 percent mixes. The 30 percent mix also used a high-range water reducer not used in either of the 25 or 35 percent slag mixes.

Table 4. Mix design SS80124P24, 24 hour mix.				
Item	**Source**	**Type**	**Lbs/cy**	**Specific Gravity**
Cement	**Lafarge**	**I-II**	**752**	**3.15**
Agg. Source 1	**F-34**	**ASTM C33 No. 4**	**588**	**2.68**
Agg. Source 2	**F-34**	**ASTM C33 No. 67**	**1088**	**2.68**
Agg. Source 3	**F-34**	**ASTM C-33 No. 8**	**294**	**2.68**
Agg. Source 4	**F-194**	**WSDOT Class II Sand**	**1088**	**2.57**
Water			**263**	**1.00**
W/C Ratio			**0.35**	
Air Entrainment	**Master Builders**	**AE 90**	**5-10 oz/cy**	
High-Range Water Reducer	**Master Builders**	**Glenuim 3030 NS**	**15-60 oz/cy**	

Table 5. Mix design SS7014P48, 48 hour mix.				
Item	**Source**	**Type**	**Lbs/cy**	**Specific Gravity**
Cement	Lafarge	I-II	658	3.15
Agg. Source 1	F-34	ASTM C33 No. 4	588	2.68
Agg. Source 2	F-34	ASTM C33 No. 67	1088	2.68
Agg. Source 3	F-34	ASTM C-33 No. 8	294	2.68
Agg. Source 4	F-194	WSDOT Class II Sand	1088	2.57
Water			238	1.00
W/C Ratio			0.36	
Air Entrainment	Master Builders	AE 90	5-10 oz/cy	
High-Range Water Reducer	Master Builders	Glenuim 3030 NS	13-60 oz/cy	

The two fast setting mix designs were also very similar with the only differences in the quantity of cement and the water/cement ratio.

Construction Problems

There were significant problems with the mix delivered to the job site to the extent that the project engineer recommended that the planned use of 35 percent slag content cement be abandoned (see Appendix B). The problems with the concrete mix was attributed to the contractors using an off site concrete batch plant with a travel time of approximately one hour. As a result, there were several instances when the concrete began to set prior to being processed through the paver. The variability of the compressive strength test results for the 25 percent slag mix noted in the section that follows corroborates this observation.

Test Section

The test section of 30 percent slag runs from Milepost 0.57 to Milepost 0.77 in the northbound outside lane and truck lane as shown on the map in Figure 2. The truck lane is the outside lane that exits to the right after the D Street Overcrossing. The remainder of the mainline paving used the 25 percent slag mix design.

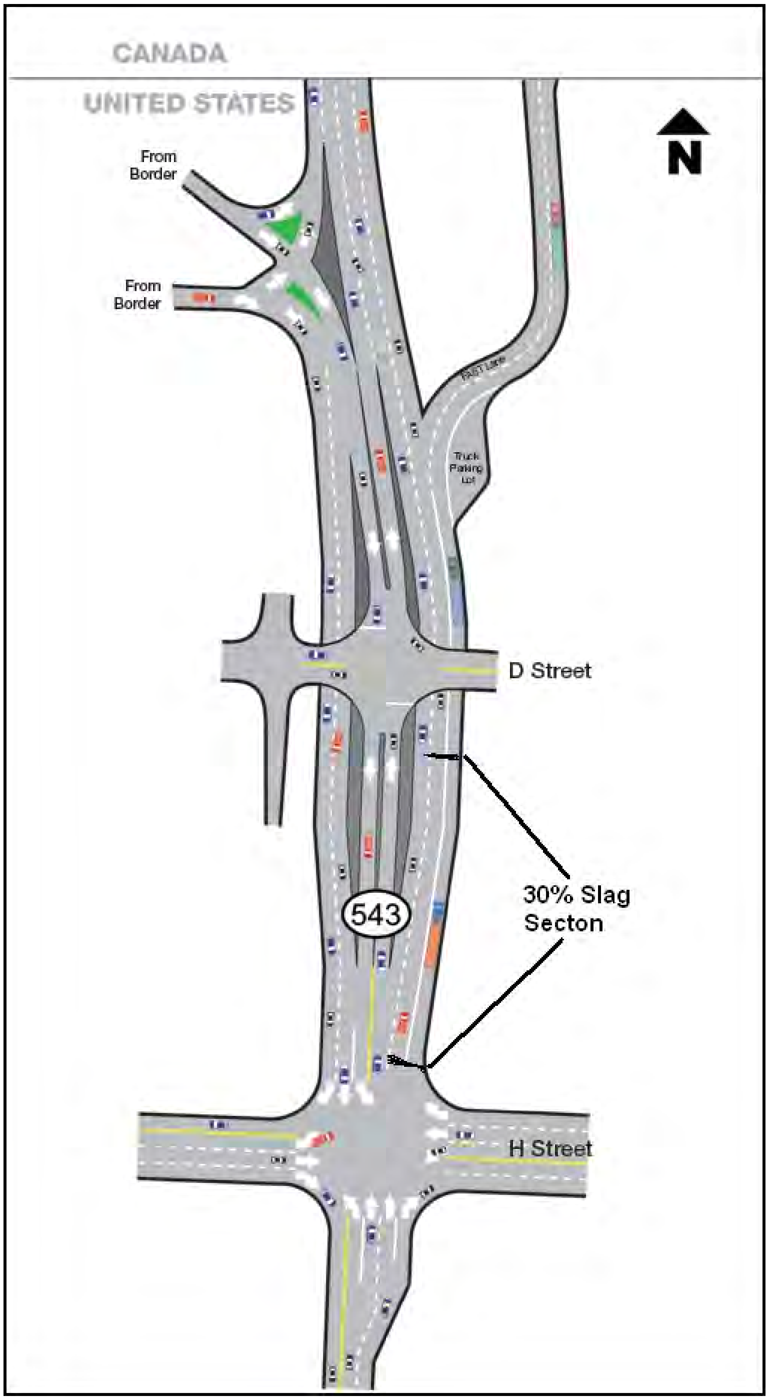

Figure 2. Project lane configuration and test section location.

Construction Test Results

The compressive and flexural strength results from the cylinders cast on the project are listed in Tables 6 through 9 for each of the four mix designs. The 25 percent slag mix design had a wide variation in strengths throughout the course of the paving. The compressive strengths ranged from a low of 3,800 psi to a high of 5,590 psi, with an average compressive strength of 4,737 psi. The 1,790 psi range in the individual cylinder results and a standard deviation of 437 psi supports the probability that there was either a large variation in the proportioning of the mix at the concrete plant or in the mixer trucks on the way to the job site.

Table 6. Compressive and flexural strengths for the 25 percent slag mix design (SS6012P25) cylinders.

Date	Starting Station	Ending Station	Concrete (cy)	Compressive Strength (psi)	Flexural Strength (psi)
6/15/07	L 1+268.43	L 1+286.44	77	5,310	837
6/20/07	LR 1+656.00	LR 1+876.00	517	4,310	754
6/22/07	T 1+876.00	T 2+034.00	427	3,800	708
6/26/07	T 1+926.00	T 2+045.00	346	4,640	782
9/5/07	T 2+051.20	T 2+214.94	249	4,150	740
9/6/07	T 2+051.20	T 2+213.80	212	4,220	746
9/10/07	LL 1+945.00	LL 2+025.00	213	4,770	793
9/11/07	LL 1+970.10	LL 1+993.20	570	4,580	777
9/19/07	LL 1+777.40	LL 1+945.50	395	5,250	832
9/21/07	LL 1+518.20	LL 1+700.20	457	4,560	776
9/22/07	L 1+325.20	L 1+478.60	508	5,590	859
9/25/07	L 1+286.44	L 1+326.84	97	4,810	797
10/1/07	L 1+287.80	L 1+478.60	310	5,230	831
10/2/07	L 1+510.00	L 1+611.99	148	4,700	788
10/3/07	L 1+286.44	L 1+486.60	236	4,570	777
10/8/07	L 1+839.89	L 1+910.02	224	4,470	768
10/9/07	L 1+837.70	L 1+990.00	313	4,680	786
10/15/07	L 1+510.12	L 1+546.98	205	5,030	815
10/17/07	L 1+541.01	L 1+559.98	355	5,140	824
10/18/07	L 1+949.10	L 1+995.32	68	4,570	777
10/19/07	L 1+802.15	L 1+860.63	147	5,100	820
			AVE	4,737	790
			STD DEV	437	37

The 30 percent slag mix had a 240 psi range in compressive strength values with a low of 4,910 psi and a high of 5,150 psi and an average of 5,040 psi. The standard deviation of 110 psi was the lowest of the four mix designs used and indicates that the concrete supplier may have been more careful with this mix because of its experimental nature.

Table 7. Compressive and flexural strengths for the 30 percent mix design (SS6012P30) cylinders.

Date	Starting Station	Ending Station	Concrete (cy)	Compressive Strength (psi)	Flexural Strength (psi)
6/19/07	L 1+286.44	L 1+406.00	-	4,990	741
6/19/07	LR 1+406.00	LR 1+538.00	-	5,150	753
6/19/07	LR 1+538.00	LR 1+ 656.00	873	4,910	735
6/19/07	-	-	-	5,110	750
			AVE	5,040	745
			STD DEV	110	8

The 24 and 48 hour mixes followed the pattern of the 25 percent slag mix with a lot of variability in the compressive strengths and moderate to high standard deviations.

Table 8. Compressive and flexural strengths for the 24 hour mix design (SS80124P24) cylinders.

Date	Starting Station	Ending Station	Concrete (cy)	Compressive Strength (psi)	Flexural Strength (psi)
9/12/07	L 1+255+80	L 1+275.64	51	6,680	991
9/13/07	L 1+ 255.80	L1+261.40	67	6,610	986
9/14/07	L 1+264.80	L 1+291.80	80	7,680	1,062
10/4/07	I/S H Street & SR 543		149	7,870	1,075
10/5/07	L 1+247.83	L 1+250.21	48	7,550	1,053
10/12/07	L 1+231.12	L 1+247.09	42	6,920	1,008
			Average	7,218	1,029
			STD DEV	547	39

Table 9. Compressive and flexural strengths for the 48 hour mix design (SS7014P48) cylinders.					
Date	Starting Station	Ending Station	Concrete (cy)	Compressive Strength (psi)	Flexural Strength (psi)
9/20/07	LL 1+692.10	LL 1+778.90	289	6,470	943
10/10/07	-	-	50	6,640	956
10/11/07	H 1+232.55	H 1+245.90	143	7,050	985
			Average	6,720	961
			STD DEV	298	22

Additional cylinders were cast and broken at 2, 5, 14, 28, 180 and 365 days to provide an idea of the progressive strength gain of the 30 percent slag mix (Table 10). The strength versus time graph (Figure 3) shows that the mix gains most of its strength by 28 days. The same test series was not done for the 25 percent mix; therefore, the difference in strength gain for the two mixes could not be reported.

Table 10. Compressive strengths for 30 percent slag mix design cylinders with time.	
Test Date	Compressive Strength (psi)
2 days	2,580
6 days	3,380
14 days	4,140
28 days	5,110
180 days	5,330
1 year	5,780

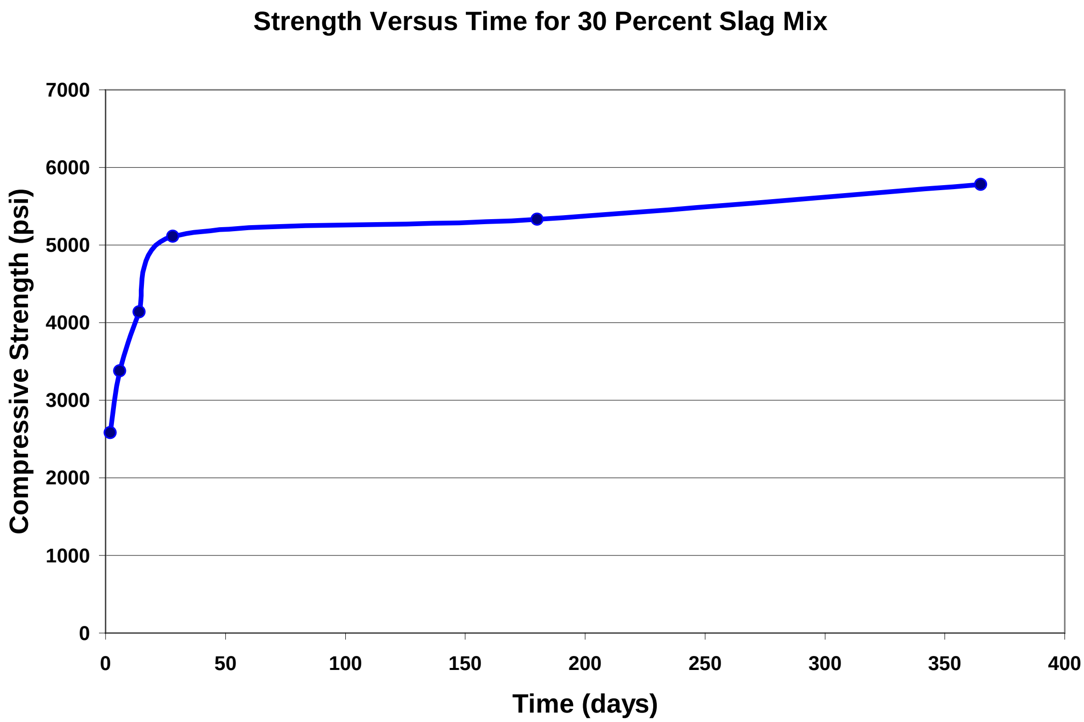

Figure 3. Strength versus time for 30 percent slag mix.

Post-Construction Test Results

Wear and ride measurements on the 30 percent slag and control sections were conducted on April 21, 2009 (approximately 1.5 years after construction) with results summarized in Table 11. Friction measurements made on April 22, 2009 are also summarized in Table 11.

Table 11. Average wear, ride and friction results for April 2009.

Section	Dir./Lane	Wear (mm)	Ride (IRI)	Friction (FN)
30% Slag	NB1	2.4	93	50.5
Control	NB1	2.5	180	53.8
Control	NB2	3.0	148	52.9
Control	SB1	2.7	106	50.5
Control	SB2	3.1	117	41.5

The wear measurements seem a bit high for a new pavement and the ride measurements are definitely high, especially Lanes 1 and 2 of the northbound control section. The high ride measurements correlate with the problems cited during construction with the consistency and workability of the mix. The friction measurements are excellent with only the SB Lane 2 being slightly on the low side for a new pavement.

Final Test Results

Wear, ride and friction resistance tests were performed in the spring and fall of each year bracketing the studded tire season. The tests provide a before and after measurement of any changes due to studded tires. Pavement condition survey results will also be reported. The wear measurements will be presented first because the primary reason for using the high slag content mixes was to mitigate studded tire wear. A discussion of ride, friction resistance, and pavement condition survey results will follow the section on wear.

Wear

The 2.7 mm rut depth on the 30% slag section after six years indicates that studded tires are not having a large impact on this section (Table 12). The same rut depth was also recorded for the control section that makes up the remaining length of northbound lane 1. This would indicate that the higher slag content mix was not having any impact on wear. The remaining lanes (NB2, SB1 and SB2) had greater rut depths ranging from 3.1 to 3.6 mm, however, these greater depths may be the result of the as built condition of the lanes. Note that the initial readings on these lanes ranged from 2.7 to 3.1 mm. If these initial rut depths are subtracted from the spring 2013 readings the amount of increase in rut depth ranges from 0.2 to 0.5 mm which is similar to the 0.3 mm change for the 30% slag lane.

Table 12. Wear measurements for all lanes.

Section	Dir/Lane	Spring 2009 (mm)	Fall 2010 (mm)	Spring 2011 (mm)	Fall 2011 (mm)	Spring 2012 (mm)	Fall 2012 (mm)	Spring 2013 (mm)	Change Spring 2009 to 2013 (mm)
30% Slag	NB1	2.4	2.2	2.6	2.4	2.4	2.4	2.7	0.3
Control	NB1	2.5	2.2	2.7	2.5	2.6	2.3	2.7	0.2
Control	NB2	3.0	3.0	3.2	3.1	3.1	3.0	3.5	0.5
Control	SB1	2.7	2.8	2.7	2.8	2.9	2.7	3.1	0.4
Control	SB2	3.1	2.9	3.1	2.7	3.1	2.7	3.6	0.5

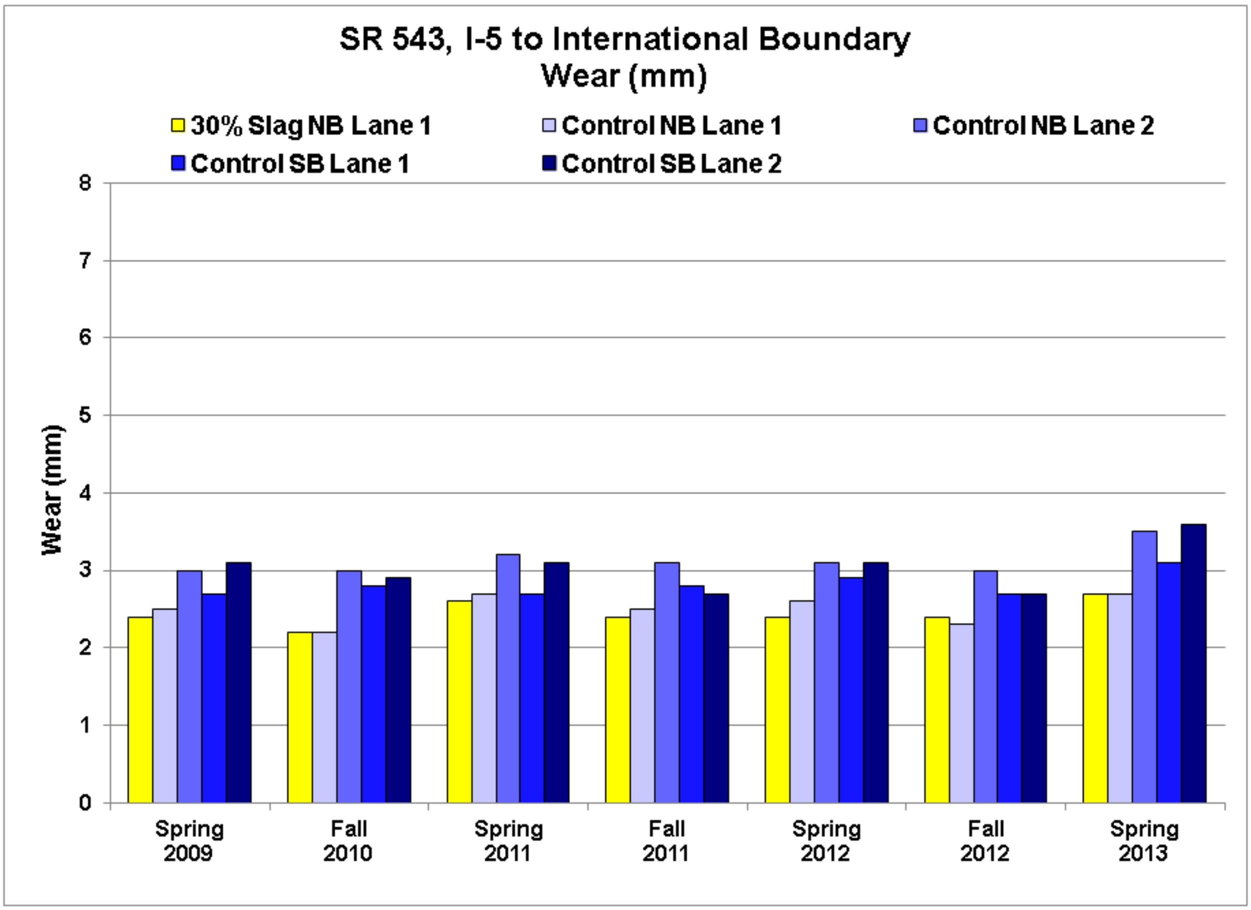

Figure 4. Wear measurements for all lanes.

A review of the images from the WSPMS revealed that the transverse tining texture on the pavement is still present in the wheel paths for the travel lanes throughout the entire project. It appears that the pavement was diamond ground to meet smoothness requirements and it is only in these areas that the transverse tining texture is absent. The rut depths that indicate very little studded tire wear are supported by the presence of the original transverse tining texture.

One of the possible reasons for the absence of wear on this section is the 40 mph speed limit. The damage done by studded tires is directly related to the speed of the vehicles. Table 13 presents the results of a study performed in Finland relating vehicle speed in kilometers per hour and pavement wear in cubic millimeters (Unhola 1997). A decrease in vehicle speed from 62 (100km/h) mph to 43 mph (70 km/h) could potentially decrease the pavement wear from 0.034 in^3 to 0.016 in^3 (0.56 cm^3 to 0.27 cm^3), or over a 50 percent reduction in wear.

Table 13. Pavement wear due to vehicle speed (Unhola 1997).

Vehicle Speed ((km/h (mph))	Pavement Wear ((cm^3(in^3))
50 (30)	0.20 (0.012)
60 (37)	0.23 (0.014)
70 (43)	0.27 (0.016)
80 (50)	0.32 (0.020)
90 (55)	0.42 (0.026)
100 (62)	0.56 (0.034)
110 (67)	0.78 (0.048)
120 (74)	1.19 (0.073)

Ride

The ride measurements are somewhat difficult to interpret (Table 14). The ride on the 30% slag section increases slightly over the study period. The readings for the remainder of the NB1 lane decrease slightly, if the spring 2009 reading is considered an outlier. The readings for the other lanes also decrease over the study period.

Table 14. Ride measurements for all lanes.								
Section	Dir/Lane	Spring 2009 (IRI)	Fall 2010 (IRI)	Spring 2011 (IRI)	Fall 2011 (IRI)	Spring 2012 (IRI)	Fall 2012 (IRI)	Spring 2013 (IRI)
30% Slag	NB1	93	97	105	108	94	102	102
Control	NB1	180	140	145	134	137	136	135
Control	NB2	148	118	121	117	120	117	117
Control	SB1	93	79	81	87	73	71	70
Control	SB2	105	103	85	88	88	79	85

The bar chart (Figure 5) shows the relatively minor changes in the ride over time. The spring 2009 readings for all of the lanes appear to be an anomaly.

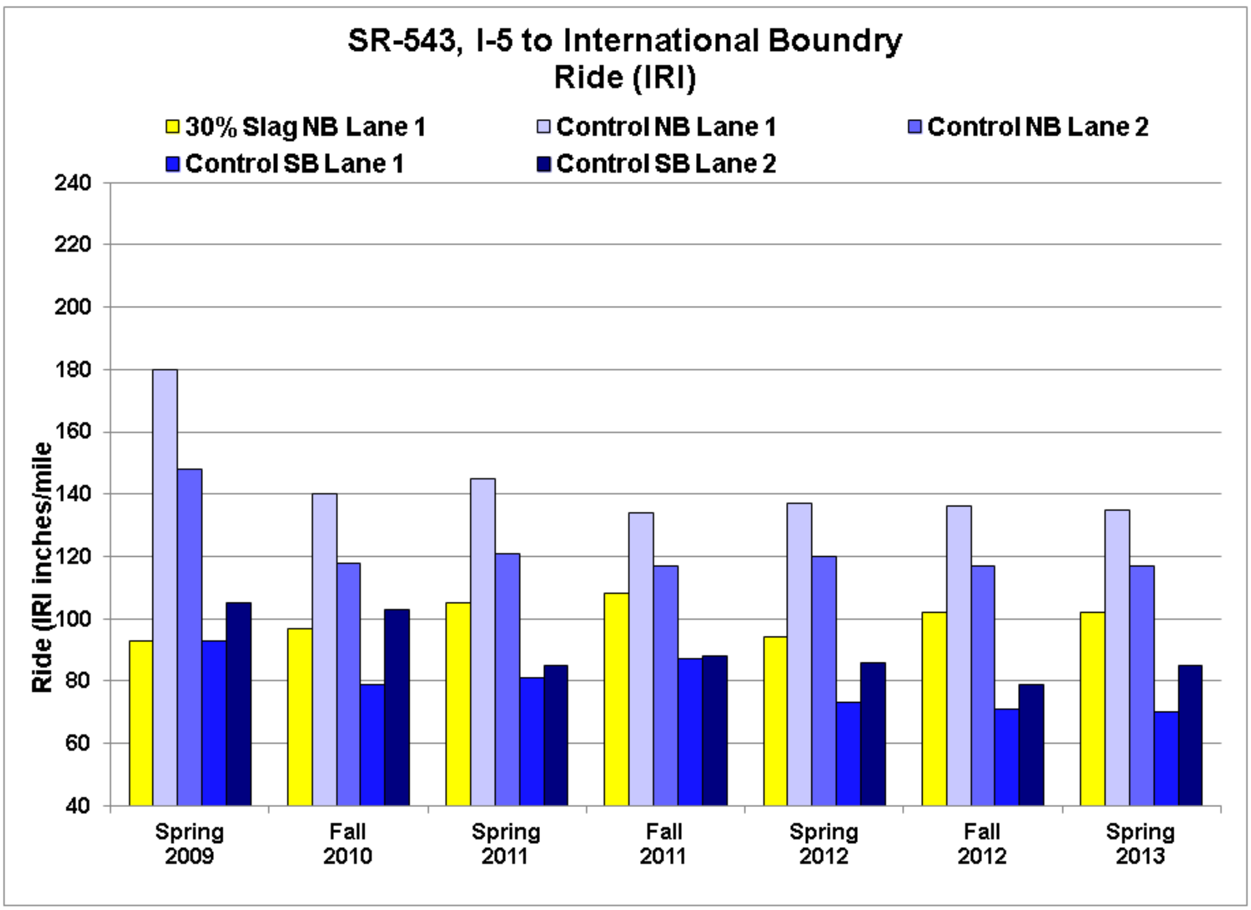

Figure 5. Ride measurements for all lanes.

Friction Resistance

Friction resistance data for the project are listed in Table 15 and shown graphically in Figure 6. The values are very good and consistent with the exception of SB2 which is inconsistent for an unknown reason. Overall the values are well above the level where there is a safety concern (FN less than 30).

Table 15. Friction resistance measurements for all lanes.

Section	Dir/Lane	Spring 2009 (FN)	Fall 2010 (FN)	Spring 2011 (FN)	Fall 2011 (FN)	Spring 2012 (FN)	Fall 2012 (FN)	Spring 2013 (FN)
30% Slag	NB1	50.5	53.6	50.7	50.2	51.6	51.7	47.6
Control	NB1	53.8	54.7	54.8	52.7	56.7	55.4	47.6
Control	NB2	52.9	56.3	51.9	51.5	52.3	49.1	53.9
Control	SB1	50.5	56.0	49.2	51.5	48.8	48.1	46.5
Control	SB2	41.5	48.9	36.4	40.6	39.9	49.9	38.3

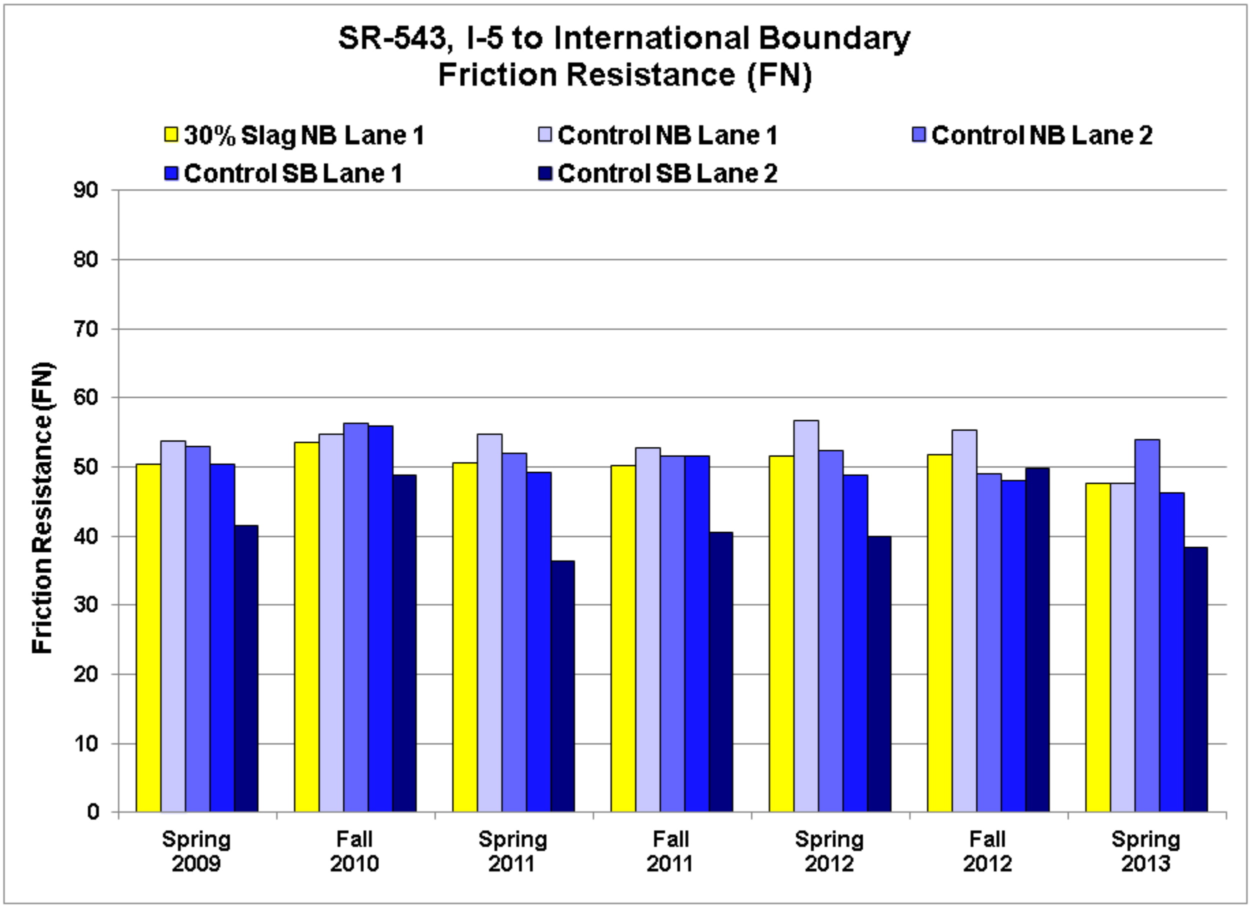

Figure 6. Friction resistance measurements for all lanes.

Pavement Condition Survey Results

The WSPMS data indicated a rating of 100 (no defects) on this section after six years of service. The detailed information indicated medium spalling in the increasing milepost direction. A review of the WSPMS survey images shows that the transverse tining is absent in the wheel paths in many areas which is consistent with the wear measurements.

Conclusions

After 6 years of traffic there is no evidence that the concrete pavement built with the higher slag content mix is more resistant to wear from studded tires. The lower vehicle speeds on this section may be a major contributor to the lower rates of wear. Even though the purpose of building these sections was to determine studded tire wear resistance, it seems that the slag mix is performing equivalent to the control mixes.

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Appendix A

Mix Designs

Washington State Department of Transportation

Concrete Mix Design

Contractor	Submitted By	Date
Acme Concrete Paving, Inc.	Chris Papich	12/13/2006

Concrete Supplier	Plant Location
Cowden Gravel and Ready Mix	Blain, Wa *

Contract Number	Contract Name
C 7064	SR 543-I5 International Boundary Widening

This mix is to be used in the following Bid Item No(s): 81,237,247,254

Concrete Class: *(check one only)*
☐ 3000 ☐ 4000 ☐ 4000D ☐ 4000P[a] ☐ 4000W[a] ☐ Concrete Overlay ☒ Cement Concrete Pavement[d]
☐ Other

Remarks:

Cowden id: SS6012P25

Mix Design No. 7084-25SLAG

Cementitious Materials	Source	Type or Class	Sp. Gr.	Lbs/cy
Cement	Lafarge	TYPE I/II	3.15	423
Fly Ash [a]				
Microsilica				
Latex				
Slag	Lafarge	NewCem	2.87	141

Concrete Admixtures	Manufacturer	Product	Type	Est. Range (oz/cy)
Air Entrainment	Master Builder	AE-90		5-10
Water Reducer	Master Builder	Polyheed 997		25-30
High-Range Water Reducer				
Set Retarder				
Other				

Water (Maximum) 238 (lbs/cy) Reclaimed/Recycled Water[e] (Maximum) ______ (lbs/cy)

Water Cementitious Ratio (Maximum) ~~.36~~ .42 *

Design Performance	1	2	3	4	5	Average
28 Day Compressive Strength (cylinders) psi	4,850	4,810	4,820	4,800	4,960	4,850
14 Day Flexural [d] Strength (beams) psi	810	790	800	795	800	800

Reviewed By: [signature] 3-28-07

PE Signature Date

Mix design no. revised 6/4/07, added Cowdens ID No.

Distribution: Original - Contractor ✓

Copies To - State Materials Lab-General Materials Eng. ; Regional Materials Lab; Project Inspector

DOT Form 350-040 EF
Revised 5/2003

Combined Gradation Chart

Concrete Aggregates	Component 1	Component 2	Component 3	Component 4	Component 5	Combined Gradation
WSDOT Pit No.	F-34	F-34	F-34	F-194		
ASR Mitigation Required? [b]	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☐ Yes ☐ No	
Grading [c]	ASTM C33 NO. 4/67	ASTM C33 NO. ~~67~~ 467	ASTM C-33 NO. 8	WSDOT Class II Sand		
Percent of Total Aggregate	19.7	32	15.16	33.13		100%
Specific Gravity	2.68	2.68	2.68	2.57		
Lbs/cy (ssd)	624	1014	481	1053		
Percent Passing						
2 inch	100	100	100	100		
1-1/2 inch	91	100	100	100		98.1
1 inch	15	100	100	100		83.3
3/4 inch	.4	94	100	100		78.6
1/2 inch	0	41	100	100		61.5
3/8 inch	0.02	8	88	100		49
No. 4	0	0.69	26	100		37.3
No. 8	0	0.1	4	96		32.4
No. 16	0	0	0	73		24.2
No. 30	0	0	0	44		14.4
No. 50	0	0	0	17		5.5
No. 100	0	0	0	7		2.3
No. 200	0	0	0	4		1.1

Aggregate Correction Factor: ____________ Fineness Modulus: 2.64 (Required for Class 2 Sand)

Notes:

a Required for Class 4000D and 4000P mixes.

b If Alkali Silica Reactivity Mitigation is required per WSDOT ASA Database - Attach evidence that mitigating measure controls expansion in the form of ASTM C 1260 / AASHTO T303, ASTM C 1293, or ASTM C 295 test results

c AASHTO No. 467, 57, 67, 7, 8; WSDOT Class 1, Class 2; or combined gradation. See Standard Specification 9-03.1

d Required for Cement Concrete Pavements

e Attach test results indicating conformance to Standard Specification 9-25.1

DOT Form 350-040 EF
Revised 5/2003

Washington State Department of Transportation

Concrete Mix Design

Contractor	Submitted By	Date
Acme Concrete Paving, Inc.	Chris Papich	12/13/2006

Concrete Supplier	Plant Location
Cowden Gravel and Ready Mix	Blain, Wa

Contract Number	Contract Name
C 7064	SR 543-I5 International Boundary Widening

This mix is to be used in the following Bid Item No(s): 81,237,247,254

Concrete Class: ***(check one only)***

☐ 3000 ☐ 4000 ☐ 4000D ☐ 4000P [a] ☐ 4000W [a] ☐ Concrete Overlay ☒ Cement Concrete Pavement [d]
☐ Other

Remarks:

Mix Design No. 7084-30SLAG SS6012P30

Cementitious Materials	Source	Type or Class	Sp. Gr.	Lbs/cy
Cement	Lafarge	TYPE I/II	3.15	395
Fly Ash [a]				
Microsilica				
Latex				
Slag	Lafarge	NewCem	2.87	169

Concrete Admixtures	Manufacturer	Product	Type	Est. Range (oz/cy)
Air Entrainment	Master Builder	AE-90		5-10
Water Reducer	Master Builer	Polyheed 997		25-30
High-Range Water Reducer				
Set Retarder				
Other				

Water (Maximum) 217 (lbs/cy) Reclaimed/Recycled Water [e] (Maximum) ______ (lbs/cy)

Water Cementitious Ratio (Maximum) .38

Design Performance	1	2	3	4	5	Average
28 Day Compressive Strength (cylinders) psi	5,040	5,050	5,030	5,020	5,080	5,040
14 Day Flexural [d] Strength (beams) psi	750	740	760	740	740	745

Reviewed By: [signature] PE Signature 6-18-07 Date

Distribution: Original - Contractor
Copies To - State Materials Lab-General Materials Eng.; Regional Materials Lab; Project Inspector

DOT Form 350-040 EF
Revised 5/2003

Combined Gradation Chart

Concrete Aggregates	Component 1	Component 2	Component 3	Component 4	Component 5	Combined Gradation
WSDOT Pit No.	F-34	F-34	F-34	F-194		
ASR Mitigation Required? [b]	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☐ Yes ☐ No	
Grading [c]	ASTM C33 NO. 4	ASTM C33 NO.67	ASTM C-33 NO. 8	WSDOT Class II Sand		
Percent of Total Aggregate	19.69	32	15.18	33.13		100%
Specific Gravity	2.68	2.68	2.68	2.57		
Lbs/cy (ssd)	624	1014	481	1050		
Percent Passing						
2 inch	100	100	100	100		
1-1/2 inch	91	100	100	100		98.1
1 inch	15	100	100	100		83.3
3/4 inch	.4	94	100	100		78.6
1/2 inch	0	41	100	100		61.5
3/8 inch	0.02	8	88	100		49
No. 4	0	0.69	26	100		37.3
No. 8	0	0.1	4	96		32.4
No. 16	0	0	0	73		24.2
No. 30	0	0	0	44		14.4
No. 50	0	0	0	17		5.5
No. 100	0	0	0	7		2.3
No. 200	0	0	0	4		1.1

Aggregate Correction Factor: ______________ Fineness Modulus: 2.64 ____________ (Required for Class 2 Sand)

Notes:

a Required for Class 4000D and 4000P mixes.

b If Alkali Silica Reactivity Mitigation is required per WSDOT ASA Database - Attach evidence that mitigating measure controls expansion in the form of ASTM C 1260 / AASHTO T303, ASTM C 1293, or ASTM C 295 test results

c AASHTO No. 467, 57, 67, 7, 8; WSDOT Class 1, Class 2; or combined gradation. See Standard Specification 9-03.1

d Required for Cement Concrete Pavements

e Attach test results indicating conformance to Standard Specification 9-25.1

DOT Form 350-040 EF
Revised 5/2003

Washington State Department of Transportation

Concrete Mix Design

Contractor	Submitted By	Date
Acme Concrete Paving, Inc.	Chris Papich	12/13/2006

Concrete Supplier	Plant Location
Cowden Gravel and Ready Mix	Blain, Wa

Contract Number	Contract Name
C 7064	SR 543-I5 International Boundary Widening

This mix is to be used in the following Bid Item No(s): 81,237,247,254

Concrete Class: *(check one only)*
☐ 3000 ☐ 4000 ☐ 4000D[a] ☐ 4000P ☐ 4000W[a] ☐ Concrete Overlay ☒ Cement Concrete Pavement[d]
☐ Other

Remarks:

Mix Design No. 7084-35SLAG SSP012635

Cementitious Materials	Source	Type or Class	Sp. Gr.	Lbs/cy
Cement	Lafarge	TYPE I/II	3.15	369
Fly Ash[a]				
Microsilica				
Latex				
Slag	Lafarge	NewCem	2.87	195

Concrete Admixtures	Manufacturer	Product	Type	Est. Range (oz/cy)
Air Entrainment	Master Builder	AE-90		5-10
Water Reducer	Master Builer	Polyheed 997		25-30
High-Range Water Reducer				
Set Retarder				
Other				

Water (Maximum) 217 (lbs/cy) Reclaimed/Recycled Water[e] (Maximum) ______ (lbs/cy)

Water Cementitious Ratio (Maximum) .38

Design Performance	1	2	3	4	5	Average
28 Day Compressive Strength (cylinders) psi	5,540	5,550	5,530	5,520	5,600	5,550
14 Day Flexural[d] Strength (beams) psi	810	800	800	805	810	805

converts to > 3618 psi

Reviewed By: ______________________ PE Signature ______________ Date

Distribution: Original - Contractor
Copies To - State Materials Lab-General Materials Eng. ; Regional Materials Lab; Project Inspector

DOT Form 350-040 EF
Revised 5/2003

Combined Gradation Chart

Concrete Aggregates	Component 1	Component 2	Component 3	Component 4	Component 5	Combined Gradation
WSDOT Pit No.	F-34	F-34	F-34	F-194		
ASR Mitigation Required? [b]	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☐ Yes ☐ No	
Grading [c]	ASTM C33 NO. 4	ASTM C33 NO.67	ASTM C-33 NO. 8	WSDOT Class II Sand		
Percent of Total Aggregate	19.7	32.02	15.19	33.09		100%
Specific Gravity	2.68	2.68	2.68	2.57		
Lbs/cy (ssd)	624	1014	481	1048		
Percent Passing						
2 inch	100	100	100	100		
1-1/2 inch	91	100	100	100		98.1
1 inch	15	100	100	100		83.3
3/4 inch	.4	94	100	100		78.6
1/2 inch	0	41	100	100		61.5
3/8 inch	0.02	8	88	100		49
No. 4	0	0.69	26	100		37.3
No. 8	0	0.1	4	96		32.4
No. 16	0	0	0	73		24.2
No. 30	0	0	0	44		14.4
No. 50	0	0	0	17		5.5
No. 100	0	0	0	7		2.3
No. 200	0	0	0	4		1.1

Aggregate Correction Factor: ____________ Fineness Modulus: 2.64 (Required for Class 2 Sand)

Notes:

[a] Required for Class 4000D and 4000P mixes.

[b] If Alkali Silica Reactivity Mitigation is required per WSDOT ASA Database - Attach evidence that mitigating measure controls expansion in the form of ASTM C 1260 / AASHTO T303, ASTM C 1293, or ASTM C 295 test results

[c] AASHTO No. 467, 57, 67, 7, 8; WSDOT Class 1, Class 2; or combined gradation. See Standard Specification 9-03.1

[d] Required for Cement Concrete Pavements

[e] Attach test results indicating conformance to Standard Specification 9-25.1

DOT Form 350-040 EF
Revised 5/2003

Washington State Department of Transportation

Concrete Mix Design

Contractor	Submitted By	Date
Acme Concrete Paving, Inc.	Chris Papich	12/13/2006

Concrete Supplier	Plant Location
Cowden Gravel and Ready Mix	Blain, Wa

Contract Number	Contract Name
C 7064	SR 543-I5 International Boundary Widening

This mix is to be used in the following Bid Item No(s): 81,237,247,254

Concrete Class: ***(check one only)***

☐ 3000 ☐ 4000 ☐ 4000D ☐ 4000P[a] ☐ 4000W[a] ☐ Concrete Overlay ☒ Cement Concrete Pavement[d]

☐ Other

Remarks:

Cowden id# SS80124P24

Mix Design No. 7084-24HR

Cementitious Materials	Source	Type or Class	Sp. Gr.	Lbs/cy
Cement	Lafarge	TYPE I/II	3.15	752
Fly Ash[a]				
Microsilica				
Latex				
Slag				

Concrete Admixtures	Manufacturer	Product	Type	Est. Range (oz/cy)
Air Entrainment	Master Builder	AE-90		5-10
Water Reducer				
High-Range Water Reducer	Master Builder	Glenuim 3030 NS	F	~~50-60~~ ~~75~~ 15-60 RM
Set Retarder		added by WSDOT		
Other				

Water (Maximum) 263 (lbs/cy) Reclaimed/Recycled Water[e] (Maximum) (lbs/cy)

Water Cementitious Ratio (Maximum) .35

Design Performance	1	2	3	4	5	Average
28 Day Compressive Strength (cylinders) psi	6,600	6,680	6,630	6,700	6,740	6,670
14 Day Flexural[d] Strength (beams) psi	980	1,000	970	1,010	980	990

Reviewed By: [signature] PE Signature 5-16-07 Date

Distribution: Original - Contractor
Copies To - State Materials Lab-General Materials Eng.; Regional Materials Lab; Project Inspector

DOT Form 350-040 EF
Revised 5/2003

mix design No revised 6/4/07, added Cowdens id No.

Combined Gradation Chart

Concrete Aggregates	Component 1	Component 2	Component 3	Component 4	Component 5	Combined Gradation
WSDOT Pit No.	F-34	F-34	F-34	F-194		
ASR Mitigation Required? [b]	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☐ Yes ☐ No	
Grading [c]	ASTM C33 NO. 4	ASTM C33 NO.67	ASTM C-33 NO. 8	WSDOT Class II Sand		
Percent of Total Aggregate	20	37	10	33		100%
Specific Gravity	2.68	2.68	2.68	2.57		
Lbs/cy (ssd)	588	1088	294	1088		
Percent Passing						
2 inch	100	100	100	100		
1-1/2 inch	91	100	100	100		98.1
1 inch	15	100	100	100		83.0
3/4 inch	.4	94	100	100		77.9
1/2 inch	0	41	100	100		58.2
3/8 inch	0.02	8	88	100		44.8
No. 4	0	0.69	26	100		35.9
No. 8	0	0.1	4	96		32.1
No. 16	0	0	0	73		24.1
No. 30	0	0	0	44		14.5
No. 50	0	0	0	17		5.6
No. 100	0	0	0	7		2.3
No. 200	0	0	0	4		1.3

Aggregate Correction Factor: ____________ Fineness Modulus: 2.64 (Required for Class 2 Sand)

Notes:

[a] Required for Class 4000D and 4000P mixes.

[b] If Alkali Silica Reactivity Mitigation is required per WSDOT ASA Database - Attach evidence that mitigating measure controls expansion in the form of ASTM C 1260 / AASHTO T303, ASTM C 1293, or ASTM C 295 test results

[c] AASHTO No. 467, 57, 67, 7, 8; WSDOT Class 1, Class 2; or combined gradation. See Standard Specification 9-03.1

[d] Required for Cement Concrete Pavements

[e] Attach test results indicating conformance to Standard Specification 9-25.1

DOT Form 350-040 EF
Revised 5/2003

Washington State Department of Transportation

Concrete Mix Design

Contractor	Submitted By	Date
Acme Concrete Paving, Inc.	Chris Papich	12/13/2006

Concrete Supplier	Plant Location
Cowden Gravel and Ready Mix	Blain, Wa

Contract Number	Contract Name
C 7064	SR 543-I5 International Boundary Widening

This mix is to be used in the following Bid Item No(s): 81,237,247,254

Concrete Class: *(check one only)*
☐ 3000 ☐ 4000 ☐ 4000D ☐ 4000P[a] ☐ 4000W[a] ☐ Concrete Overlay ☒ Cement Concrete Pavement[d]
☐ Other

Remarks:

Cowden id# 557014 P48

Mix Design No. 7084-48HR

Cementitious Materials	Source	Type or Class	Sp. Gr.	Lbs/cy
Cement	Lafarge	TYPE I/II	3.15	658
Fly Ash[a]				
Microsilica				
Latex				
Slag				

Concrete Admixtures	Manufacturer	Product	Type	Est. Range (oz/cy)
Air Entrainment	Master Builder	AE-90		5-10
Water Reducer				
High-Range Water Reducer	Master Builder	Glenuim 3030 NS	F	~~50-60~~ 13-60 RY
Set Retarder		added by		WSDOT
Other				

Water (Maximum) 238 (lbs/cy) Reclaimed/Recycled Water[e] (Maximum) ______ (lbs/cy)

Water Cementitious Ratio (Maximum) .36

Design Performance	1	2	3	4	5	Average
28 Day Compressive Strength (cylinders) psi	6,800	6,870	6,790	6,820	6,900	6,840
14 Day Flexural[d] Strength (beams) psi	950	970	970	1,000	960	970

Reviewed By: [illegible] 5-16-07
PE Signature Date

Mix Design No. revised 6/4/07, added Cowden's ID No.

Distribution: Original - Contractor
Copies To - State Materials Lab-General Materials Eng. ; Regional Materials Lab; Project Inspector

DOT Form 350-040 EF
Revised 5/2003

Combined Gradation Chart

Concrete Aggregates	Component 1	Component 2	Component 3	Component 4	Component 5	Combined Gradation
WSDOT Pit No.	F-34	F-34	F-34	F-194		
ASR Mitigation Required? [b]	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☒ Yes ☐ No	☐ Yes ☐ No	
Grading [c]	ASTM C33 NO. 4	ASTM C33 NO.67	ASTM C-33 NO. 8	WSDOT Class II Sand		
Percent of Total Aggregate	20	37	10	33		100%
Specific Gravity	2.68	2.68	2.68	2.57		
Lbs/cy (ssd)	588	1088	294	1088		
Percent Passing						
2 inch	100	100	100	100		
1-1/2 inch	91	100	100	100		98.1
1 inch	15	100	100	100		83.0
3/4 inch	.4	94	100	100		77.9
1/2 inch	0	41	100	100		58.2
3/8 inch	0.02	8	88	100		44.8
No. 4	0	0.69	26	100		35.9
No. 8	0	0.1	4	96		32.1
No. 16	0	0	0	73		24.1
No. 30	0	0	0	44		14.5
No. 50	0	0	0	17		5.6
No. 100	0	0	0	7		2.3
No. 200	0	0	0	4		1.3

Aggregate Correction Factor: ____________ Fineness Modulus: 2.64 (Required for Class 2 Sand)

Notes:

- a Required for Class 4000D and 4000P mixes.
- b If Alkali Silica Reactivity Mitigation is required per WSDOT ASA Database - Attach evidence that mitigating measure controls expansion in the form of ASTM C 1260 / AASHTO T303, ASTM C 1293, or ASTM C 295 test results
- c AASHTO No. 467, 57, 67, 7, 8; WSDOT Class 1, Class 2; or combined gradation. See Standard Specification 9-03.1
- d Required for Cement Concrete Pavements
- e Attach test results indicating conformance to Standard Specification 9-25.1

DOT Form 350-040 EF
Revised 5/2003

Appendix B

Project Engineer E-Mail

E-mail was reproduced exactly from the original.

Damitio, Chris

From: Damitio, Chris

Sent: Thursday, June 21, 2007 1:33 PM

To: Williams, Kurt R; Foster, Marco

Cc: Fuller, Patrick

Subject: Slag-SR543

Kurt,

We got the ride numbers back on the sections we paved the first couple of days and they are horrible. We haven't run the $'s yet but one section was at 3" per .1 mile with .7 being the standard.

Overall I found he mud to be extremely stiff and at the slower production rates we were seeing I think it was setting up prior to going through the paver. Granted I think we had the "B" team and equipment from Acme here it was a common observation from both the Acme and DOT team that the mud was "hot". I think another factor may be Cowden as the supplier. In my view they have shown a lack of detail in QC and this may have lead to inconsistencies or properties that were unexpected.

Appearance wise the pavement looks good and the only cracking evident at this time is at the joints but the workability is a big question in my mind.

I would like to recommend we skip the 35% test section unless Acme can show us how the ride is going to improve. I am concerned that the added slag may be creating a workability challenge that is difficult to react to unless all suppliers, pavers, personnel and equipment are at the top of their game.

CHRIS 788-7403

Appendix C

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

Use of Higher Slag Content in Concrete Pavements

SR-543, I-5 to International Boundary Widening Contract 7064
Milepost 0.20 to Milepost 1.09

Prepared by

Kurt Williams, P.E.
Assistant Construction Engineer, Roadway
Washington State Department of Transportation

Jeff Uhlmeyer, P.E.
Pavement Design Engineer
Washington State Department of Transportation

Introduction

Washington State Department of Transportation's (WSDOT) Portland Cement Concrete Pavement (PCCP) construction program has been relatively small since the construction of the Interstate system in the 1960's and early 70's. As many of these early pavements deteriorate and require reconstruction, the best possible construction practices will be essential in order to provide pavements that will last 40 years or longer.

One of the challenges facing WSDOT is the availability of fly ash for use in concrete pavements. Class F fly ash has been used by WSDOT for many years because of the local availability of this material from the Centralia Power Plant. Recently this facility has changed the type of coal it is burning to a lower grade variety and as a result will be producing only Class C fly ash. As a substitute for fly ash and a portion of the cement, Ground Granulated Blast Furnace Slag (GGBFS) can be added. This project will utilize up to 25 percent of the slag in the mix, but WSDOT would like to experiment with high slag content mixes (30 to 35 percent slag). One benefit of switching to high slag content mixes may be a reduction in studded tire wear because high slag content mixes produce higher strengths. This experimental feature will investigate the performance of high slag mixes and the possible reductions in wear from studded tires.

Plan of Study

Contract 7064, I-5 to International Boundary Widening, places approximately 11,500 cubic yards of portland cement concrete pavement (PCCP) on SR 543. Under this proposal two approximately 650-foot test sections (approximately 435 cubic yards each) will be placed, the first incorporating 30 percent slag and the second incorporating 35 percent slag. The existing 3,000 psi compressive strength mix design, which will utilize about 23 percent slag, will be modified for the two test sections by adjusting the proportions. The adjusted proportions using the 30 percent slag equates to 169 pounds of slag and 395 pounds of cement and for the 35 percent slag equates to 197 pounds of slag and 367 pounds of cement.

Layout

The two 650-foot test sections will be placed in the northbound lanes between approximately MP 0.34 to 0.92 (metric Station 1+286 and 1+900) for a total length of 0.58 miles (2,014 feet). A change order will be processed to include the two test sections in the contract. The exact location will be determined by the Project Engineer in consultation with the Contractor.

Control Section

The remainder of the project paved with the standard 3,000 psi compressive strength mix with 23 percent slag will be the control section for the higher slag content test sections.

Testing Plan

Pavement wear and smoothness measurements will be made on a twice yearly basis, in the spring, after studded tires are no longer legal, and again in the fall prior to the use of studs. The sections will also be monitored for friction resistance on a yearly basis. These tests will measure any changes in performance of the pavement with time as a result of studded tire wear. Pavement condition survey results will be collected on an annual basis as part of the normal Washington State Pavement Management System (WSPMS) survey routine.

Reporting

An “End of Construction” report will be written following completion of the test sections. This report will include construction details, construction test results, and other details concerning the overall process. Annual summary reports will also be issued over the next five years. At the end of the period, a final report will be written which summarizes performance characteristics and future recommendations for use of high slag content mixes.

Staffing

The Region Project office will coordinate and manage all construction aspects. Representatives from HQ Materials Laboratory and HQ Construction Office will also be involved with documenting the construction and performance.

Contacts and Report Author

Kurt Williams
Assistant Construction Engineer, Roadway
Washington State DOT
(360) 705-7830
Willikr@wsdot.wa.gov

Jeff Uhlmeyer
Pavement Design Engineer
Washington State DOT
(360) 709-5485
Uhlmeyj@wsdot.wa.gov

Cost Estimate

Construction Costs

There is no additional cost for using the 30 and 35 percent slag for the two 650-foot test section. The cement supplier, Lafarge, is absorbing the cost for the extra slag and mix design modifications and ACME is placing the PCCP at the original contract bid price.

Testing Costs

Condition Survey – will be conducted as part of statewide annual survey, no cost

Rut Measurements – 10- surveys (2 hours each) requires traffic control = $12,000

Friction Measurements – 6 surveys (2 hours each) 6,000

Report Writing Costs

Initial Report – 20 hours = $1,500

Annual Report – 5 hours (1 hour each) = $500

Final Report – 10 hours = $1,000

Total Cost = $21,000

Schedule

The construction is scheduled for the summer of 2007. The testing schedule is therefore summarized in the following table.

Date	Condition Survey (Annual)	Wear and Smoothness Measurements	Friction Measurements	End of Const. Report	Annual Report	Final Report
Oct 2007		X	X	X		
Spring 2008	X	X				
Fall 2008		X	X		X	
Spring 2009	X	X				
Fall 2009		X	X		X	
Spring 2010	X	X				
Fall 2010		X	X		X	
Spring 2011	X	X				
Fall 2011		X	X		X	
Spring 2012	X	X				
Fall 2012		X	X			X