Evaluation of Portland Cement Concrete Pavement with High Slag Content Cement

WA-RD 728.1

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June 2009

Washington State
Department of Transportation
Office of Research & Library Services

WSDOT Research Report

Experimental Feature Report

Post-Construction and Performance 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

1. REPORT NO.
WA-RD 728.1

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
Evaluation of Portland Cement Concrete Pavement With High Slag Content Cement

5. REPORT DATE
June 2009

6. PERFORMING ORGANIZATION CODE
WA 07-03

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

. PERFORMING ORGANIZATION NAME AND ADDRESS
Washington State Department of Transportation
Materials Laboratory, MS-47365
Olympia, WA 98504-7365

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Washington State Department of Transportation
Transportation Building, MS 47372
Olympia, Washington 98504-7372
Project Manager: Kim Willoughby, 360-705-7978

13. TYPE OF REPORT AND PERIOD COVERED
Post-Construction and Performance Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
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. This report details the construction of the pavement, construction quality control tests, and initial base line wear, friction, and smoothness results.

17. KEY WORDS
Ground Granulated Blast Furnace Slag, GGBFS, concrete performance, studded tires

18. DISTRIBUTION STATEMENT
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	34	

DISCLAIMER

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Introduction

This experimental feature will investigate the performance of high slag 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. 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 substitute for portland cement because it has cementitious properties just like 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 that is used as a flux in the making of iron, 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 granules with a high content of glass. These granules are dried and ground to produce a cememtitious material.

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 later age strength of slag cement are comparable too or higher than same concrete with all hydraulic 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 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 used on this project, there are no problems reported in the literature.

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 on SR 543. 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 cement without slag. The later two mix designs were 24 hour and 48 hour mixes, indicating that they were 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 delivered appear to be most attributed to the contractors delivery method of utilizing an off site concrete batch plant with concrete mixer trucks with a one way delivery time of approximately one hour. As a result the there were several instances when the concrete began to take a set prior to being processed through the paver. The variability of the compressive strength test results for the 25 percent slag mix design noted in the section that follows corroborates this observation.

Test Section

The test section of 30 % 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% slag mix design.

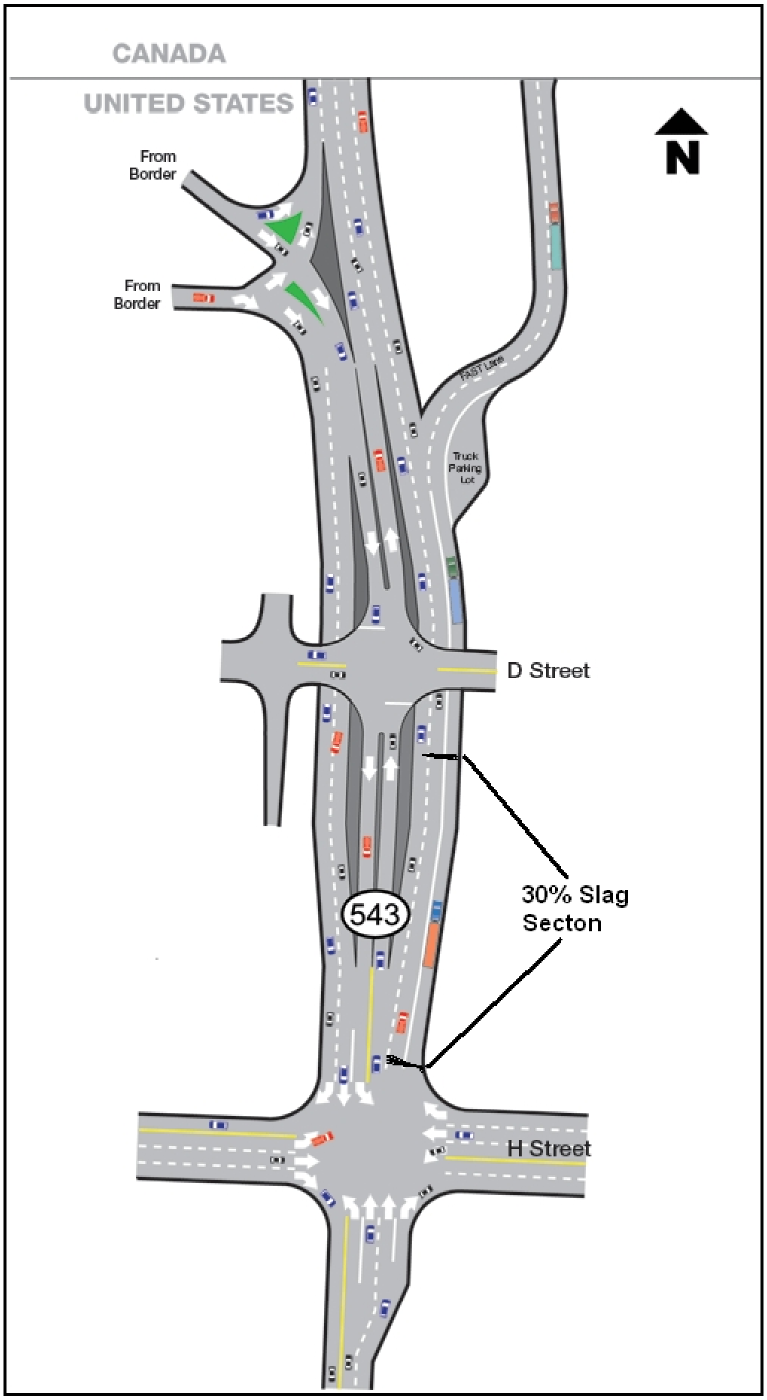

Figure 2. Project lane configuration and test section location.

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 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
		Total	**6074**		
			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 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
		Total	**873**		
			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 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	1062
10/4/07	I/S H Street & SR 543		149	7,870	1075
10/5/07	L 1+247.83	L 1+250.21	48	7,550	1053
10/12/07	L 1+231.12	L 1+247.09	42	6,920	1008
		Total	**437**		
			Average	**7,218**	**1029**
			STD DEV	**547**	**39**

Table 9. Compressive and flexural strengths for 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
		Total	**482**		
			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 be not observed.

Table 10. Compressive strengths for 30 percent slag mix design cylinders with time.	
Test Date	Compressive Strength (psi)
2 day	2580
6 day	3380
14 days	4140
28 days	5110
180 days	5330
1 year	5780

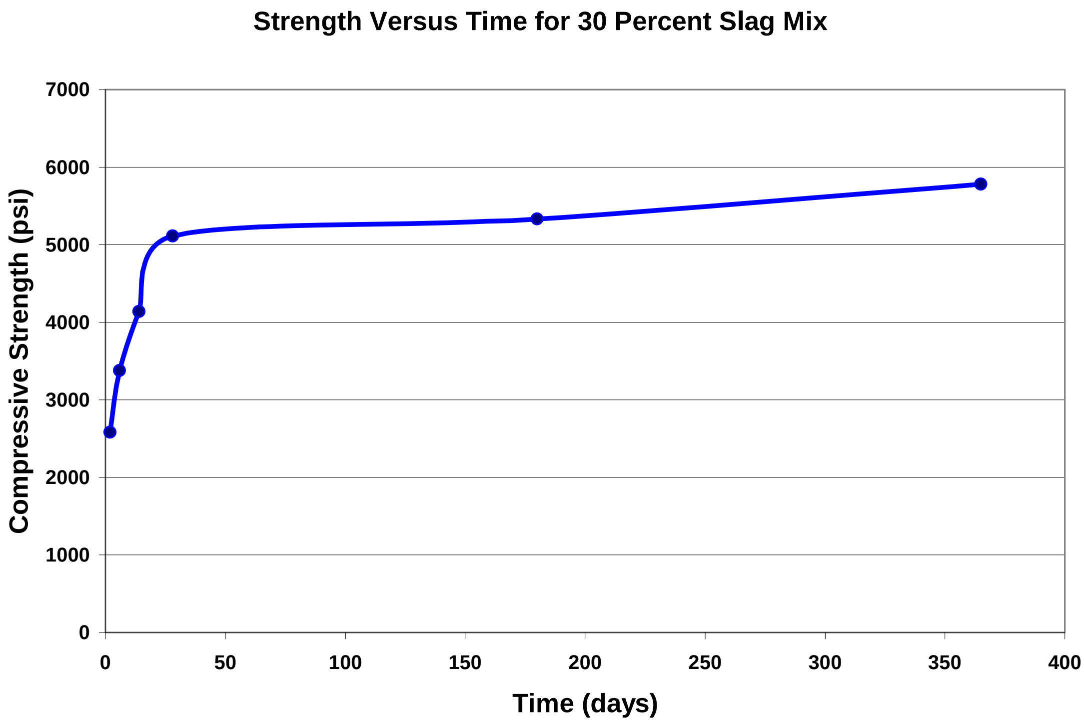

Figure 3. Strength versus time for 30 percent slag mix.

Post-Construction Test Results

Wear and ride measurements on the 30 percent slag and control sections were conducted on April 21, 2009 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	Direction	Lane	Wear (mm)	Ride (IRI)	Friction (FN)
30% Slag	NB	1	2.4	93	50.5
Control	NB	1	2.5	180	53.8
Control	NB	2	3.0	148	52.9
Control	SB	1	2.7	106	50.5
Control	SB	2	3.0	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.

Evaluation Plan

The experimental feature work plan (Appendix C) for this project calls for wear, ride, and friction testing for five years on a twice yearly basis in the spring and fall to bracket the season when studded tires are legal. Pavement condition will be monitored on a yearly basis using data from the Washington State Pavement Management System (WSPMS). The lane configuration of the finished project is shown in Figure 2.

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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: 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

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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. 7084-35SLAG 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

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/ CL II

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~~-60 RH
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
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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
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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: [signature] PE Signature 5-16-07 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

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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

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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
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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