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FIELD INSTALLATION IN PENNSYLVANIA TO ASSESS SHRP RECOMMENDATIONS FOR ASR CONTROL: PART 2 LABORATORY TESTING OF JOB MATERIAL

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ABSTRACT

In May of 1997, the Pennsylvania Department of Transportation placed a pavement test section on the Lackawanna Valley Industrial Highway (LVIH) to test some recommendations for alkali-silica reactivity (ASR) prevention in new concrete resulting from the Strategic Highway Research Program (SHRP). In addition to a control section containing high alkali cement and highly reactive coarse and fine aggregates, eleven other sections were placed, most of which contained the same cement and aggregates, and different proportions of Class F fly ash, ground granulated blast furnace slag (GGBFS), and/or $LiOH \cdot H_2O$. One of the eleven sections contained low alkali cement. A laboratory testing program for the materials utilized on the job, intended to help correlate laboratory test results with field test results, was also planned and executed. Based on the ASTM C 441 test results, the 100% high alkali cement test section will show the worst field performance, the test section containing 15% Class F fly ash plus Na_2O_{eq}:$LiOH \cdot H_2O$ of 1:0.75 by weight will show the best field performance, and the other test section combinations of high alkali cement plus mineral admixture or $LiOH \cdot H_2O$, and low alkali cement, will fall between these two extremes. The predicted field performances of the seven combinations of high alkali cement and mineral admixtures that could be tested utilizing both ASTM C 441 and AASHTO T 303 ranked somewhat differently by the two different test procedures. Only monitoring of the actual pavement test sections will demonstrate which of the two test procedures better predicts the actual field performance of these seven test sections.

Keywords: Alkali-silica reactivity (ASR), ASR prevention, Class F fly ash, ground granulated blast furnace slag (GGBFS), lithium, $LiOH \cdot H_2O$, ASTM C 441, AASHTO T 303.

INTRODUCTION

The results of the research on alkali-silica reactivity (ASR) from the Strategic Highway Research Program (SHRP) were published in 1993. A number of recommendations were made at that time with respect to ASR, including the following:

1. Additional research, including evaluation of field performance of highway structures, should be conducted to further substantiate the rapid immersion test criteria suggested for evaluating safe cement alkali levels and pozzolan requirements to avoid deleterious ASR for particular aggregates (Stark et al. 1993)."

2. "Addition of LiOH should be seriously considered as a means of preventing development of deleterious ASR. It does not need to be tested, and it maintains its effectiveness in the presence of fly ashes and deicer salts (Stark et al. 1993)."

In 1994, Federal Highway Administration solicited participation in the SHRP Concrete and Structures Test and Evaluation Project 34 as a means of implementing the ASR research results from SHRP. This project consisted of three parts:

a.) participation in a mortar bar round robin utilizing the rapid mortar bar test for the ASR potential of aggregates. This test method is now known as ASTM C 1260 or AASHTO T 303;
b.) participation in a field evaluation of the SHRP ASR pavement test sections in New Mexico and Nevada; and
c.) ASR remediation field trials for new/existing concrete structures.

The Pennsylvania Department of Transportation responded to the invitation to participate in Evaluation Project 34 by submitting a work plan and an estimate of the project participation cost to FHWA's Office of Technology Assessment in May of 1995. In August of 1995, FHWA returned a signed work order to the Department for its participation in Evaluation Project 34, and a series of meetings were held in 1995 and 1996 with personnel from the Department, FHWA, FMC Corporation (suppliers of the LiOH admixture), and the contractor, New Enterprise Stone and Lime, in order to finalize the exact location where the ASR pavement test section would be placed, and the mixture designs that would be utilized in the ASR pavement test section. The location selected was on the Lackawanna Valley Industrial Highway (see Fig. 1), which is a new four-lane highway that extends northeast from the intersection of Interstates 81 and 380/84 toward Carbondale, in Lackawanna County.

The planning meetings for the ASR pavement test section resulted in agreement on the use of twelve different mix designs for the test section. Table 1 lists the pertinent details of the twelve individual mix designs. The Na_2O_{eq}, as determined by X-ray fluorescence, for the high and low alkali job cements are as listed in Table 1. The same sources of high alkali cement, reactive coarse aggregate, reactive fine aggregate, Class F fly ash, and ground granulated blast furnace slag (GGBFS) were utilized, where applicable, throughout the mixtures. A previous paper (Thomson and Stokes 1999) reported details of the project construction.

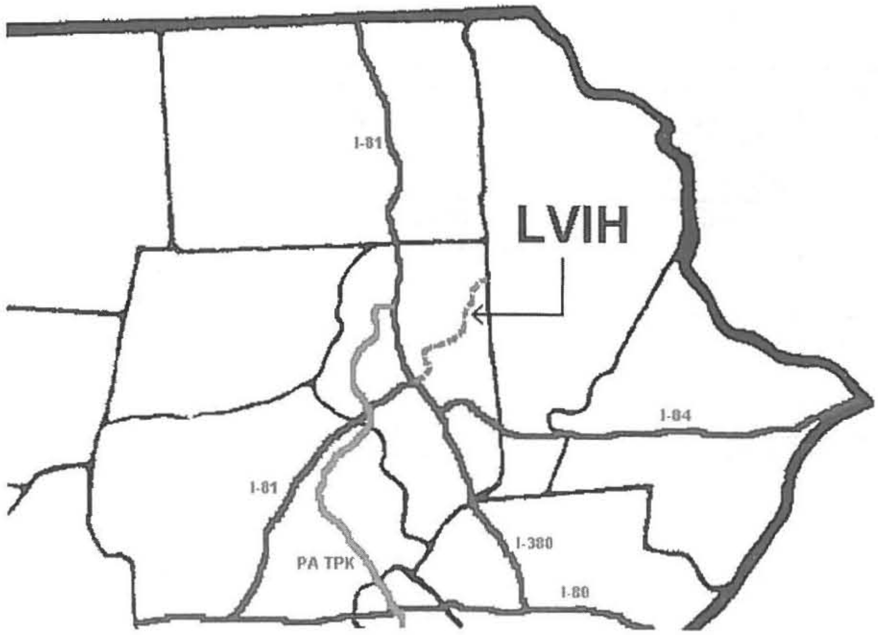

Fig. 1: Map showing location of the Lackawanna Valley Industrial Highway in Northeastern Pennsylvania.

LABORATORY TESTING OF JOB MATERIALS

A portion of the work plan submitted by the Department consisted of laboratory testing of materials used in the pavement test section. Originally, the work plan specified that each material combination used in the pavement test section would be tested by AASHTO TP 14, "Standard Test Method for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction"(now assigned the permanent designation AASHTO T 303), to provide laboratory test data to verify the field testing. However, no modification of this test method has been approved by either ASTM or AASHTO to test the effectiveness of low-alkali cements in combination with specific aggregates. In addition, test data published from a study done in New Mexico (McKeen et al. 1998) demonstrates that AASHTO T 303 mortar bars made with lithium-based admixtures and then placed in 1N NaOH experience leaching of a significant portion of the lithium from the bars during the 14-day immersion period in the NaOH. Therefore, the job materials laboratory testing program was modified to include the following:

TABLE 1: Components Used in the Twelve LVIH Pavement Test Sections

Mix #	Cementitious Materials	Coarse Agg't	Fine Agg't	Chemical Admixture
1	100% high alkali cement (Na_2O_{eq} = 0.86%)	reactive	reactive	none
2	100% high alkali cement	reactive	reactive	$LiOH \cdot H_2O$ to give cement Na_2O_{eq} : $LiOH \cdot H_2O$ of 1: 0.75 by weight
3	100% high alkali cement	reactive	reactive	$LiOH \cdot H_2O$ to give cement Na_2O_{eq} : $LiOH \cdot H_2O$ of 1:1 by weight
4	100% high alkali cement	reactive	reactive	$LiOH \cdot H_2O$ to give cement Na_2O_{eq} : $LiOH \cdot H_2O$ of 1:1.25 by weight
5	100% low alkali cement (Na_2O_{eq} = 0.37%)	reactive	reactive	none
6	75% high alkali cement & 25% GGBFS	reactive	reactive	none
7	60% high alkali cement & 40% GGBFS	reactive	reactive	none
8	50% high alkali cement & 50% GGBFS	reactive	reactive	none
9	85% high alkali cement & 15% Class F fly ash	reactive	reactive	none
10	80% high alkali cement & 20% Class F fly ash (also used for normal paving mix on job)	reactive	reactive	none
11	75% high alkali cement & 25% Class F fly ash	reactive	reactive	none
12	85% high alkali cement & 15% Class F fly ash	reactive	reactive	$LiOH \cdot H_2O$ to give cement Na_2O_{eq} : $LiOH \cdot H_2O$ of 1: 0.75 by weight

TABLE 2: ASTM C 441 Mortar Bar Expansion Results for LVIH Job Materials

Date Made	Mix #	Components Tested	Test Bars % Lin. Expansion	Controls (Mix 5) % Lin. Expansion
4/14/99	1	100% high alkali cement	0.432%	0.300%
4/14/99	9	85% high alkali cement & 15% Class F fly ash	0.239%	0.324%
5/11/99	10	80% high alkali cement & 20% Class F fly ash	0.221%	0.336%
5/11/99	11	75% high alkali cement & 25% Class F fly ash	0.155%	0.351%
7/22/99	2	100% high alkali cement & Na_2O_{eq} : $LiOH \cdot H_2O$ of 1: 0.75	0.014%	0.302%
7/22/99	3	100% high alkali cement & Na_2O_{eq} : $LiOH \cdot H_2O$ of 1:1	0.014%	0.251%
7/22/99	4	100% high alkali cement & Na_2O_{eq} : $LiOH \cdot H_2O$ of 1: 1.25	0.011%	0.260%
7/22/99	12	85% high alkali cement, 15% Class F fly ash, & Na_2O_{eq} : $LiOH \cdot H_2O$ of 1: 0.75	0.008%	0.259%
6/17/99	6	75% high alkali cement & 25% GGBFS	0.187%	0.296%
6/17/99	7	60% high alkali cement & 40% GGBFS	0.026%	0.306%
6/17/99	8	50% high alkali cement & 50% GGBFS	0.024%	0.312%

1.) ASTM C 441 testing of all of the cementitious materials combinations, including those treated with varying doseages of $LiOH \cdot H_2O$. The Pyrex glass aggregate used in the ASTM C 441 test bars was prepared by crushing 9.5 mm (3/8 in.) Pyrex glass rods. The control bars for each of the ASTM C 441 test bar sets were made with the low alkali cement that was used in the low alkali cement pavement test section on the LVIH.

2.) AASHTO T 303 testing of all the high alkali cement and mineral admixture combinations, with all seven of these combinations being tested first with the fine aggregateused in the pavement test section, and then with the coarse aggregateused in the pavement test section.

ASTM C 441 Mortar Bar Test Results

The ASTM C 441 test bars and companion control bars were made in four different batches over a period of approximately two months. Table 2 lists the expansions of the ASTM C 441 test mixtures and their companion controls, which were made with the low alkali cement used in pavement test section placed with low alkali cement.

The ASTM C 441 mortar bar test results for the LVIH job materials show that the mix with the highest expansion was the 100% high alkali cement mix, followed by the 100% low alkali cement mix (average of 11 sets of control bars). The mix with the lowest amount of expansion combined 85% high alkali cement, 15% Class F fly ash, and an $LiOH{\cdot}H_2O$ dosage to give an Na_2O_{eq} : $LiOH{\cdot}H_2O$ ratio of 1: 0.75. Table 3 lists the rankings for all the ASTM C 441 mortar bar combinations, from least effective to most effective. If one were to apply the criterion from Table 2A of ASTM C 618, that the expansion of a test mixture made with a mineral admixture expressed as a percentage of a low-alkali cement control at 14 days should be no more than 100%, to evaluate the effectiveness of the various cement/admixture combinations in controlling alkali-silica reactions, then all of the mixtures tested, except for the 100% high alkali cement, would be considered effective in controlling ASR. All of the mix combinations listed in Table 2, except for the high alkali cement, have lower expansions than the control bars made with the low alkali cement. The low alkali cement would also be considered effective in controlling alkali-silica reaction by ASTM C 441, since the average expansion for all of the control bar sets is less than the expansion for the mortar bars made with the 100% high alkali cement.

TABLE 3: Ranking of Effectiveness of LVIH Job Mixes by ASTM C 441 Mortar Bar Test Results

Ranking	Mix #	ASTM C 441 Test Result % Linear Expansion
Least Effective	1 (Control)	0.432%
	5 (L.A. cem.) (avg. of 11)	0.299%
	9 (15% F.A.)	0.239%
	10 (20% F.A.)	0.221%
	6 (25% GGBFS)	0.187%
	11 (25% F.A.)	0.155%
	7 (40% GGBFS)	0.026%
	8 (50% GGBFS)	0.024%
	2 (LiOH 1:0.75)	0.014%
	3 (LiOH 1:1)	0.014%
	4 (LiOH 1:1.25)	0.011%
Most Effective	12 (15% F.A. & LiOH 1:0.75)	0.008%

AASHTO T 303 Mortar Bar Test Results

The AASHTO T 303 mortar bars were made in two batches over the period of approximately three weeks, utilizing a total of seven different combinations of high alkali cement and mineral admixtures of the LVIH job materials, and two different aggregates, the fine and coarse aggregates used in the LVIH ASR pavement test section. Table 4 summarizes the AASHTO T 303 mortar bar expansion results for all 14 combinations of cementitious materials and aggregates, listing the results for Mix #1 first (no remediation), then the mixes with increasing proportions of Class F fly ash, and finally the mixes with increasing proportions of GGBFS. Table 5 lists the rankings for all the AASHTO T 303 mortar bar combinations for both aggregates, from least effective to most effective, based on the amount of expansion measured.

TABLE 4: AASHTO T 303 Mortar Bar Test Results for Seven Cementitious Materials Combinations and Two Aggregates

Mix #	% Linear Expansion	
	Fine Aggregate	Coarse Aggregate
1 (Control)	0.257%	0.402%
9 (15% F.A.)	0.074%	0.247%
10 (20% F.A.)	0.046%	0.156%
11 (25% F.A.)	0.017%	0.101%
6 (25% GGBFS)	0.127%	0.301%
7 (40% GGBFS)	0.034%	0.113%
8 (50% GGBFS)	0.016%	0.065%

All seven combinations of cementitious materials tested in the AASHTO T 303 mortar bars are ranked in the same order from least effective to most effective, based on the amount of expansion in the mortar bars, by both aggregates used in the AASHTO T 303 test bars. If one applies the criterion that the expansion must be at or below 0.10% in order for the test mixture to be considered effective in controlling excessive expansion caused by ASR, then according to the fine aggregate AASHTO T 303 test results, five of the cementitious materials combinations tested are effective in controlling excessive expansion due to ASR. Only Mix 1 and Mix 6 (100% high alkali cement and 75% high alkali cement/25% GGBFS, respectively) would *not* be considered effective in controlling ASR. However, if one applies the same criterion for effectiveness in controlling ASR to the AASHTO T 303 mortar bars made with the coarse aggregate, then only two of the mixes, Mix 11 and Mix 8 (75% high alkali cement/25% Class F fly ash, and 50% high alkali cement/50% GGBFS, respectively) *would be considered effective* in controlling ASR. Perhaps completion of the testing on the ASTM C 1293 concrete prisms (which were also made with the job materials), which is being done at Construction Technology Laboratories by the Portland Cement Association, will help resolve the conflicting test results obtained from the AASHTO T 303 mortar bars. However, final resolution of the conflicting conclusions from the AASHTO T 303 mortar bar tests about the effectiveness of the seven combinations of cementitious materials tested in controlling excessive expansion due to ASR can only be accomplished by continued monitoring of the actual pavement test sections through time.

TABLE 5: Ranking of Effectiveness of LVIH High Alkali Cement and Mineral Admixture Combinations, Based on AASHTO T 303 Mortar Bar Tests With LVIH Coarse and Fine Aggregates

Ranking	Mix #	% Linear Expansion	
		Fine Aggregate	Coarse Aggregate
Least Effective	1 (Control)	0.257%	0.402%
	6 (25% GGBFS)	0.127%	0.301%
	9 (15% F.A.)	0.074%	0.247%
	10 (20% F.A.)	0.046%	0.156%
	7 (40% GGBFS)	0.034%	0.113%
	11 (25% F.A.)	0.017%	0.101%
Most Effective	8 (50% GGBFS)	0.016%	0.065%

Comparison of ASTM C 441 and AASHTO T 303 Test Results

Comparison of the ASTM C 441 test results to the AASHTO T 303 test results for the seven combinations of high alkali cement and mineral admixtures which could be tested by both test procedures highlights the lack of agreement in predicted performance (see Table 6). For only three of the seven cementitious materials combinations, Mix #1(100% high alkali cement), Mix #11(75% high alkali cement/25% Class F fly ash), and Mix #8 (50% high alkali cement/50% GGBFS) do all of the ASTM C 441 and AASHTO T 303 test results agree on the effectiveness (or lack thereof) of the mixture combination in preventing ASR. Furthermore, the order in which the two different test procedures ranks the effectiveness of the seven cementitious material combinations show some striking differences. ASTM C 441 ranks Mix #6 (25% GGBFS) as more effective than either Mix #9 (15% Class F fly ash) or Mix #10 (20% Class F fly ash). AASHTO T 303 ranks Mix #6 as *less* effective than either

TABLE 6: Comparison of ASR Remediation Effectiveness Predictions Between ASTM C 441 and AASHTO T 303.

	Effective in ASR Prevention?		
	ASTM C 441	AASHTO T 303	
Mix #		Fine Agg't.	Coarse Agg't.
1 (Control)	No	No	No
9 (15% F.A.)	Yes	Yes	No
10 (20% F.A.)	Yes	Yes	No
6 (25% GGBFS)	Yes	No	No
11 (25% F.A.)	Yes	Yes	Yes
7 (40% GGBFS)	Yes	Yes	No
8 (50% GGBFS)	Yes	Yes	Yes

Mix #9 or Mix #10. Also, ASTM C 441 ranks Mix #7 (40% GGBFS) as *more* effective than Mix #11 (25% Class F fly ash), whereas AASHTO T 303 ranked Mix #7 as *less* effective than Mix #11.

CONCLUSIONS

1. The results of the ASTM C 441 testing of the job materials from the LVIH ASR pavement test section predict that all of the material combinations will be effective in preventing ASR except for the 100% high alkali cement pavement test section.
2. The results of the AASHTO T 303 testing of seven of the cementitious materials combinations made with the LVIH job materials predict that at least two, and possibly more, of these seven combinations will be effective in preventing ASR.
3. The two test methods differ in their predictions of how well seven of the cementitious materials combinations placed in the LVIH pavement test section will perform.
4. Completion of the ASTM C 1293 testing being conducted by the Portland Cement Association may help to resolve the conflicting results from the ASTM C 441 and AASHTO T 303 tests.
5. Monitoring of the actual field performance of all of the LVIH pavement test sections will be the only way to demonstrate which of the two different test procedures, ASTM C 441 or AASHTO T 303, better predicts the actual field performance of the LVIH pavement test sections.

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