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Alkali-Aggregate Reaction in Concrete

LABORATORY AND FIELD EXPERIENCE WITH ASR IN TEXAS, USA

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ABSTRACT:

The Concrete Durability Center (CDC) at The University of Texas at Austin is currently performing alkali-silica reaction (ASR) testing in one of the largest projects of its kind in North America. The research project incorporates 12 aggregates originating in Texas and 13 aggregates from across the U.S. and Canada. While traditional accelerated testing methods are employed (ASTM C 1260, C 1293, etc.), the project also aims to use unique testing regimes and to correlate laboratory testing with field conditions. One new testing technique involves an outdoor exposure site that monitors performance of large concrete blocks subjected to fluctuating environmental conditions. These observations are correlated to laboratory investigations.

Unique to this project is the future construction of a 12-span pre-stressed concrete bridge near Conroe, Texas. This bridge will be constructed from pre-stressed concrete girders containing high alkali cement and a fine aggregate from Texas that has been shown to exhibit considerable expansion due to ASR under accelerated testing conditions. Twelve concrete mixtures employing different ASR mitigation strategies were determined for use in the bridge. These mixtures were then subjected to simulated field conditions in the outdoor exposure site to assess their viability for use in an actual structure. The bridge, when constructed, will be heavily instrumented to monitor expansion. In effect, it is a *true* field study testing the effectiveness of ASR mitigation techniques.

A brief overview of the testing methods at The Concrete Durability Center will be given with specific attention to selection of the mixtures for use in the showcase bridge. Additionally, long-term testing results from the outdoor exposure site will be conveyed with specific attention paid to the performance of the mixtures for use in the future showcase bridge.

Key words: Alkali-silica reaction, Test methods, Outdoor exposure site, Aggregate, Mitigation

1.0 INTRODUCTION

Until the middle of the 1990's the state of Texas was unaware of concrete degradation due to alkali-silica reaction (ASR) and/or delayed ettringite formation (DEF). In 1998 the state was alerted of the problem when 56 of 69 prestressed bridge girders cast in San Marcos, Texas were found to be heavily damaged by ASR and/or DEF after only six months of exposure [1]. There was difficulty determining which of these two reactions initiated deterioration and subsequently which resulted in the most damage to the beams. Therefore the Texas Department of Transportation (TxDOT) classified such damage as premature concrete deterioration (PCD).

In order to limit PCD several special provisions were implemented which sought to limit ASR and DEF in new concrete. In order to verify the validity of these new provisions TxDOT Project 0-4085 was initiated in 1999. Although the larger goals of this research project include investigations into ASR, DEF and their interdependence, the focus of this paper will remain on ASR. A host of traditional laboratory testing methods were employed in this project to assess susceptibility to ASR including ASTM C 1260 and 1293. Additionally, several innovative testing regimes were used. Two of these unique methods are an outdoor exposure site to monitor long-term expansion of large concrete blocks and the future construction of a 12-span showcase bridge near Houston, Texas USA.

Specific attention to the mixture selection for the showcase bridge will be given in this paper. Testing procedures for assessing aggregate reactivity, response to mitigation procedures and applicability to the pre-casting industry will be explored.

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2.0 BRIDGE DESCRIPTION

One of the main goals of this research project was to demonstrate that a known alkali-silica reactive fine aggregate from the state of Texas could be mitigated using several different mixture designs. In addition to proving this through extensive laboratory testing, a 12-span bridge will be constructed using a known reactive fine aggregate, non-reactive coarse aggregate and a high alkali cement.

The bridge to be constructed consists of 12 spans and is approximately 700 feet in total length. The width varies from 168 to 174 feet. The bridge accommodates eight lanes of traffic and is oriented at an 80° skew. It is located just south of Conroe, Texas in Montgomery County on IH-45 [2].

The girders selected for this project consist of the outermost girders in each span. A total of 24 girders each with external exposure will comprise the study. Each girder will be instrumented with thermocouples to detect internal temperature during curing and throughout the life of the structure. Vibrating wire gages placed at several discrete locations within the beam will monitor expansion. Results will be sent via cell phone modem to The University of Texas at Austin. In total 12 different mitigated mixtures were chosen for use in the construction of the girders. Fig. 1 shows the basic layout of the bridge and the location of the mitigated girders [2].

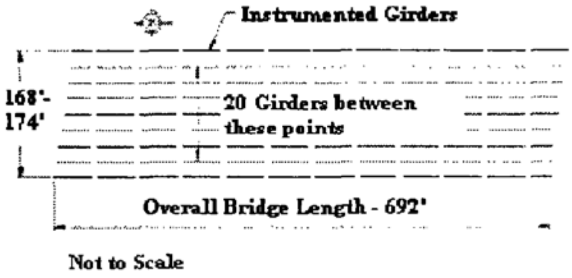

Figure 1: Bridge schematic

3.0 MATERIAL PROPERTIES

Traditional testing methods used in this project were also augmented by new unique strategies. As a result, a variety of materials were necessary to meet ASTM standards, to provide continuity between testing procedures and to correlate previous testing results with TxDOT. The project began with twelve aggregates from the state of Texas, two from Canada and five from other locations within the United States. The twelve aggregates from Texas consisted of seven fine and five coarse aggregates. Two additional coarse aggregates from Canada were used to provide correlation to international testing results. Table 1 shows these aggregates with a brief mineralogical description and source location. A designation of "F" and "C" is used for fine and coarse aggregates, respectively.

Table 1: Aggregate descriptions

ID	Mineralogy	Source
F1	Mixed quartz/chert/feldspar sand	El Paso, TX
F2	Mixed quartz/chert sand	Mission, TX
F3	Quartz sand	Cleveland, TX
F4	Quartz	Austin, TX
F5	Quartz	Amarillo, TX
F6	Tan dolomite carbonate	San Antonio, TX
F7	Mixed quartz/chert sand	Robstown, TX
C1	Chert and quartzite	Eagle Lake, TX
C2	Tan dolomite carbonate	Eagle Pass, TX
C3	Limestone	Elgin, OK
C4	Tan dolomite (marble)	Helotes, TX
C5	Mixed quartz/chert	Ashtown, AR
C6	Tan dolomite (marble)	San Antonio, TX
C7	Limestone	Ontario, CA
C8	Mixed mineralogy gravel	Canada
C9	Chert with quartz and limestone	Victoria, TX
C10	Rhyolitic volcanic rocks with quartz and granite	Albuquerque, NM

Several cements were used in this project for the various testing methods. Table 2 gives the oxide analysis and designations for the different cements.

Table 2: Cement chemical composition

	CM1	CM2	CM4	CM5	CM6
Type	I	I	I	III	III
SiO_2 %	19.8	20.14	20.86	18.6	19.97
Al_2O3 %	5.5	4.67	5.01	5.45	50.3
Fe_2O3 %	2	2.36	1.81	2.53	3.4
CaO %	61.6	57.31	65.38	60.99	64.36
MgO %	2.6	1.57	1.41	2.37	1.04
Na_2O_{eq} %	0.95	0.72	0.52	1.19	0.55
SO_3 %	4.2	2.68	2.87	4.37	3.82
LOI %	1.4	-	1.44	-	-
Blaine, m^2/kg	399	355	354	529	537

Cement 1 (CM1) was used for all ASTM C 1293 testing and the majority of outdoor exposure blocks unless noted otherwise. This cement conforms to the requirements of ASTM C 1293 that the total alkali content must be 0.9 ± 0.1% Na_2O_{eq}. Cement 2 (CM2) was used for all ASTM C 1260 mixtures shown in this paper and was chosen for direct comparison to testing performed by TxDOT. Cement 4 (CM4) was used for certain exposure blocks to provide a lower alkali content to determine the threshold necessary to induce expansion in certain highly reactive aggregates. Cement 5 (CM5) is the cement to be used in the construction of the showcase bridge to give a "worse-case scenario" with an extremely high alkali cement (1.19% Na_2O_{eq}).

Cement 6 (CM6) is the precast concrete producer's standard low-alkali cement and will be used as a potential mitigation method in the bridge [3].

The majority of mitigation options examined for the showcase bridge employ the use of supplementary cementing materials (SCMs) and chemical admixtures. These materials represent commercially available products in Texas and in the majority of areas in North America. Table 3 details the chemical constituents of these materials.

Table 3: SCM chemical compositions

	Fly Ash		Silica Fume (SF)	Slag (120)	Metakaolin (Mk)	Ultra-Fine Fly Ash (M3)
	FA2-F	FA4-C				
SiO_2 %	54.1	34.4	93.2	35.9	51.0	48.4
Al_2O3 %	26.2	18.3	-	12.0	40.0	26.2
Fe_2O3 %	3.0	6.5	2.1	0.9	1.0	3.7
CaO %	10.8	24.6	0.8	44.1	2.0	14.1
MgO %	2.4	4.0	0.3	8.9	0.1	2.5
Na_2O_{eq} %	0.3	1.4	0.5	0.6	0.5	0.1
SO_3 %	0.3	2.0	0.2	1.6	-	0.9
LOI %	0.1	0.1	2.2	-	2.0	0.1

Lithium nitrate was chosen as the only chemical admixture for use in the showcase bridge mixtures and is a 30% solution. The manufacturer recommended dosages are 4.6 L $LiNO_3$ per kg of Na_2O_{eq}. Testing for mitigated mixtures involved dosages at 50, 75 and 100% of the manufacturer's recommended dosage [3].

4.0 MITIGATED MIXTURE SELECTION AND RESULTS

4.1 ASTM C 1260 Testing

Originally it was conveyed that the timeline for construction of the showcase bridge was to occur within a few months. Therefore it was necessary to chose mitigated mixtures in a timely manner. As a result, initial mixture selection was based on the 14-day ASTM C 1260 test [4]. Thought to be an aggressive test to assess alkali-silica reactivity, this would give a conservative guideline to mixture selection.

The process of selecting the reactive aggregate for use in the bridge began with twelve Texas aggregates, which were comprised of seven fine and five coarse aggregates. The results of ASTM C 1260 testing are shown below in Fig. 2 and Fig. 3 for fine and coarse aggregates, respectively.

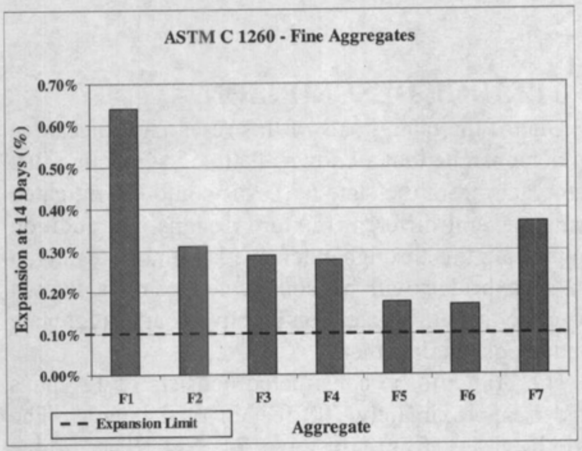

Figure 2: ASTM C 1260 expansion results for fine aggregates

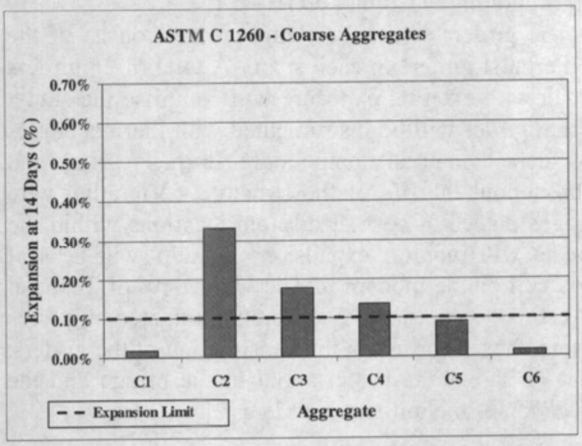

Figure 3: ASTM C 1260 expansion results for fine aggregates

From these two figures it can be seen that fine aggregate (F1) was the most reactive at approximately 0.65% at 14 days in ASTM C 1260 testing. Initially this was the aggregate chosen for use in the mitigated bridge mixtures as it would provide the "worse-case scenario" for reactivity, and subsequent mitigation strategies.

Once this highly reactive aggregate was chosen, extensive ASTM C 1260 testing was performed on a wide range of mitigated mixtures. Fig. 4 and Fig. 5 demonstrate the most effective mitigation options. It is important to note that several SCMs, which were not shown in Table 3 are portrayed in this graph. These SCMs were not ultimately chosen for use in the showcase bridge and are therefore only included for informational purposes.

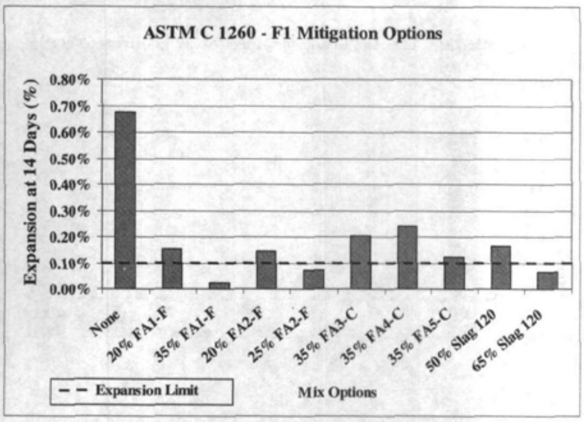

Figure 4: Fine aggregate (F1) mitigation options tested using ASTM C 1260

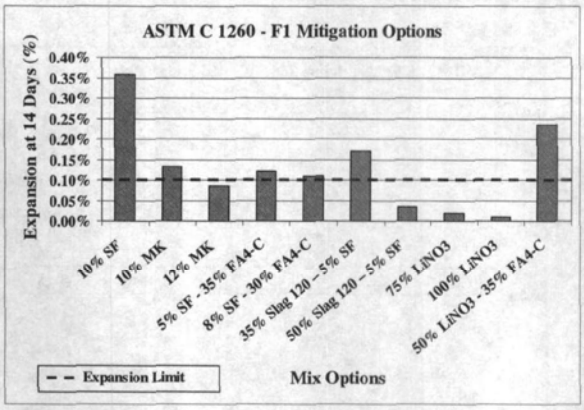

Figure 5: Fine aggregate (F1) mitigation options tested using ASTM C 1260

Due to the high reactivity of F1, there were few mitigation options that fell below an acceptable expansion limit of 0.1% at 14 days. Additionally, many of the options that did pass the expansion criteria were not feasible for use in a precast operation (i.e. 65% slag or 35% Class F fly ash) due to the need for high-early strengths.

It was also observed that performing ASTM C 1260 testing with this aggregate at lower soak solution normalities (e.g., 0.5 and 0.75N) resulted in higher expansions than the standard version of the test performed at a soak solution normality of 1.0N NaOH. Although ASTM C 1260 is not the ideal test for assessing cement alkalinity, subsequent testing using the concrete prism test (ASTM C 1293) and outdoor exposure site testing confirmed that aggregate F1 is highly reactive at lower alkali loadings. In fact, alkali loadings as low as 2.2 kg/m^3 resulted in significant cracking in outdoor exposure blocks using aggregate F1. One prescriptive option, based on TxDOT specifications, was selection of a concrete mixture with a low-alkali loading for use in the showcase bridge. Based on the behavior of F1 there was concern in using it for such an application.

Thus, the fact that aggregate F1 was difficult to mitigate using SCM's or low-alkali loadings, led the research team to seek another reactive aggregate for the showcase bridge.

After considering other potential aggregate sources for the showcase bridge, an alternative fine aggregate was selected which showed poor field performance in bridge structures in Texas. This aggregate, F7, was found to be highly reactive in laboratory testing (0.37% at 14 days in ASTM C 1260) and more amenable to mitigation methods.

Numerous mitigation techniques were tested using aggregate F7. Fig. 6 and Fig. 7 depict the most effective mitigation options.

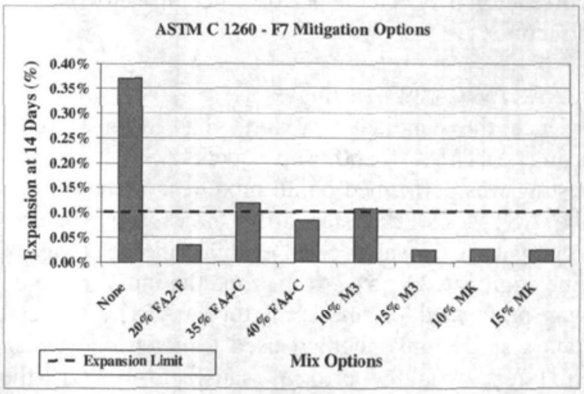

Figure 6: Fine aggregate (F7) tested mitigation options using ASTM C 1260

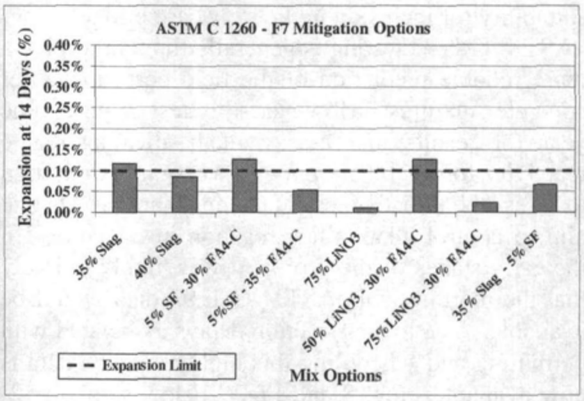

Figure 7: Fine aggregate (F7) tested mitigation options using ASTM C 1260

Based on this testing 12 mixtures were chosen for use in the showcase bridge. These mixtures are noted below:

- 20% Fly Ash 2 – Class F
- 40% Fly Ash 4 – Class C
- 15% Ultra-Fine Fly Ash (M3)
- 10% Metakaolin (MK)
- 40% Slag – Grade 120
- 75% $LiNO_3$ (30% Solution)
- 35% Fly Ash 4 (C) & 5% Silica Fume

- 30% Fly Ash 4 (C) & 5% UFFA (M3)
- 20% Fly Ash 2 (F) & 5% Silica Fume
- 30% Fly Ash 4 (C) & 75% $LiNO_3$
- 35% Slag (120) & 5% Silica Fume
- low alkali cement (0.55% Na_2O_{eq})

There will also be a control structure on a small scale constructed close (within 5 km) to the actual showcase bridge to provide the "do nothing" option. This structure will consist of four girders. Two of these girders will contain the control mixture of highly reactive aggregate, high alkali cement and no mitigation options. The other two girders will consist of mixtures from the actual bridge to provide a correlation between the performance of the two structures.

4.2 ASTM C 1293 Testing

Once the candidate mixtures had been selected using ASTM C 1260, subsequent ASTM C 1293 testing was performed on all mixtures. According to the ASTM C 1293 standard a non-reactive coarse aggregate (C6) was used to evaluate the reactivity of fine aggregate F7 [5]. At the time the initial research was performed on these mixtures, ASTM C 1260 data was the only method used to determine which mixtures would perform satisfactorily in the showcase bridge. It was thought that this data along with preliminary ASTM C 1293 data would dictate the performance of these mixtures and thus their suitability for inclusion in the showcase bridge.

ASTM C 1293 testing is generally thought to give a more reliable prediction of the field performance of concrete mixtures. However, this test requires one year for results that assess alkali-silica aggregate reactivity for aggregate only. Two years is required to assess the effectiveness of chemical and SCMs that aim to control alkali-silica reaction in concrete. In the early stages of the project it was highly unlikely that the more reliable ASTM C 1293 data would be available. Due to construction delays associated with permitting and scheduling this highly coveted data is now available. Fig. 8 and Fig. 9 below show the 2-year expansion data for the mitigated showcase bridge mixtures.

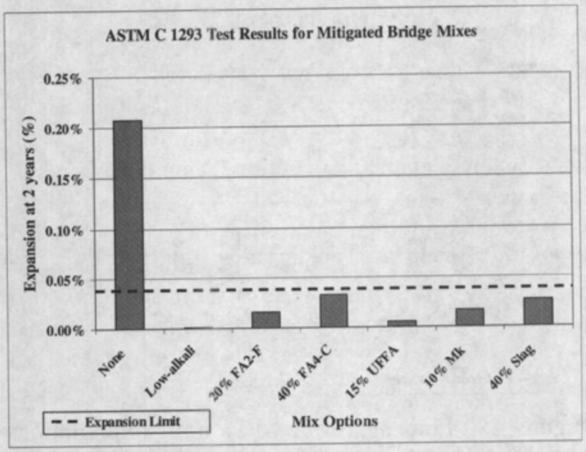

Figure 8: ASTM C 1293 expansion results at 2 years for mitigated bridge mixtures

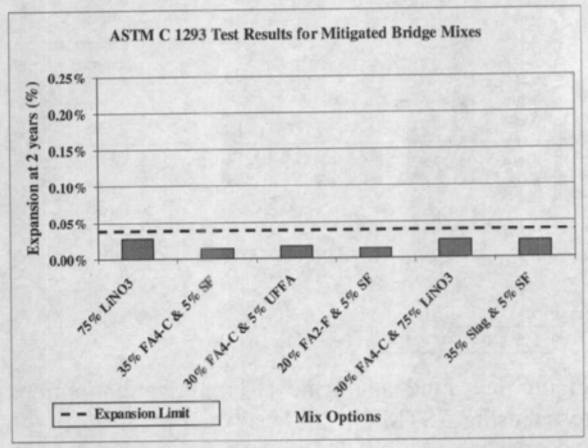

Figure 9: ASTM C 1293 expansion results at 2 years for mitigated bridge mixtures

The majority of the data shown for ASTM C 1293 testing are the results at 2 years of testing. However, results for three of the mixtures show data at 18 months of testing. This was due to failure of the containers in the high temperature and humidity environment. Subsequent loss of moisture inside the containment vessel resulted in significant reduction in length of the prisms rather than expansion. This affected the following mixtures: 15% UFFA, 35% Fly Ash 4 (C) & 5% Silica Fume and 30% Fly Ash 4 (C) & 5% UFFA. Based on the trends of these mixtures up to 18 months of testing and the combined results of ASTM C 1260 testing and outdoor exposure blocks, it is believed that these mixtures will perform well in the showcase bridge.

4.3 Outdoor Exposure Site

The use of fast track construction methods and economic constraints has pushed the concrete industry to use test methods for ASR which are rapid and on a scale much smaller than elements being constructed in the field. The current methods, namely ASTM C 227, C 1260 and C 1293 are considered acceptable but are not without certain limitations. Additionally, the way by which climatic exposure affects ASR is not considered in these test methods. Unique to TxDOT Project 0-4085 is the construction of an outdoor exposure site for large scale concrete elements to address such limitations of laboratory testing.

Most importantly the ability for ASTM C 1260 and ASTM C 1293 testing to address field performance is unknown. Long-term results from the outdoor exposure site will help to gage the reliability of such test methods and may allow for modifications to improve their accuracy in assessment of true performance. ASTM C 1293 is performed on the same large scale mixtures that are placed in the outdoor exposure site.

A stand-alone weather station is set up with a data acquisition system, which allows for continual measurement (on the half hour) of temperature, humidity, precipitation, barometric pressure, wind speed and direction. Additionally, a non-reactive block comprised of a non-reactive fine (F6) and coarse aggregate (C6) has been instrumented with thermocouples at five different locations within the block. This temperature is monitored every hour. This is done in an effort to correlate climatic variations with expansion due to ASR in the exposure blocks. A detailed description of these results is beyond the scope of the current paper and will be explored in depth in subsequent publications.

Measurements of the exposure blocks are made only under certain climatic conditions. The ambient temperature must be 23 °C ± 1.5 °C. The weather must be mostly cloudy to cloudy and not raining. Additionally, the non-reactive control block is measured periodically throughout one measurement period to ensure that expansion due to thermal affects is not occurring. Due to the high summer temperatures and an average of 300 of 365 days a year of sun, block measuring is sporadic and often limited to only a few hours in the early morning.

The outdoor exposure blocks measure nominally 710 mm x 380 mm x 380 mm. Fig. 10 shows a typical exposure block.

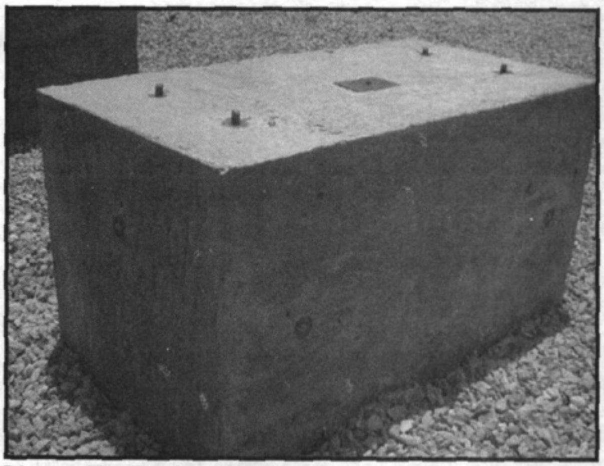

Figure 10: Typical Outdoor Exposure Block

Exposure blocks are measured for expansion using two digital comparators of differing length. Measurements are taken between twelve points on the exposure blocks, resulting in eight total measurements. These points are created by casting 9.5 mm (diameter) by 76 mm (length) bolts into the fresh concrete. These bolts have a machined "demec point" at the end. A special drill bit is used to machine these measuring points into each bolt before it is cast into the block. A constructed "jig" and form ensures proper sizing of the block and proper placement of bolts for measuring purposes.

The digital strain gages used for measurement purposes are accurate to 0.00127 mm. Fig. 11 shows the locations of measurements taken on an exposure block.

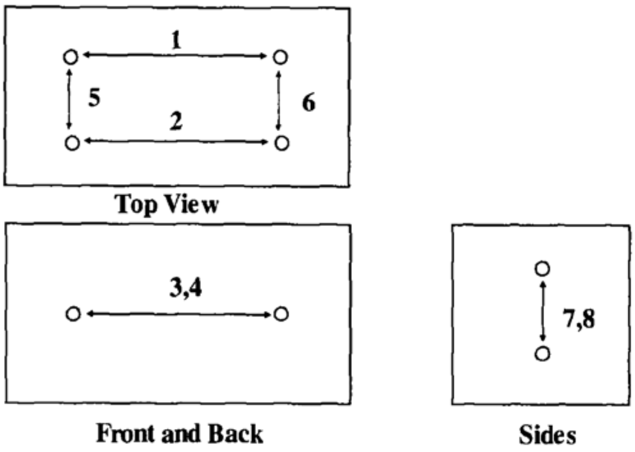

Figure 11: Exposure block measurement locations

Measurements are taken along each one of the principle directions shown above. When graphically representing expansion measurements, they are referred to as if one were standing facing the block:

- 1-Top Back
- 2-Top Front

- 3-Front
- 4-Back
- 5-Top Left
- 6-Top Right
- 7-Left Side
- 8-Right Side

Fig. 12 gives a graph of exposure block measurements for the control showcase bridge mixture (F7 not mitigated).

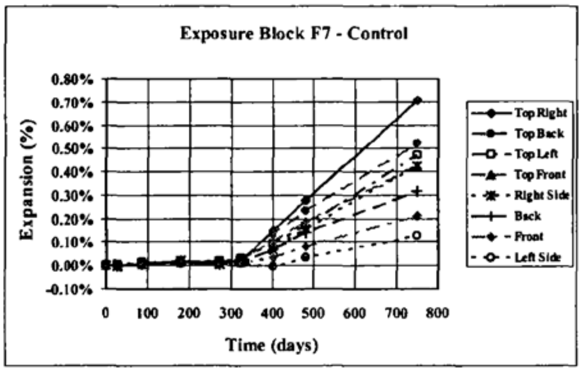

Figure 12: Exposure block expansion for F7 not mitigated

All mixtures selected for use in the showcase bridge were cast in outdoor exposure blocks and have been monitored for at least 2 years. Table 4 depicts expansions of the twelve selected mixtures and the control. The measurements reported are the average of the eight measurements taken for each block.

Table 4: Exposure block expansions at various ages

Showcase Bridge Mixes	Expansion (%)	Age (days)
Control - F7	0.4	749
20% FA2	0.011	746
40% FA4	0.018	737
15% UFFA	0.014	749
10% Metakaolin	0.015	749
40% Slag	0.0052	746
75% LiNO3	0.012	744
35% FA4 & 5% SF	-0.005	730
30% FA4 & 5% UFFA	0.016	728
20% FA2 & 5% SF	0.011	573
30% FA4 & 75% $LiNO_3$	0.031	550
35% Slag & 5% SF	0.017	575
Low-alkali cement	-0.008	594

Although there is not an established acceptable standard limit for expansion of field concrete, all of the mitigated mixtures have exhibited outstanding performance to date with expansions less than an expansion criteria of 0.04% at 2 years in ASTM C 1293 testing. Additionally, no cracking (often a symptom of ASR induced damage) has been observed at the time of paper submission.

Table 5 compares the expansion values of the showcase bridge mixtures between several testing procedures: ASTM C 1260, ASTM C 1293 and outdoor exposure block testing. The age of outdoor exposure blocks corresponds to the ages presented above in Table 4.

Table 5: Showcase bridge mixtures comparing ASR related expansion testing

	ASTM C 1260	**ASTM C 1293**	**Exposure Blocks**
Showcase Bridge Mixes	**14 day Expansion (%)**	**2 year Expansion (%)**	**Expansion (%)**
Control - F7	**0.29**	**0.21**	0.4
20% FA2-F	0.04	0.016	0.011
40% FA4-C	0.08	0.007	0.018
15% UFFA	0.02	0.005*	0.014
10% Metakaolin	0.03	0.017	0.015
40% Slag	**0.12**	0.027	0.0052
75% LiNO3	0.01	0.028	0.012
35% FA4-C & 5% SF	0.06	0.013	-0.005
30% FA4-C & 5% UFFA	0.06	0.017	0.016
20% FA2-F & 5% SF	-	0.013	0.011
30% FA4-C & 75% $LiNO_3$	0.02	0.015*	0.031
35% Slag & 5% SF	0.07	0.023	0.017
Low-alkali cement	**0.23**	0.001*	-0.008

*measurements at 18 months
bold indicates data which did not pass the expansion criteria

The values seen above show that two of the mixtures did not meet the expansion criteria of ASTM C 1260 testing (40% Slag and low-alkali cement). Since the ASTM C 1260 is an aggressive test it is often regarded that if a mixture passes 1260 it should have good field performance. However, if it does not meet the expansion criteria it is best to perform complimentary testing, namely the more reliable ASTM C 1293 test. In both ASTM C 1293 testing and outdoor exposure block measurements these two mixtures showed good performance.

5.0 APPLICATION TO PRE-CAST OPERATION

In the pre-cast industry economy plays a major role in the success of a given company. This economy is mostly met through high production volumes of pre-cast elements. As a result pre-cast concrete mixtures often require high early strengths for release of pre-stressing and good workability for ease of placement and expedient operations. In an effort to meet these demands testing was done on the selected bridge mixtures to ensure they could meet the high demands at a pre-casting plant, thus making them viable options for future use.

For this portion of the testing regime the selected bridge mixtures were adjusted to meet the mixture proportions used by the pre-caster. These mixtures cast in the laboratory will help to provide a basis for their performance at the pre-casting plant, but are not meant to provide a direct correlation to mixing on a large scale. The results will be used to gage the feasibility of these mixtures in terms of workability and strength parameters [3].

The laboratory mixtures were patterned after the typical mixture design shown below in Table 6.

Total cementitous content is shown as "Type II Cement" and was adjusted by weight based on the various SCMs included in the showcase bridge mixtures.

Table 6: Pre-cast mixture proportions

Typical Precast Mixture Proportions	
Type III Cement	363 kg/m^3
Water	122 kg/m^3
Coarse Agg	1208 kg/m^3
Fine Agg	731 kg/m^3
Water Reducer	103.5 ml*
Super-plasticizer	768 ml*

*per 45 kg cement

The measured fresh properties are shown below in Table 7. The target slump values were between 152 and 203 mm, however values outside this range were recorded, since trial batching will occur at the plant to determine exact admixture dosages [3].

Table 7: Fresh concrete properties

Bridge Mix	Mix	Slump (mm)	Water Reducer* (oz)	Super-Plasticizer* (oz)	Air (%)	Placement Temp. (° C)
# 1	High-alkali control	228.6	88.7	532.3	NA	25.0
# 2	Low-alkali	266.7	88.7	532.3	1.5	25.0
# 3	20% FA2-F	254	88.7	443.6	1.5	23.3
# 4	40% FA4-C	228.6	88.7	473.1	NA	23.3
# 5	15% UFFA	114.3	88.7	532.3	2.0	23.9
# 6	10% Mk	50.8	88.7	532.3	3.0	23.9
# 7	40% Slag	228.6	88.7	561.8	1.5	23.3
# 8	75% LiNO3	95.25	88.7	532.3	2.5	23.3
# 9	35% FA4-C & 5% SF	228.6	88.7	532.3	2.0	23.9
# 10	30% FA4-C & 5% UFFA	266.7	88.7	532.3	1.5	23.9
# 11	20% FA2-F & 5% SF	190.5	88.7	532.3	NA	23.3
# 12	30% FA4-C & 75% $LiNO_3$	203.2	88.7	561.8	2.5	23.3
# 13	35% Slag & 5% SF	114.3	88.7	561.8	3.0	23.9

*per 45 kg cement

Compressive strength results for each mixture were measured using the average of three 101.6 mm x 203.2 mm cylinders. Cylinders were initially cured at 23 °C and 90% relative humidity. However this led to low one-day compressive strengths, due to the incorporation of SCMs. In an effort to more closely match the temperatures seen in the curing of the pre-cast girders a 24-hour curing period at 38 °C was used. Table 8 shows the compressive strength at one day in the 23 °C versus 38 °C testing regime.

Table 8: Comparison of compressive strength at one day in 23 °C versus 38 °C curing

Compressive Strength, MPa		
Mixture	**23 °C**	**38 °C**
High-alkali	31.2	34.5
Low-alkali	33.6	38.8
20% FA2-F	17.6	23.5
40% FA4-C	16.4	30.2
15% UFFA	27.0	30.7
10% Mk	28.7	33.9
40% Slag	15.5	32.1
75% LiNO3	31.7	32.6
35% FA4-C & 5% SF	16.0	28.3
30% FA4-C & 5% UFFA	9.4	27.5
20% FA2-F & 5% SF	21.6	27.4
30% FA4-C & 75% $LiNO_3$	15.1	30.5
35% Slag & 5% SF	19.4	31.7

It can be seen that the mixtures containing high amounts of fly ash suffered the biggest drop in compressive strength at one day under a curing temperature of 23 °C. However, for all mixtures cured at 38 °C, compressive strength values were significantly higher and represented values typically needed for pre-stress release at early ages. Several of the mixtures will likely require additional curing time to meet desired release strengths. It will be desirable to cast these mixtures for the actual bridge on the last day of the week so that an additional 2-3 days of curing time will be available over the weekend in order to meet required strengths.

Table 9 shows 28-day splitting-tensile strength values for the showcase bridge mixtures.

Table 9: 28-day Splitting tensile strengths

Mixture	28-Day Splitting Tensile (MPa)
High-alkali	5.1
Low-alkali	6.8
20% FA2-F	5.3
40% FA4-C	5.5
15% UFFA	5.6
10% Mk	5.5
40% Slag	5.5
75% LiNO3	5.1
35% FA4-C & 5% SF	5.2
30% FA4-C & 5% UFFA	5.7
20% FA2-F & 5% SF	4.8
30% FA4-C & 75% $LiNO_3$	5.0
35% Slag & 5% SF	5.6

The averaged results of three 101.6 mm x 203.2 mm cylinders were used to determine the splitting tensile strengths of each mixture. The values obtained for each mixture demonstrate adequate tensile strengths that are above values presented in the ACI 318-02 building code [3,6]. These strengths ensure good bond and shear strength development from the concrete.

6.0 CONCLUSION

This paper summarized the process used to select the materials and mixture proportions, using a known alkali-silica reactive fine aggregate for a showcase bridge to be constructed in Texas, USA. The actual bridge construction was initially scheduled for 2001, but due to environmental permitting issues (unrelated to this project), the construction date was delayed considerably. This paper discussed the initial approach to selecting materials and mixture proportions at a time when the construction was expected to be initiated within a few months, forcing the research team to rely exclusively on the accelerated mortar bar test (ASTM C 1260) for mixture selection. However, due to delays in construction, the research team now has the unique luxury of having long-term concrete prism and exposure block data available to confirm the initial selection of materials and mixtures. Detailed information on the actual construction of the bridge and subsequent field performance will be reported in future publications.

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