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COMPARISON OF LABORATORY PERFORMANCE TESTS USED TO ASSESS ALKALI-SILICA REACTIVITY

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ABSTRACT

Alkali-silica reaction of certain concrete aggregates can lead to premature deterioration and maintenance problems in concrete structures. The CSA A23.1-14A/ASTM C1293 concrete prism test (CPT) and the CSA A23.2-25A/ASTM C1260/ASTM C1567 accelerated mortar bar test (AMBT) are the two main procedures used in CSA and ASTM standards for examining the potential alkali-silica reactivity (ASR) of aggregates and also for assessing the effectiveness of supplementary cementing materials (SCMs) in suppressing ASR. The long testing duration of the CPT and the unreliability of the rapid AMBT have led to development and evaluation of a third method, the accelerated concrete prism test (ACPT). All three methods were performed using a range of different aggregates and SCM partial replacements of cement. Expansion data were compared with one another and with known field performance, where available. Results show good correlation between CPT and ACPT expansions and these tests appear to be good predictors of field performance. The AMBT, on the other hand, can be very misleading with certain aggregates.

Keywords: Concrete prism test, Accelerated mortar bar test, Alkali-silica reaction

1. INTRODUCTION

Concrete, the most consumed structural material, is composed of two phases: aggregate and cement paste. Deleterious reaction between certain aggregates containing unstable silica and the alkali hydroxide ions within the cement paste phase is known as alkali-silica reaction (ASR). ASR is slow; however, it can eventually lead to serious cracking and serviceability problems. Common approaches for ASR mitigation include selecting an aggregate that has no significant source of unstable silica and incorporating sufficient supplementary cementing materials (SCMs) to reduce the concentration of alkali hydroxide ions in pore solution (ACI 221.1R 1998).

For examining the potential alkali-silica reactivity of aggregates and the effectiveness of SCMs in suppressing ASR, there are currently two main test procedures. These are the accelerated mortar bar (AMBT) and concrete prism tests (CPT). The AMBT has been standardized in CSA/ASTM as CSA A23.2-25A, ASTM C1260, and ASTM C1567. Respective CPT standards are CSA A23.2-14A and ASTM C1293.

The AMBT is rapid, giving results within 16 days. However, in some cases this test is unreliable: some nonreactive aggregates or aggregate-SCM combinations are incorrectly identified as reactive and vice versa (Feng and Clark 2012) (Thomas et al. 2007). CPT has been found to be reliable, but it is very time consuming. This method requires 1-2 years, which is unacceptable for projects with short lead time.

There is an urgent need for a new or modified test that is both rapid and reliable. Some research has focused on expediting the CPT, primarily by changing the temperature from 38°C to 60°C. The accelerated method is referred to as ACPT and has been found to be associated with several issues including excessive alkali leaching (Ideker et al. 2010). The objective of this study was to compare the results of AMBT with CPT relative to aggregates with known field performance, and to assess the reliability of ACPT.

2. MATERIALS AND METHODS

2.1 Materials

A suite of 13 aggregates with different mineralogy and geographical origin were selected with emphasis on those known to provide inaccurate AMBT classifications. Source location, brief petrographic description, and reported field performance of each, are summarized in Table 1.

Table 1: Source Location, Petrographic Description, and Field Performance of Aggregates

Aggregate ID	Reference	Source Location	Description	Field Performance
BK	(Meininger et al. 2014)	SC, USA	Quartz, quartzite ravel, reactive quartzite	Reactive
WR	(Naranjo 2013)	TX, USA	Chert with quartz and limestone	Reactive
AD	(Naranjo 2013)	TX, USA	Chert and quartzite	Reactive
ST	(Meininger et al. 2014)	MD, USA	granite gneiss	Reactive
RH	(Meininger et al. 2014)	VA, USA	Quarried granite-granite gneiss	Reactive
GR	(Meininger et al. 2014)	VA, USA	Quarried metabasalt and greenstone	Reactive
GE	(Giebson and Ludwig 2013)	Germany	Granodiorite	Reactive
EC	(Meininger et al. 2014)	WI, USA	Mixed siliceous sand and gravel	Non-reactive
PS	(Hooton and Rogers 1989)	ON, Canada	Carbonate sand	Non-reactive
NS	(Peterson et al. 2013)	MN, USA	Pierre shale	Non-reactive
SU	(Hooton and Rogers 1989)	ON, Canada	Siliceous gravel	Reactive
SP	(Hooton and Rogers 1989)	ON, Canada	Quarried limestone	Reactive
DM	(Parkes, 2014)	ON, Canada	Dolomitic Limestone	Non-reactive

The cementitious materials used for this study were Holcim (now CRH Canada) Mississauga general use cement (GU), Holcim Mississauga Type S ground granulated blast furnace slag (Slag), Boral Pawnee, Colorado Type C fly ash (C-FA), and Boral Big Brown, Texas CSA Type CI/ASTM Type F fly ash (CI-FA). Their chemical compositions, as given in plant certificates, are provided in Table 2.

Table 2: Chemical Analyses of Cementitious materials

	GU Cement	Slag	C-FA	CI-FA
Chemical Analysis (%)				
SiO_2	19.39	41.68	32.42	50.3
Al_2O_3	5.13	8.52	18.75	19.2
Fe_2O_3	2.3	0.61	5.02	4.84
CaO	61.89	39.05	27.31	16.6
MgO	2.39	11.46	7.75	3.46
SO_3	4.08	2.81	2.17	0.88
K_2O	1.15	0.36	0.4	0.88
Na_2O	0.25	0.3	2.11	1.63
Na_2Oeq	1	0.54	2.37	2.21

2.2 AMBT

Mortar mixtures with four different binders were proposed: 100% GU, 25% Slag, 25% C-FA, and 25% CI-FA. The plain GU mixture was repeated for all thirteen aggregates; whereas, the SCM mixtures were only performed with SP. In compliance with ASTM C1260/C1567, the W/CM was 0.47 and the ratio of dry aggregate to cementitious materials was 2.25 by mass.

ASTM C305 was followed for mixing of mortar using a Hobart mechanical mixer. Each mixture was compacted into two double-bar molds fitted with gauge studs. The molds were covered with plastic and placed over water in a sealed container, at 23˚C for 24h. Afterwards, the hardened mortar bars were demolded, and totally immersed in 23˚C tap water. The containers were stored in ovens and heated to 80˚C for another 24h. At the end of the water curing period, the hot mortar bars were removed from the containers, and their zero length reading was taken using a comparator and a reference bar. The 4 bars of each mixture were subsequently immersed in a container filled with 3L of 1.0 N NaOH solution preheated to 80˚C.

The lengths of the bars were measured periodically. At any age, the percentage expansion of each bar was calculated by subtracting its periodical reading from its zero reading and by dividing the difference by the effective gauge length and reporting it to the nearest 0.001%. The average expansion of the bars was determined.

2.3 CPT and ACPT

Concretes with eight different aggregate types were cast with and without SCMs (100% GU, 25% Slag, 25% C-FA, and 25% CI-FA). Crushed DM with a fineness modulus 2.7 was used as non-reactive sand for the coarse aggregates being tested. As per ASTM C1293, the cementitious materials content was 420 kg/m^3, the dry mass of coarse aggregate per unit volume of concrete was 0.70, and W/CM was 0.44 by mass. NaOH was dissolved in mixing water to bring the alkali content of concrete mixtures to 1.25% by mass of cement. Aggregate mass and water content were corrected for the moisture content of coarse and fine aggregate before batching.

Concretes were mixed in a 15L capacity pan mixer according to ASTM C192. Each concrete mix was compacted into two three-gang steel moulds with stainless steel pins. After finishing the surface of concrete, the moulds were covered with plastic and then saturated burlap. After 24h, the prisms were demoulded and the initial length measurements were taken. The prisms were placed over water in two different buckets having a perforated rack in the bottom and a wick of absorbent material around the inside wall. One of the buckets was placed at 38˚C, and the other at 60˚C. Length measurements for plain GU cement concretes are being continued until 3m and 1yr at 60˚C and 38˚C, respectively. Expansions of SCM blended concrete are being monitored up to 6m and 2yr at 60˚C and 38˚C, respectively.

3. RESULTS AND DISCUSSION

Tables 3 and 4 show the AMBT, CPT, and ACPT expansions for the different aggregates, binder types and compositions tested. Most of the 1yr and 2yr CPT expansions are not yet available, but will be measured and reported at a later date.

Table 3: Expansions of Aggregates with Plain GU Cement

		Accelerated Mortar Bar Test Exp'n (%)		Concrete Prism Test Exp'n (%)		Accelerated Concrete Prism Test Exp'n (%)
		80°C		38°C		60°C
Aggregate ID	Field Performance	14d	28d	3m	9m	3m
BK	Reactive	0.107	0.287	0.013	0.029	0.033
WR	Reactive	0.118	0.144	-	-	-
AD	Reactive	0.081	0.123	-	-	-
ST	Reactive	0.090	0.185	0.023	0.034	0.047
RH	Reactive	0.062	0.109	0.025	0.044	0.040
GR	Reactive	0.075	0.240	0.032	0.050	0.052
GE	Reactive	0.072	0.137	0.022	0.034	0.046
EC	Non-reactive	0.264	0.499	0.016	0.017	0.017
PS	Non-reactive	0.140	0.226	-	-	-
NS	Non-reactive	0.389	0.562	-	-	-
SU	Reactive	0.287	0.500	-	-	-
SP	Reactive	0.362	-	0.162	0.243	0.09
DM	Non-reactive	0.015	-	0.015	0.027	0.020

Table 4. Expansions for Blended Cements

		Accelerated Mortar Bar Test Exp'n (%)		Concrete Prism Test Exp'n (%)				Accelerated Concrete Prism Test Exp'n (%)	
		80°C		40°C				60°C	
Aggregate	Cementitious materials	14d	28d	3m	6m	1yr	16 m	3m	6m
SP	100% GU Cement	0.362	-	0.162	0.218	0.269	-	0.085	-
	75% GU+25% SLAG	0.201	0.455	0.027	0.037	0.063	0.067	0.033	0.043
	85% GU+15% C-FA	0.391	0.829	0.056	0.078	0.143	0.150	0.097	0.112
	85%GU+15% CI-FA	0.189	0.389	0.009	0.020	0.045	0.051	0.033	0.061

If the average 14d AMBT expansions in 1N NaOH at 80˚C is greater than 0.10%, the aggregate is generally considered as reactive; expansions below 0.10% are assumed to be indicative of innocuous behaviour. The AMBT clearly provides misleading information on long-term performance of aggregates tested. Only 5 out of the 13 aggregates (BK, WR, SU, SP, and DM) were correctly identified, of which 2 were very close to the limit (BK and WR). Considering the multi-laboratory precision, these could be incorrectly classified when tested in other labs. For 3 aggregates (EC, PS, and NS), the AMBT is overly conservative. These will be referred to as false positives. For the remaining 5 aggregates (AD, ST, RH, GR, and GE), the AMBT failed to identify the non-reactive character of the aggregate. These will be referred to as false negatives and are of the greatest concern.

To improve accuracy, ASTM C1260 indicates that 14d expansions between 0.10% and 0.20% should be taken as indecisive. Taking this approach does not provide a significant improvement: only one of the incorrectly identified aggregates falls in this range. Moreover, CSA A23.2-25A proposes a 0.15% limit for aggregates that are not quarried siliceous limestone. Although this modification is beneficial for one aggregate tested in this study (PS), it leads to incorrect identification of two other aggregates (BK, and WR) properly classified with the 0.10% limit. ACI

Committee 221 has suggested the possibility of using a 0.08% limit. This change is not effective, as the 14d expansion of only 2 out 5 false negatives is above 0.08%. Another approach of extending the test period to 28d and keeping the 0.10% limit eliminates all of the false negatives; however, it may increase false positive results.

A 1-year expansion limit of 0.04% is used for the CPT. Generally, CPT is thought to be a more realistic predictor of field performance. At 9m, most of the known deleterious aggregates have exhibited expansions close to or exceeding 0.04% and the expansions of the tested non-reactive aggregates are currently well below this limit.

For assessing the reactivity of aggregates using the ACPT, a 3m limit of 0.04% has been suggested (DeGrosbois and Fontaine 2000). It can be seen that this test correctly identifies 7 out of the 8 aggregates tested. It is likely that significant alkali leaching occurred with the ACPT because levelling out or even drops in expansion before the end of test period were observed. However, even when considering this disadvantage, the ACPT still appears to be a more realistic predictor than the AMBT and shows potential for standardization in CSA or ASTM.

To determine the effectiveness of SCMs in mitigating ASR, the same 0.10% 14-day limit is used for assessing AMBT expansions. For the CPT and ACPT, the test is extended to 2 years at 38˚C and 6m at 60˚C respectively (Touma et al. 2001) and a limit of 0.04% is used. All three methods consistently classified the SCM replacement levels tested with SP (25% Slag, 15% C-FA, and 15% CI-FA) as insufficient to mitigate deleterious expansion; in Table 4. 15% C-FA is the most expansive mixture. The expansion of 15% CI-FA was higher than 25% Slag in the ACPT, but lower in the AMBT and the CPT. This is not unexpected because CSA A23.2-27A would require at least 50% Slag or 25% F-FA for adequate mitigation with the SP aggregate.

The 14d AMBT expansions versus 9m CPT expansions for plain GU mixtures and 16m CPT expansions for blended mixtures are plotted in Figure 1. Figure 2 presents the 3m and 6m ACPT length changes versus 9m and 16m CPT expansions for plain GU and blended mixtures, respectively. It can be observed that the scatter between the AMBT and the CPT expansions is greater than that between the ACPT and the CPT.

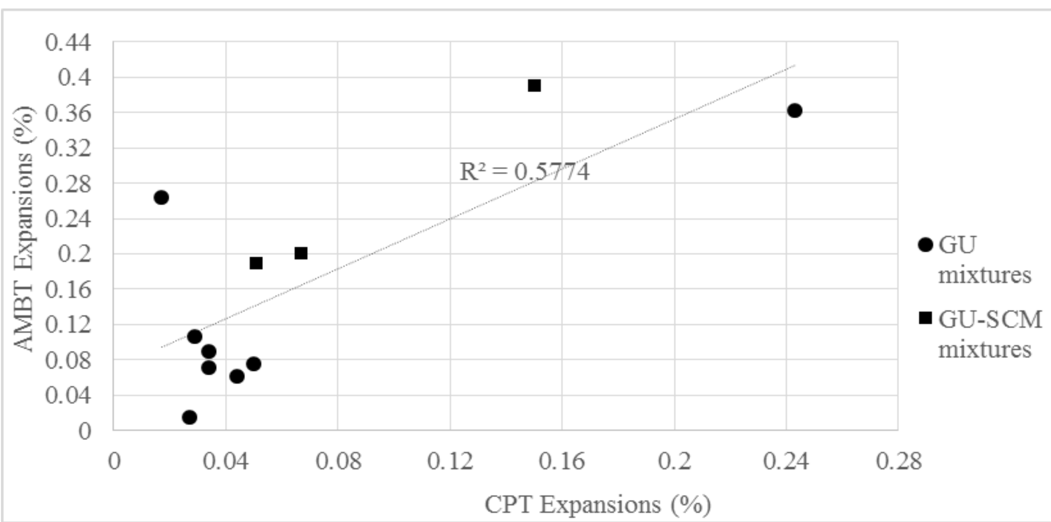

Figure 1: 14d AMBT expansions versus 9m CPT expansions for plain GU mixtures and 16m CPT expansions for blended mixtures

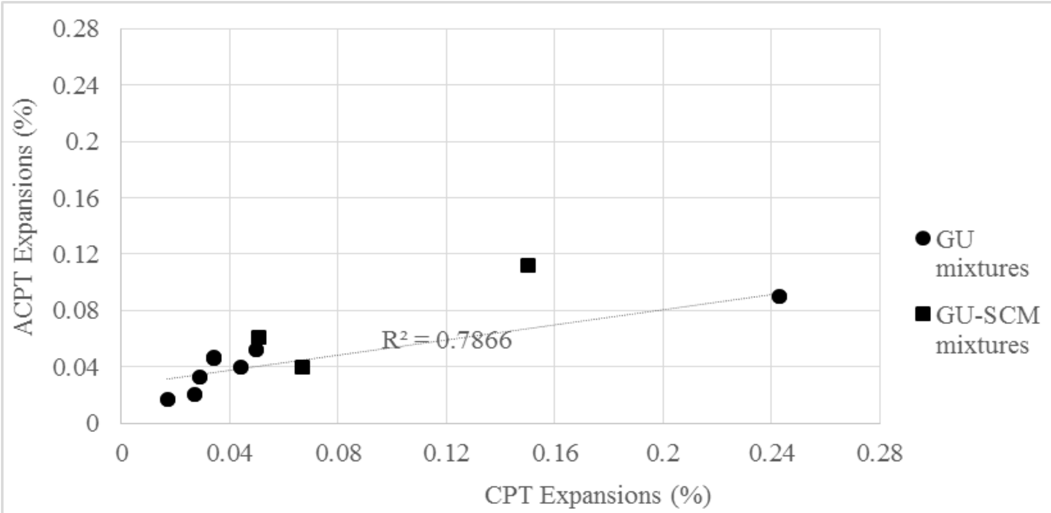

Figure 2: 3m and 6m ACPT length changes versus 9m and 16m CPT expansions for plain GU and blended mixtures, respectively

4. CONCLUSIONS

Accelerated mortar bar, concrete prism, and accelerated concrete prism tests were performed on several different aggregate types and SCM replacements and compared to field performance. Results show that the accelerated mortar bar test is very unreliable for prediction of field performance. The accelerated concrete prism test can be subject to excessive alkali leaching, but still provides more accurate results than the commonly used AMBT.

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