IMPROVING THE RELIABILITY OF THE ASTM C1260 ACCELERATAED MORTAR BAR TEST

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Abstract

Due to its rapidity, the ASTM C1260 accelerated mortar bar test (AMBT) is the most commonly used technique for examining the potential alkali-silica reactivity (ASR) of concrete aggregates. Unfortunately, with some many types of aggregates, results obtained with this test are often unreliable and lead to identification of reactive aggregate as non-reactive and vice versa. One concern is that ettringite decomposes at 80°C, leading to increased sulfate in solution, resulting in reduced hydroxyl concentration. To improve the reliability of this test, modifications to the current procedure were evaluated, namely, reduction of the storage temperature from 80°C to 60°C and 40°C. Standard and modified versions of the AMBT were performed using a suite of correctly and incorrectly identified aggregates. Pore solutions of sealed cement paste exposed to 40°C, 60°C, and 80°C for 35d were also extracted and analyzed. Results show that lowering the storage temperature to 60˚C increased the hydroxyl concentration of pore solutions and in some cases, 14d expansions increased dramatically. As well, extending the 60˚C test period to 28d was effective in terms of more reliably identifying the reactivity of some aggregates. The effects of mitigation using pozzolans and slag on both the pore solution composition and expansion are being investigated.

Keywords: Accelerated mortar bar test; ASTM C1260; Pore solution alkalinity; Temperature effects

1 INTRODUCTION

If a concrete aggregate is alkali-silica reactive, unless adequately mitigated, concrete structures may deteriorate over time and cause serviceability problems. For this reason, it is essential to correctly determine the potential reactivity of aggregates prior to their use in concrete. Currently, the most common standard procedures used in North America for this purpose are the ASTM C1260 Accelerated Mortar Bar Test (AMBT) [1-4] and the ASTM C1293 Concrete Prism Test (CPT) [5-7]. Unfortunately, neither of these is ideal; the CPT is more reliable [8] but takes one year, whereas the AMBT is rapid but often unreliable [9-12]. Even with its shortcomings, due to the short lead time of many construction projects, the AMBT is the most practiced method.

The use of only the AMBT to evaluate aggregates is problematic in some geological regions. Some aggregates that perform well in the field can be classified as reactive [9,10] (false positives) with this test and some reactive aggregates can be incorrectly identified as non-reactive (false negatives) [11, 12]. False identification of aggregates may subsequently lead to increase in the costs of construction, inefficient use of natural resources, or excessive maintenance and rehabilitation activities at later ages.

The AMBT has been adopted as ASTM C1260 [1], CSA A23.2-25A [2], and RILEM AAR-2 [3]. Although these test standards slightly differ in some aspects, they are fundamentally similar as they are based on the original method proposed by Oberholster and Davies [4]. In brief, the AMBT procedure involves the following steps: 1) aggregates being examined are crushed to standard sizes and cast into mortar bars, 2) the mortar is moist cured for 24h, 3) the bars are demolded then submerged in water and heated to 80°C over a period of 24h, 4) their initial lengths are recorded, 5) the bars are submerged in 1.0N NaOH solution at 80°C for 14d, 6) their final lengths are recorded, and 7) the average of the length changes of the bars is calculated. The suggested expansion criterion varies between the standards; however, a 0.10% limit is typically specified. Aggregates exhibiting average length changes greater than 0.10% at 14d are generally considered as potentially reactive and those showing expansions below 0.10% are regarded as non-reactive.

In order to improve the accuracy of the AMBT, some researchers have suggested different modifications to the expansion criterion. To reduce false positives for aggregates with known satisfactory field performance [10], the Canadian (CSA) standard adopted a 0.15% expansion limit at

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14d [2,13]. To compensate for false negatives, on the other hand, ACI Committee 221 [14] recommended that only aggregates with expansions below 0.08% be identified as non-reactive. Unfortunately, changes in expansion limits can only be effective in reducing either false positives or false negatives, but not both. Some agencies (such as the Northwest Region of the Federal Aviation Administration) have specified a 28d expansion limit of 0.10%, but this also has the effect of increasing the number of false positive results and preventing the use of good aggregates.

For more reliability, various interperation methods have also been proposed. Johnston and Fournier [15], for instance, introduced a kinetic-based method for interpreting the results of the AMBT. Touma [16] found, however, that their method of interperation failed to improve the accuracy of the test and it led to the same results as the standard version.

In this paper, an alternative for improving the test method is proposed, and that is by reducing the storage temperature of the AMBT procedure. It is known that ettringite becomes unstable and breaks down at temperatures approaching 70°C [17]. Storing ASTM C1260 mortar bars at 80°C leads to ettringite decomposition, increasing sulfate concentrations in pore solution at the expense of hydroxyl ion concentrations (to maintain charge balance) [18]. The strategy used in the current study was to reduce the temperature of the AMBT to prevent ettringite decomposition, resulting in pore solutions and ASR mechanisms more representative of those taking place in the field.

Modified versions of the AMBT, setting the storage temperature to 60˚C or 40˚C (as opposed to 80˚C), and extending the duration in NaOH solution to 28d or 56d (as opposed to 14d) were evaluated. These modified versions, as well as the standard AMBT, were performed using a series of correctly identified, false positive, and false negative aggregates with respect to their field performance. To verify effects of temperature, pore solutions were also extracted from sealed paste samples exposed to 40˚C, 60˚C, and 80˚C for 35d and analyzed.

2 MATERIALS AND METHODS

2.1 Materials

Eleven aggregates of differing mineralogy and source locations were selected, many of these based on differences between ASTM C1260 test results and field performance. Their brief petrographic description, field performance, and AMBT classification, based on the data provided from the suppliers, are given in Table 1.

The portland cement used was CSA A3001 Type GU (similar to ASTM C150 Type I). Its chemical composition, as given in the mill certificate, is provided in Table 2.

2.2 Test Methods

Mortar Bars

The standard AMBT as adopted by ASTM C1260, as well as several test modifications, were conducted with each of the eleven aggregates.

For the standard tests, coarse aggregates were crushed. Crushed and fine aggregates were sieved, washed, dried, and size fractionated. 1 part of cement to 2.25 parts of graded aggregate and water-cement ratio of 0.47 (as per ASTM C1260) were mixed in accordance with ASTM C305 and cast into four 25mm×25mm×250mm gage length bar molds with stainless steel gauge studs at both ends. The molds were covered with plastic and placed over water in a sealed container, at 23˚C for 24h. Subsequently, the hardened mortar bars were demolded, and then immersed in a container in 23˚C tap water. The container was then placed in an oven at 80°C for 24h. The zero readings were taken at 48h after casting. The specimens were then submerged in preheated 1.0N NaOH solution and maintained at 80°C for 28d. The lengths of the mortar bars were measured periodically all using the same comparator and reference bar as used for the zero reading. The percentage expansion of each bar was calculated and the average of the expansions of the four bars was determined.

For the modified tests, the standard procedure was applied except that the storage temperature in water and alkali solution was reduced from 80˚C to 60˚C and 40˚C and testing was continued to 28d and 56d.

Paste Cylinders

One 0.50 W/C paste mixture was cast. The mixing sequence was in accordance with ASTM C305, but using a handheld kitchen mixer and a Pyrex mixing bowl of 1L capacity. The paste was poured into three 5 x 10 cm polyethylene bottles and tightly sealed. The bottles were rotated at room temperature for 24h to prevent segregation, and then placed in ovens set at 40˚C, 60˚C, and 80˚C over water in a container.

After 35d, the bottles were taken out, samples were crushed from the bottom half, and pore solution was extracted under pressures of up to 500 MPa. Immediately afterwards, the extracted pore solution was centrifuged to remove any particulates. A portion was used to determine the OH^- concentration by titration. The remaining pore solution was diluted with a 5% HNO_3 solution to prevent precipitation of solid phases, stored in an air-tight vial, for determination of K, Na, S, and Ca concentrations using inductively coupled plasma, atomic emission optical spectroscopy (ICP-AEOS).

3 RESULTS AND DISCUSSION

Table 3 shows the average 14d and 28d expansions for samples maintained at 80˚C and 60˚C, and the 28d and 56d expansions of samples maintained at 40˚C. Expansions exceeding 0.10% are shown in bold. The known field performance of each aggregate is also provided for comparison (ASR=deleteriously reactive, OK=good performance).

The 14d expansions at 80˚C are those of the standard ASTM C1260 test. Considering the expansion limit of 0.10%, it can be seen from Table 3 that, the SU and SP aggregates, which are known to be reactive in the field, are correctly identified with the standard ASTM C1260 test. However, NS, which passes the CPT (with an expansion of approximately 0.033% at 1yr [19]) and does not create significant serviceability problems in the field, is incorrectly classified as reactive (false positive). The standard version also fails to predict the non-reactive character of the PS and EC aggregates in the field. Aggregates ST, RH, GR, and GE, which expand greater than 0.04% at 3m under the accelerated concrete prism test (ACPT) at 60˚C (unpublished work from the authors of this paper) and are deleterious in the field, are incorrectly identified as non-reactive (false negatives). Reactive AD and WR aggregates also exhibit expansions close to, or slightly above, the 0.10% limit. In summary, expansion results from only three of the 11 aggregates tested by ASTM C1260 were able to correctly identify their ASR field performance.

At first glance, prolonging the 80˚C testing duration from 14d to 28d appears to be effective in correctly classifying the aggregates tested. However, this is only because 8 of the 11 aggregates tested are known to be reactive; extending the test limit to 28d is incapable of improving the accuracy for existing false positives and would lead to more non-reactive aggregates being identified as reactive.

Modifying the temperature to 60˚C either using 14d or extending the testing period to 28d improved the accuracy and correctly identified the field performance of 5 of the 11 aggregates. At 60˚C, one of the three false positive aggregates, PS, is correctly identified as non-reactive both at 14d and 28d, and at 14d, the false positive EC aggregate was also correctly identified. Also one out of five aggregates with false negative AMBT results, i.e., AD, is correctly identified as reactive at 60˚C. Both of the two correctly identified reactive aggregates, SU and SP, are still correctly identified as reactive at after 28d at 60˚C, but the Reactive SU aggregate did not reach 0.10% after 14 days at 60˚C. The significant increase in expansion of the WR aggregate at 60˚C should also be noted.

The 28d expansions at 40˚C incorrectly showed all aggregates to be non-reactive and, even after 56d, expansions were lower than with the ASTM C1260 standard test for 6 of the 8 aggregates tested. Since the objective is the rapidity of the AMBT, it seems that lowering the storage temperature to 40˚C is undesirable.

It is generally believed that elevated temperatures will only accelerate the kinetics of ASR. However, the results obtained suggest otherwise. Two of the ASTM C1260 false negative aggregates tested, AD and WR, actually expanded much more at the lower temperature of 60˚C than at 80˚C after 14d. This is attributed to the significant reduction in pore solution alkalinity at 80˚C that maybe inadequate to trigger deleterious expansions with these particular chert-containing aggregates.

Table 4 compares the pore solution composition (mmol/L) for pastes at different temperatures. The charge balance from the sum of the cations and anions is also been provided. As can be seen, $[K^+]$ and $[Na^+]$ are not significantly affected by temperature. However, $[SO_4^{2-}]$ rises remarkably with temperature, particularly from 60˚C to 80˚ C, due to ettringite decomposition. As temperature increases, suppression of $[OH^-]$ occurs to maintain charge balance: $[SO_4^{2-}]$ increases; whereas, the sum of cations remains somewhat constant. This confirms the work by Hunger et. al. [18]. $[Ca^{2+}]$ is much higher at 80˚C; although solubility of $Ca(OH)_2$ is inversely related to temperature.

Changes in pore solution concentration can influence expansion and chemical composition of ASR gel. At 80˚C, SO_4^{2-} may attack certain aggregates. Differences in $[Ca^{2+}]$ in laboratory tests from those found in pore solutions of field concrete may change the expansive behavior of the ASR gel [23]. A reduction in $[OH^-]$ can lead to reduced dissolution of reactive silica. This can be inferred from Figure 1 where the quantity of ASR gel infilling air voids of mortar bars, containing WR aggregate that had been tested at 60˚C and 80˚C, is compared. The backscattered electron micrographs in Figure 1 were taken in a Hitachi 2460N scanning electron microscope under high vacuum on epoxy-impregnated, polished, and carbon coated thin-sections.

Further research is in progress to investigate the influence of temperature and mortar bar immersion solution on (a) concentration of ions for mixes with and without supplementary cementing materials and, (b) to determine influence of pore solution composition on reaction mechanisms and characteristics of products formed in ASR test samples.

4 SUMMARY AND CONCLUSIONS

The current ASTM C1260 version of the AMBT is often unreliable and can yield both false positive and false negative results with some aggregates of known reactivity. The goal of this research was to make modifications that could help improve its accuracy. The modified versions of the test involved changing the storage temperature and period of testing. The standard and modified versions of the test were performed on eleven aggregates that were both correctly identified and incorrectly identified by the standard ASTM C1260 test method. It was found that reducing the temperature of the AMBT to 60˚C and extending the test period to 28d is effective in terms of correctly identifying three out of nine aggregates that exhibit false positive and negative test results in ASTM C1260. Improvements are thought to be due to the more realistic pore solution composition at 60˚C compared to 80˚C resulting from preventing decomposition of ettringite in the cement paste fraction of the mortar bars.

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TABLE 1: Aggregate description, field performance, and AMBT classification.

Agg.	Location	Ref.	Description	Field Performance	AMBT Classification
SU	Ontario, Canada	[10]	Siliceous gravel	Reactive	Reactive
SP	Ontario, Canada	[10]	Quarried limestone	Reactive	Reactive
NS	Minnesota, USA	[19]	Pierre shale	Good*	Reactive
PS	Ontario, Canada	[10]	Carbonate sand	Good	Reactive
EC	Wisconsin, USA	[20]	Siliceous gravel	Good	Reactive
ST	Maryland, USA	[20]	Granite gneiss	Reactive	Non-reactive
RH	Virginia, USA	[20]	Quarried granite-granite gneiss	Reactive	Non-reactive
GR	Virginia, USA	[20]	Quarried metabasalt, greenstone	Reactive	Non-reactive
GE	Germany	[21]	Granodiorite	Reactive	Non-reactive
AD	Texas, USA	[22]	Chert and quartzite	Reactive	Non-reactive
WR	Texas, USA	[22]	Chert with quartz and limestone	Reactive	Non-reactive

* Can cause gel formation in air voids and minor popouts on concrete surfaces

TABLE 2: Chemical analysis of cement (wt %).

SiO_2	19.39
Al_2O_3	5.13
Fe_2O_3	2.30
CaO	61.89
MgO	2.39
SO_3	4.08
Na_2O	0.25
K_2O	1.15
Na_2O_{eq}	1.01
Loss on ignition	2.54

TABLE 3: Average 14d and 28d expansions (%) at 80°C and 60°C, and average 28d and 56d expansions (%) at 40°C.

Aggregate	Field performance	14d at 80°C	28d at 80°C	14d at 60°C	28d at 60°C	28d at 40°C	56d at 40°C
SU	ASR	**0.287**	**0.505**	0.047	**0.173**	0.014	0.032
SP	ASR	**0.362**	**0.752**	**0.214**	**0.409**	0.050	**0.172**
NS	OK	**0.389**	**0.562**	**0.232**	**0.319**	-	-
PS	OK	**0.140**	**0.231**	0.028	0.086	0.010	0.031
EC	OK	**0.264**	**0.499**	0.043	**0.184**	-	**-**
ST	ASR	0.090	**0.185**	0.022	0.043	0.012	0.019
RH	ASR	0.061	**0.110**	0.022	0.049	0.009	0.013
GR	ASR*	0.075	**0.143**	0.031	0.058	0.011	0.016
GE	ASR	0.072	**0.137**	0.017	0.027	-	**-**
AD	ASR	0.081	**0.123**	**0.325**	**0.606**	0.063	**0.351**
WR	ASR	**0.118**	**0.144**	**0.345**	**0.616**	0.049	**0.171**
# Correctly identified		3/11	8/11	5/11	5/11	1/8	4/11
* this aggregate does not fail the CPT, but is claimed to be reactive in the field [21]							

TABLE 4: Concentration of ionic species (mmol/L) in 35d old, sealed cement pastes stored at 40°C, 60°C, and 80°C.

	K^+	Na^+	SO_4^{2-}	OH^-	Ca^{2+}	Sum of Cations	Sum of Anions
40°C	780	164	65.4	848	1.31	947	979
60°C	718	126	137	615	2.01	848	889
80°C	778	175	338	273	8.35	970	949

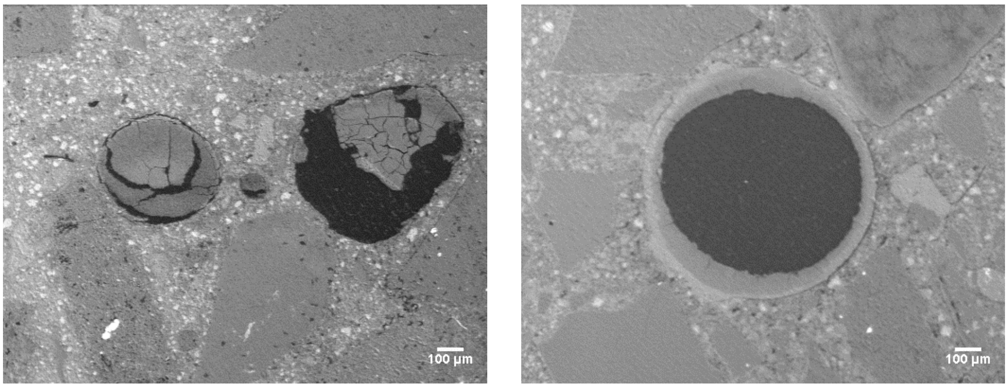

FIGURE 1: Typical amounts of ASR gel infilling air voids of mortars, cast with WR aggregate in 1N NaOH for 14d, higher for 60°C (on left) compared to 80°C (on right).