Theme: Concrete Durability

Reliability of extending AS1141.60.1 and 60.2 test methods to determine ASR mitigation

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Abstract

The Australian Standards AS 1141.60.1 and AS 1141.60.2 were published in 2014 as Accelerated Mortar Bar Test (AMBT) and Concrete Prism Test (CPT) to determine the potential alkali-silica reactivity (ASR) of aggregates. Both methods were extended to evaluate the effectiveness of supplementary cementitious material (SCM) in mitigating ASR, similar to ASTM C1567 and CSA A23.2-14A, in a research program undertaken by the Cement, Concrete and Aggregates Australia (CCAA). Eight aggregates were tested with various dosages of either fly ash or slag and expansions measured up to 35 days and 2 years for AMBT and CPT respectively. In addition, the efficacy of SCMs to mitigate ASR was determined for four additional reactive aggregates based on the AMBT. The results were evaluated based on the corresponding reactivity criteria in the two Australian Standards. They showed that fly ash or slag can effectively be used to mitigate ASR and that the AMBT provided a more conservative dosage of SCM in mitigation ASR than the CPT. The required fly ash or slag dosages are also found to be consistent with recommendations given in HB79. Most importantly, there are findings from many exposure sites around the world that showed the reliability of AMBT and CPT in predicting the effectiveness of SCM-mitigated solution in long-term field-exposed large concrete blocks.

1. Introduction

Current Australian Testing Methods

Two Australian Standards testing methods to determine the potential alkali-silica reactivity of aggregates were published in 2014. They are AS 1141.60.1 Accelerated Mortar Bar Test (AMBT) and AS 1141.60.2 Concrete Prism Test (CPT). Both methods are silent on their applications for the efficacy of supplementary cementitious material (SCM) on mitigation. The Australian AMBT and CPT methods adopted similar testing procedures to the ASTM C1260 and ASTM C1293 respectively. Interestingly, ASTM C1567 and Canadian Standard CSA A23.2-14A used the same testing procedures as ASTM C1260 and ASTM C1293 respectively in determining the effectiveness of cement system in preventing alkali-silica reactivity.

2. Experimental program

A total of 12 aggregates were tested to both the Australian AMBT and CPT as shown in **Table 1**. Broadly two types of supplementary cementitious materials (SCM): fly ash and slag; were used. The fly ash and slag are complied with AS3582.1 and AS3582.2 respectively. A number of Type GP cements, complying with AS3972, were used. The source of GP cement and SCMs was chosen according to their availability in the location of individual aggregate. Thus, the outcomes of these tests are highly relevant to the usage of all the aggregates. Testings were conducted in 3 commercial laboratories in Sydney.

Extension of Australian Test Methods for Mitigation

AS 1141.60.1 test procedures are similar to ASTM C1260 and ASTM C1567 with the latter used to determine the potential ASR of combinations of cementitious materials and aggregate. AS 1141.60.1 will be used to test the effectiveness of various SCM in mitigating ASR. Comparison will be made in the use of the respective criteria in AS 1141.60.1 and ASTM C1567 to gauge the efficacy of SCM.

AS 1141.60.2 test procedures are similar to ASTM C1293 and Canadian Standard CSA A23.2-14A, both of which are used to determine the length change of concrete due to ASR and with an extended testing period from one year to two years for combinations of cementitious materials for mitigation determination. Comparison will be made in the use of the respective criterion in AS 1141.60.2 and ASTM C1293 in gauging the efficacy of SCM.

Testing to AS 1141.60.1 was extended to 35 days and AS 1141.60.2 extended to 2 years.

3. Experimental Results

3.1 Alkali-Silica Reactivity by AMBT and CPT

The 10, 14 & 21-day AMBT expansion results and 1-year CPT expansion results of all 12 aggregates are tabulated in **Table 1**. It can be seen that similar rock type from different quarries, such as the three meta greywacke aggregates and two dacite aggregates can exhibit very different susceptibility to alkali-silica reactivity (ASR) determined from the expansion tests.

The degree of reactivity of each aggregate, determined from AMBT, may differ from that determined from the CPT. CPT results have been found to be more reliable and consistent with long-term field performance (Sirivivatnanon *et al*., 2016). In **Table 1**, it can be seen that a basalt, a quartz, a hornsfel and one dacite are found to be reactive by the AMBT but non-reactive by the CPT. Testing of the effectiveness of SCM to mitigate ASR commenced following the AMBT results prior to the availability of CPT results.

Table 1 Aggregates and range of supplementary cementitious materials used

	Aggregate	SCM	AS1141.60.1 AMBT				AS1141.60.2 CPT	
			10-day	14-day	21-day	AS1141.60.1 Classification	1-year	ASTM C1778 Classification
1	Hornfels	30-50% Slag	0.17	0.27	0.40	Reactive	0.070	Moderate R
2	Rhyodacite	15-30% FA	0.23	0.32	0.43	Reactive	0.059	Moderate R
3	Meta Greywacke	15-25% FA	0.23	0.30	0.39	Reactive	0.053	Moderate R
4	Basalt	15-30% FA	0.52	0.73	1.05	Reactive	0.007	Non-R
5	Dacite	10-25% FA	0.35	0.47	0.64	Reactive	0.233	Highly R
6	Rhyolite	15-25% FA	0.24	0.35	0.47	Reactive	0.142	Highly R
7	Meta Greywacke	10-25% FA	0.23	0.34	0.49	Reactive	0.158	Highly R
8	Quartz	15-25% FA	0.09	0.15	0.27	Slowly-R	0.003	Non-R
9	Meta Greywacke	15-25% FA	0.184	0.281	0.460	Reactive	0.113	Moderate R
10	Hornfels	15-25% FA 20-50% Slag	0.033	0.061	0.124	Slowly-R	0.008+	Non-R
11	Dacite	15-25% FA 20-50% Slag	0.308	0.426	0.562	Reactive	0.024	Non-R
12	Granite	15-25% FA 20-50% Slag	0.072	0.128	0.269	Slowly-R	0.050	Moderate R

AMBT reactivity classified to AS1141.60.1 and CPT reactivity classified to ASTM C1778 or AASHTO PP65.

3.2 Classification of Aggregate Reactivity

The reactivity of aggregates can be classified in accordance with AS1141.60.1 for AMBT results, and in accordance with ASTM C1778 or AASHTO PP65 for CPT results as there is no similar classification scale in the Australian Standards AS1141.60.2. Classifications to ASTM C1778 can either be based on AMBT expansion at 14 days and CPT expansion at 1 year as shown in **Table 2.**

Reactivity classification of all the aggregates tested are given in **Table 1**. These ASTM C1778 reactivity classes are used to correlate the efficiency of SCM in ASR mitigation to the long-term field performance of large concrete blocks at various exposure sites of aggregates with similar ASTM C1778 reactivity classification.

Table 2 ASTM C1778 or AASHTO PP65 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in Test Method ASTM C1293, %	14-Day Expansion in Test Method ASTM C1260, %
R0	Non-reactive	<0.04	<0.10
R1	Moderately reactive	≥0.04, <0.12	≥0.10, <0.30
R2	Highly reactive	≥0.12, <0.24	≥0.30, <0.45
R3	Very highly reactive	≥0.24	≥0.45

3.3 Reliability of Australian Standard AMBT and CPT in ASR mitigation

The level and type of SCM required to mitigate ASR expansion in AMBT and CPT tests of eight aggregates are summarised in **Table 3**. For the remaining four aggregates, the same were determined from the AMBT as shown in **Table 4.** If we were to adopt the current Australian Standard criteria of AMBT expansion limits at 10 and 21 days, and CPT expansion of no greater than 0.03% after 2 years (similar to 0.04% after 2 years in the Canadian Standard CSA A23.2-14A) to determine reactivity, it can be seen from the results in **Table 3** that the AMBT & CPT results are reasonably consistent in determining the type and dosage of SCM required to limit the expansion below the respective criteria. In addition, the AMBT results are more conservative in determining the minimum SCM content required to mitigate ASR.

It can also be seen that the CPT results are consistent irrespective of the use of either AS1141.60.2 or CSA A23.2-14A expansion criterion. On the other hand, AS1141.60.1 criteria result in more conservative dosage of SCM required for mitigation than ASTM C1567.

Thomas and Innis (1999) published data from 70 different combinations of SCM and aggregates tested in both the CPT and AMBT and demonstrated that there was a reasonable correlation between the 2-year expansion in the former and the 14-day expansion in the latter. They concluded that combinations of materials that expanded less than 0.10% at 14 days in the AMBT had a low risk of failing the 0.040% limit at 2 years in the CPT.

Based on the comprehensive expansion data of eight aggregates shown in **Table 3**, it can also be concluded that combinations of materials that expand less than 0.10% at 21 days in the Australian Standard AMBT had a low risk of failing the 0.03 limit at 2 years in the Australian Standard CPT. It is also important to note the consistency of the SCM dosage requirement by both CPT methods (AS1141.60.2 and CSA A23.2-14A) and hence the correlation of the AS1141.60.2 and the long-term field-exposed large concrete blocks results (Hooton *et al*., 2013, Fournier *et al*., 2016).

3.4 Type and dosage of SCM required to mitigate ASR

From **Tables 3 & 4**, it was found that both fly ash and slag are effective in mitigating ASR with a range of 15-25% fly ash and 50 or greater % slag required to mitigate ASR depending on the aggregate and its reactivity. It was also found that these ranges are consistent with the conservative dosages of 25% fly ash and 65% slag recommended in HB79 (2015).

Table 3 Summary of AMBT and CPT expansion results

Aggregate	Type	%	AMBT Expansion (%)			Classification		CPT Expansion (%)		Classification	
			10 d	14d	21 d	ASTM C1567	AS1141 60.1	1 Y	2 Y	CSA A23.2-14A	AS1141 60.2
Dacite	Eraring Flyash	0.0	0.35	0.47	0.64	R	R	0.233	-	R	R
		10.0	0.11	0.18	0.29	R	R	0.080	0.148	R	R
		15.0	0.03	0.06	0.11	N	SR	0.008	0.022	N	N
		25.0	0.01	0.01	0.02	N	N	-0.002	0.001	N	N
Rhyolite	Eraring Flyash	0.0	0.24	0.35	0.47	R	R	0.142	-	R	R
		10.0	0.04	0.07	0.12	N	SR	0.001	0.005	N	N
		15.0	0.02	0.03	0.04	N	N	-0.005	-0.003	N	N
		25.0	0.01	0.01	0.02	N	N	-0.006	0.001	N	N
Meta Greywacks	Central Qld Flyash	0.0	0.23	0.34	0.49	R	R	0.158	-	R	R
		10.0	0.10	0.19	0.30	R	R	0.058	0.115	R	R
		15.0	0.04	0.08	0.15	N	SR	0.021	0.046	R	R
		25.0	0.01	0.02	0.04	N	N	0.005	0.011	N	N
Quartz	Central Qld Flyash	0.0	0.09	0.15	0.27	R	R	0.003	-	N	N
		10.0	0.03	0.06	0.13	N	SR	-0.003	0.007	N	N
		15.0	0.01	0.03	0.05	N	N	-0.004	-0.003	N	N
		25.0	0.00	0.01	0.01	N	N	-0.008	-0.007	N	N
Hornfels	ICL Slag	0	0.17	0.27	0.40	R	R	0.070	0.155	R	R
		30.0	0.10	0.17	0.27	R	R	-0.006	0.013	N	N
		40.0	0.04	0.07	0.13	N	SR	-0.023	-0.011	N	N
		50.0	0.02	0.03	0.04	N	N	-0.011	-0.003	N	N
Rhyodacite	Mt Piper Flyash	0.0	0.23	0.32	0.43	R	R	0.059	0.087	R	R
		15.0	0.06	0.09	0.15	N	SR	0.002	0.010	N	N
		22.5	0.02	0.03	0.04	N	N	-0.006	-0.003	N	N
		30.0	0.02	0.02	0.02	N	N	-0.006	-0.001	N	N
Meta Greywacke	Sunstate Flyash	0	0.23	0.30	0.39	R	R	0.053	0.122	R	R
		15.0	0.03	0.04	0.07	N	N	-0.017	-0.009	N	N
		20.0	0.02	0.03	0.03	N	N	-0.006	-0.001	N	N
		25.0	0.01	0.02	0.02	N	N	-0.007	-0.009	N	N
Basalt	Eraring Flyash	0	0.52	0.73	1.05	R	R	0.007	0.024	N	N
		15.0	0.05	0.08	0.21	R	SR	-0.009	-0.007	N	N
		22.5	0.02	0.02	0.05	N	N	-0.010	-0.005	N	N
		30.0	0.01	0.02	0.02	N	N	-0.014	-0.009	N	N

AS1141.60.1 & 60.2 Classification: N - non reactive, SR – slowly reactive, R – reactive.
ASTM C1567 & CSA A23.2-14A Classification: N – non reactive, R – reactive.

Table 4 Summary of AMBT expansion results

Aggregate	Type	%	AMBT Expansion (%)			Classification		CPT Expansion (%)		Classification	
			10 d	14d	21 d	ASTM C1567	AS1141 60.1	1 Y	2Y	CSA A23.2-14A	AS1141 60.2
Dacite	Flyash	0.0	0.31	0.43	0.56	R	R				
		15.0	0.12	0.19	0.30	R	R				
		20.0	0.03	0.06	0.11	N	SR				
		25.0	0.02	0.03	0.05	N	N				
Dacite	Slag	0.0	0.31	0.43	0.56	R	R				
		20.0	0.31	0.42	0.55	R	R				
		30.0	0.22	0.31	0.42	R	R				
		40.0	0.13	0.19	0.29	R	R				
		50.0	0.04	0.06	0.10	N	SR				
Hornfels	Flyash	0.0	0.03	0.06	0.12	R					
		15.0	0.06	0.11	0.19	R	SR				
		20.0	0.03	0.06	0.10	N	SR				
		25.0	0.03	0.04	0.06	N	N				
Hornfels	Slag	0.0	0.03	0.06	0.12	R					
		20.0	0.12	0.20	0.29	R	R				
		30.0	0.10	0.16	0.26	R	R				
		40.0	0.06	0.10	0.18	R	SR				
		50.0	0.03	0.04	0.08	N	N				
Quartz	Flyash	0.0	0.09	0.15	0.27	R	SR				
		10.0	0.03	0.06	0.13	N	SR				
		15.0	0.01	0.03	0.05	N	N				
		25.0	0.00	0.01	0.02	N	N				
Meta Greywacke	Flyash	0.0	0.23	0.34	0.49	R	R				
		10.0	0.11	0.19	0.30	R	SR				
		15.0	0.04	0.08	0.15	N	SR				
		25.0	0.01	0.02	0.04	N	N				

Results not available

3.5 Correlation Australian Standard AMBT & CPT to long-term field performance

The results from Tables 3 & 4 showed that higher dosages of fly ash are required to mitigate ASR for highly reactive (HR) aggregates than moderately reactive (MR) aggregates. For the hornsfels moderately reactive aggregate, 30-50% of slag is required to mitigate ASR depending on the use of AMBT or CPT method. This is in general agreement with the agreement between AMBT and CPT results with the 10 and 15 years exposure results of large concrete blocks, manufactured from low-alkali cement (0.25-0.40 % Na_2O_{eq}), at CANMET outdoor exposure site in Ottawa, Canada (Fournier *et al.*, 2016). Where concrete blocks were cast from high-alkali cement (0.90% Na_2O_{eq}), 20% fly ash or 7.5-12.5% silica fume or 35-65% slag were found sufficient to mitigate ASR in moderately reactive aggregates consistent with AMBT and CPT results. However, higher dosage of 56% fly ash or 10% silica fume or 65% slag were required to mitigate ASR in highly reactive and extremely reactive (ER) aggregates.

Hooton *et al.* (2013) evaluated the effectiveness of SCM in mitigating ASR by both AMBT and CPT, they correlated the results to large unreinforced and reinforced concrete beams and pavement slabs at an outdoor exposure site in Kingston, Ontario, Canada. A high-alkali cement (0.79% Na_2Oe) was used with a highly reactive Spratt aggregate. Both AMBT and CPT showed consistent findings in SCM mitigation as in the 20-year field-exposed concrete. In particular, concrete mixes with 50% slag or a blend of 25% slag and 3.8% silica fume have neither expanded nor cracked after 20 years exposure.

As all cements used in this Australian testing program are low alkali cements (0.60% Na_2O_{eq}), it is expected that the type and required dosage of SCM found in these tests will prove to be effective for long-term performance of field structures for both MR and HR aggregates.

3.6 Extension of AS1141.60.1 and AS1141.60.2 for ASR mitigation

The current Australian Standards AS1141.60.1 and AS1141.60.2 have focused on testing the potential reactivity of aggregate without clear guidance to examine the effectiveness of cementitious system to prevent ASR. The application of the two methods to evaluate the effectiveness of fly ash and slag on 12 aggregates reported in **Tables 3 & 4** strongly support their extension for mitigation evaluation, similar to the extension of ASTM C1260 to ASTM C1567 and ASTM C1293 to CSA A23.2-14A, based on the existing criteria but applied to the 2 year expansion in the case of the AS1141.60.2.

The expansion results also confirm that the Australian Standard AMBT provides a more conservative SCM dosage requirement than the CPT. Field exposure up to 15 years (Fournier *et al*., 2016) and 20 years (Hooton *et al.*, 2013) suggested also that higher SCM dosage would provide a better safety margin for highly reactive aggregates when used with high-alkali cements.

4 Conclusions

The extensive research program reported in this paper has led to the following conclusions:

1. The adoption of AS 1141.60.1 (AMBT) and AS 1141.60.2 (CPT) testing procedures and reactivity criteria, to test for the effectiveness of SCM in mitigating ASR, have shown consistent results to the corresponding ASTM C1567 and CSA A23.2-14A. These findings support similar results reported by Thomas & Innis (1999).
2. The AMBT results are more conservative than the CPT in identifying the dosage of SCM required for ASR mitigation.
3. With the use of low-alkali cement in Australia, both AMBT & CPT are expected to deliver mitigating measures which are consistent with those found in long-term field-exposed large concrete blocks results reported by Fournier *et al.* (2016) and Hooton *et al.* (2013).
4. While it can be argued that the AMBT is an inappropriate method in theory to determine the efficacy of SCM in mitigating ASR, it is important to recognise the entrenched use of the method by VicRoads and RMS. The results reported in this work confirm the validity of such an approach in practice.
5. These findings support the extension of both Australian test methods AS 1141.60.1 (AMBT) and AS 1141.60.2 (CPT) for mitigation based on the existing expansion criteria but with an extended period of 2 years for the CPT.

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