# Comparison of accelerated test methods for ASR reactivity testing

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**Abstract**: The deleterious alkali silica reaction (ASR) affects the long term durability of concrete by reducing service life. Standardised accelerated test methods are used to rapidly asses reactivity. Rapidly accelerating the ASR reaction process may produce reactivity responses from aggregates that would not occur in field conditions. The environment in which the accelerated test is conducted is crucial in determining the degree to which the ASR reaction and associated deleterious expansion proceeds. In this study, a course reactive Australian aggregate concrete is exposed to standardised, and modified test methods to assess their effect on the observed ASR reaction. Australia has produced AS1141.60.2, a standardised concrete prism test at 38ºC for determining ASR reactivity of aggregates which is deployed in this study alongside a 60ºC concrete prism test and prism immersion test methods. This paper compares deleterious ASR expansion across a number of accelerated test methods and found good correlation between CPT and immersion based test methods.

**Keywords**: alkali-silica, ASR, durability, standard, concrete.

## 1. Introduction

The alkali-silica reaction (ASR) is a deleterious reaction that can result in cracking in concrete. ASR is the reaction between reactive silica in the aggregate and the alkali in the pore solution leading first to dissolution of the silica before precipitation of an expansive gel which has the potential to cause cracking in the concrete [1]. Minimisation of the risk of ASR is achieved by screening the aggregates for potential for ASR using accelerated test methods and by limiting the alkali content in the cement to limit of < 2.8 kg/m$^3$ $Na_2O_e$ [2].

The method for screening of aggregates is outlined in HB-79 and focusses on expansion testing using the accelerated mortar bar test (AMBT), AS 1141.60.1 [3], and the concrete prism test (CPT), AS1141.60.2 [4]. These test methods have been shown to correlate with long term expansion [5], however, there has been some concern with the limitations of these methods.

The AMBT is considered to be a conservative test as it is carried out at elevated temperature (80°C) with the mortar bars immersed in 1M NaOH solution. Such a reactive environment is likely to institute non-standard reactions in the aggregate promoting expansion resulting in the categorisation of non-reactive aggregates as reactive. Additionally, the test method is not viewed as a suitable for the assessment of the efficacy of supplementary cementitious materials (SCMs).

The CPT is considered to be a much more accurate test due to the less reactive conditions in which the screening is carried out. The measures used to accelerate the reaction are raising the alkali content of the concrete to 5.25 kg/m$^3$ and raising the temperature of the test to 38°C. The test is known to be affected by leaching which limits its capacity for the assessment of alkali thresholds as well as the efficacy of SCMs for mitigating ASR in concretes that contain reactive aggregates [6].

Due to the limitations of these standard test methods, this paper investigates the potential of alternative test methods for the assessment of ASR reactivity to overcome the conservative nature of the AMBT, the potential issues with leaching in CPT and to provide a more reliable method for assessing alkali thresholds and the efficacy of SCMs in ASR mitigation. The alternative tests methods investigated in this study are simulated pore solution tests, which uses the CPT method at 38°C, but places the concrete prisms in a solution replicated from expression of the pore solution, and the miniature concrete prism test (MCPT) which used 10 mm aggregate to prepare miniature concrete prisms and borrows from the AMBT by immersing the prims in 1M NaOH but at the lower temperature of 60°C. MCPT is published as a standard test method by AASHTO with designation T380 [7].

The pore solution immersion test is a nonstandard test that addresses alkali leaching from concrete prisms by immersing test specimens in an environment that intends to simulate the internal pore solution of the concrete has been reported [8, 9]. The premise for this approach is that if the external storage solution is comprised of a solution with an alkali composition that approximates that of the internal pore solution of the concrete, there will ideally be no concentration gradient between the concrete and its external environment. Without a significant difference between the internal and external solution composition, no leaching of alkalis should occur thus mitigating the issue within the test method. Additionally, partial acceleration of the 38°C CPT and pore solution immersion test is investigated by elevating the temperature of the test to 60°C in a similar manner to the approach using in RILEM AAR-4. The results of these tests are reported in this paper using a reactive dacite aggregate.

## 2. Method

The coarse aggregate used in this study is a reactive dacite which has been petrographically analysed and found to be a deformed quartz feldspar porphyry with a composition of approximately 45% quartz, 30% feldspar, 10% white mica, 5% chlorite, 5% calcite, 5% magnetite, 1% biotite and trace epidote. The cement used for all testing procedures is an Australian general purpose cement with a $Na_2O_e$ content of 0.47%. The NaOH and KOH used were sourced as laboratory grade solid pellets. For AMBT storage solution, distilled water was used and NaOH was added to bring the concentration to 1M. For mix water of concrete and mortar specimens, potable tap water was used. NaOH was added to the mix water in the appropriate amount to bring the alkali content of the concrete to the level specified for each standard, see Table 1.

Australian standards were followed for the preparation of the mortar and concrete specimens with the following changes to test method s noted. For CPT, the methodology of AS1141.60.2 was followed without change. For ACPT, the methodology of AS1141.60.2 was followed with the exception that the storage temperature of 60°C was used which is in line with AAR-4.1 [10]. For AMBT the methodology of AS1141.60.2 was followed with the exception that the prisms were cured for a period of 2 days in the steel mortar moulds. For MCPT, the methodology of AASHTO T380 was followed unchanged.

The pore solution immersion experiment test is a nonstandard test designed to overcome the leaching limitation of the CPT standard test. The method used is outlined in [9]The pore solution of three 50mm x 100mm paste cylinders were expressed using a pore solution extraction device and analysed with atomic emission spectroscopy. The paste cylinders were designed to have identical binder compositions to those of the concrete specimens, the binder was boosted to have 1.25% $Na_2O_e$ via addition of NaOH. The cylinders were cured for 28 days before extraction to ensure a stable internal pore solution. Base on the alkali contents of the extracted pore solutions, the appropriate pore solution bath concentration was determined to consist of 0.26M of KOH and 0.62M of NaOH. Concrete mix design and mixing procedures were identical to that used for CPT however the concretes were cured in a sealed humid environment for 28 days so that the hydration progress would align with the extracted pore solution pastes. A summary highlighting key experimental factors can be found in Table 1.

**Table 1. Summary of test method parameters.**

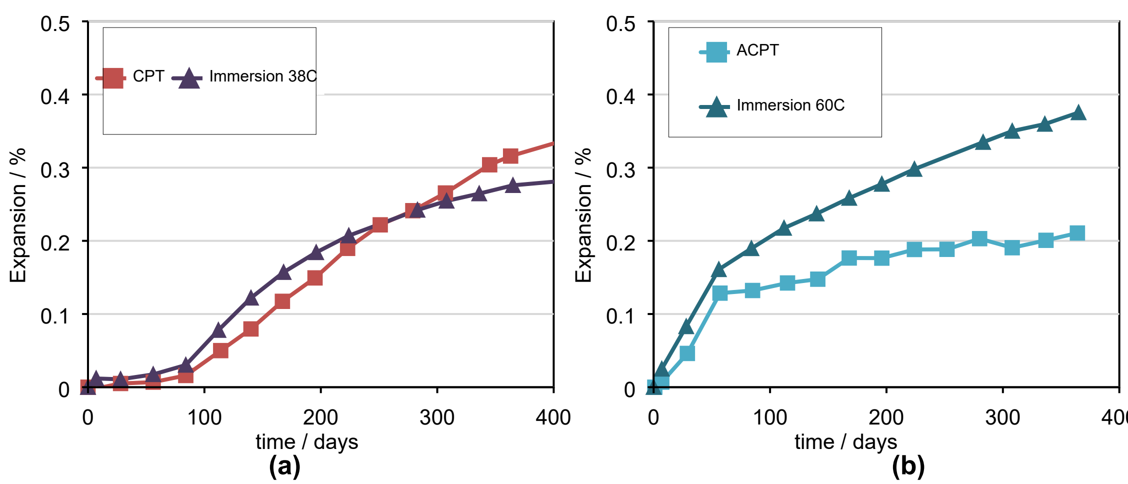
| Test Method | AMBT AS1141.60.1 (modified) | CPT AS1141.60.2 | ACPT, Modified AS1141.6 0.2 | Pore Solution Immersion Testing | MCPT AASHTO T380 |
|---|---|---|---|---|---|
| Temperature | 80°C | 38°C | 60°C | 38°C & 60°C | 60°C |
| Storage Environment | 1M NaOH Solution | 95% relative humidity | 95% relative humidity | NaOH + KOH Approx.\. Conc to Pore solution | 1M NaOH Solution |
| Specimen Type / Size | Mortar 25x25x285 mm | Concrete 75x75x285 mm | Concrete 75x75x285 mm | Concrete 75x75x285 mm | Concrete 51x51x285 mm |

| | | | | | |
|---|---|---|---|---|---|
| Standard Alkali Loading | N/A | 5.25 kg / m$^3$ | 5.25 kg / m$^3$ | 5.25 kg / m$^3$ | 5.25 kg / m$^3$ |

## 3. Results

Expansion results across CPT, ACPT and pore solution and 1M NaOH solution immersion experiments are reported in Figure 1 for CPT and pore solution immersion test specimens at 38°C (Figure 1a) and ACPT and pore solution immersion test specimens at 60°C (Figure 1b). All specimens in Figure 1 have the same mix design and concrete composition. The main point of comparison between samples in Figure 1 is that CPT and ACPT expose the specimens to humid conditions while the for pore solution immersion tests the specimens are immersed. What is notable when making the comparison between storage environments is that the expansion responses are remarkably similar when comparing specimens at the same temperature in different environments. The expansion observed for the 38°C specimens (CPT, 38°C immersion) follow very similar reaction profiles, with the onset of significant expansion beginning between 56 and 84 days in both cases. In both 38°C cases, the expansion magnitudes are similar across the testing period of 1 year, indicating that the Immersion of the samples in the simulated pore solution does not increase the reactivity of the system to a level above that of what is observed in CPT conditions. This outcome suggests that the immersion test could be a suitable test where overcoming the alkali leaching issue is a requirement such as the in the estimation of alkali thresholds or estimating the dosage of SCM required for mitigation when using reactive aggregates.

A similar outcome is observed for the 60°C specimens with the onset of expansion occurs rapidly at the start of the test. However, after a period of 56 days the expansion recorded in ACPT conditions is significantly depressed compared to the immersion specimens. The 60°C temperature of these test results in significantly greater potential for leaching of alkalis from the ACPT specimens. If a higher level of alkali is removed from the prisms, it would provide an explanation for the depressed expansion due to reduced reactivity as alkalis are removed from the prisms. The continued expansion of the pore solution immersed specimens at 60°C reflects the continued reactivity that would be expected when subjecting the specimens to 60°C and total expansion correlates with the 38°C test, but is accelerated by the elevated temperature to an earlier time. The 60°C test therefore demonstrates the necessity of adopting a test that overcomes the leaching limitation where known concrete alkali contents are required such as in alkali threshold determination or in estimating the efficacy of SCMs in ASR mitigation.




a) .
b) Expansion of.

**Figure 1. Expansion data for concrete specimens at (a) 38°C; CPT and pore solution immersion and (b) 60°C; ACPT and pore solution immersion.**

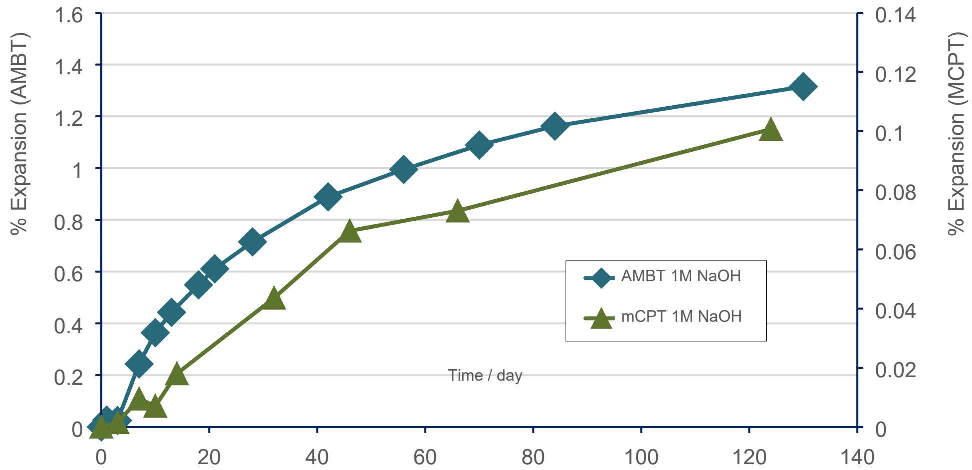



**Figure 2. Expansion of MCPT and AMBT specimens.**

Expansion of AMBT and MCPT are displayed in Figure 2. The Expansion for these tests are plotted with different y-axis scales as the expansion for AMBT far exceeds the maximum magnitude of expansion of the MCPT by a factor of ten. This is due to the design of the experiment, as AMBT is conducted at 80°C with crushed dacite used to prepare the mortar which increases the reactivity significantly. For the MCPT test, not only is the temperature reduced to 60°C, the coarse aggregate in the MCPT specimens may provide added volume stability in addition to reduced surface area for exposure of the aggregate particles to the alkali solution thus providing a significantly reduce reactivity environment resulting in significantly reduced expansion. The expansion data shows that MCPT is a much-reduced reactivity environment and thus may be a more reliable rapid test for the assessment of ASR.

The expansion for each reaction system is listed in Table 2 along with respective classifications from each standard test method. It is important to note that the classifications listed are for use when the respective standard is followed however in the case for this study there are modifications made to each test method that deviate from the standard with the exceptions of AS1141.60.2 (CPT) and T380 (MCPT). The suggestion is that the pore solution immersion experiment exhibits a more realistic reaction environment due to the absence of leaching and the potential risk of drying. With this in mind it is important to note that by the age of one year, the immersion experiment at 38°C has an expansion lower than that of CPT.

**Table 2. Expansion summary and classifications**

| Test Method | Reactivity Criteria Used | Expansion at 365 Days | Expansion at Criteria | Reactivity Classification |
|---|---|---|---|---|
| CPT | 0.3% ≤ Expansion at 52 Weeks (As1141.60.2) | 0.32 | 0.32 | Potentially reactive |
| 38C pore solution Immersion | N/A | 0.28 | N/A | N/A |
| ACPT | 0.03% ≤ Expansion at 15 Weeks (RILEM AAR-4.1) | 0.21 | 0.14 | Potentially reactive |
| 60C pore solution Immersion | N/A | 0.38 | N/A | N/A |
| MCPT | Moderate Reactive if Expansion is 0.041-0.120% at 56 days (AASTO T380) | N/A | 0.07 | Moderate reactive |

| | | | | |
|---|---|---|---|---|
| AMBT | 0.3% ≤ Expansion at 21 Days (AS1141.60.1) | N/A | 0.61 | Reactive |

## 3. Conclusions

This study investigated a variety of standard and the nonstandard test methods using a reactive aggregate. All test methods confirm that the aggregate may be classified as potentially reactivity. The following conclusion can be drawn from the study.

- At 38°C, expansion profile for the CPT (humid environment) specimens compares well with that of the pore solution immersion test specimens suggesting that the pore solution immersion test is a viable test.
- At 60°C, expansion profile for the ACPT specimens deviates from that of the pore solution immersion test specimens. A likely cause of this deviation is the excessive leaching of alkalis from the ACPT specimens resulting in stagnation of the expansion after 56 days.
- The pore solution immersion test shows potential to overcome the leaching issue of the humid environment tests where accurate knowledge of the alkali content of the concrete is required such as in alkali content threshold determination or in SCM dosage and efficacy determination.
- AMBT and MCPT test both demonstrate potential for assessing reactivity of the aggregate to ASR. The MCPT has significantly reduced expansion from reduced reactivity environment and thus is likely to be less conservative than the AMBT. The MCPT needs to be further benchmarked to demonstrate it as a viable rapid screening test in Australia.

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## 5. References

1. Rajabipour, F., et al., *Alkali-silica reaction: Current understanding of the reaction mechanisms and the knowledge gaps.* Cement and Concrete Research, 2015. **76**: p. 130-146.
2. Standards Australia, *Alkali Aggregate reaction - Guidelines on Minimising the Risk of Damage to Concrete Structures in Australia*, in *HB79*. 2015.
3. Standards Australia, *Methods for sampling and testing aggregates, Method 60.1: Potential alkali-silica reactivity - Accelerated mortar bar method*. 2014, Standards Australia.
4. Standards Australia, *Concrete prism test for assessment of alkali silica reaction in concrete aggregate*. 2014, Standards Australia.
5. Sirivivatnanon, V., et al., *Reliability of AMBT and CPT in testing the effectiveness of SCM to mitigate alkali–silica reaction of field concrete.* Construction and Building Materials, 2023. **369**: p. 130510.
6. Sinno, N. and M.H. Shehata, *Role of temperature on Alkali-Silica reaction and the efficacy of supplementary cementitious materials.* Construction and Building Materials, 2021. **313**: p. 125427.
7. AASHTO, *Standard Method of Test for Potential Alkali Reactivity of Aggregates and Effectiveness of ASR Mitigation Measures (Miniature Concrete Prism Test, MCPT)*. 2022, AASHTO.

8. Chappex, T., L. Sofia, and K. Scrivener. *A robust testing protocol for the assessment of ASR reactivity of concrete*. in *15th international conference on alkali aggregate reaction in concrete (ICAAR). Sao Paulo, Brazil*. 2016.
9. Tapas, M.J., et al., *Efficacy of SCMs to mitigate ASR in systems with higher alkali contents assessed by pore solution method.* Cement and Concrete Research, 2021. **142**: p. 106353.
10. Nixon, P.J. and I. Sims, *RILEM Recommended Test Method: AAR-4.1—Detection of Potential Alkali-Reactivity—60 °C Test Method for Aggregate Combinations Using Concrete Prisms*, in *RILEM Recommendations for the Prevention of Damage by Alkali-Aggregate Reactions in New Concrete Structures: State-of-the-Art Report of the RILEM Technical Committee 219-ACS*, P.J. Nixon and I. Sims, Editors. 2016, Springer Netherlands: Dordrecht. p. 99-116.