

Alkali silica reaction progress in an Australian aggregate concrete: immersion test studies

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Abstract. The Alkali Silica Reaction is a deleterious reaction between alkalis and reactive aggregate materials in concrete structures. ASR has caused significant damage and reduces service life of structures. To prevent ASR from affecting the service life of current and future structures, characterisation of concrete material's propensity to form ASR is vital to inform material choice for durable concrete. Minimising concrete alkali content is an important strategy in protecting the long-term durability of structures however boosting alkali of concrete in controlled experimental conditions is required to assess an aggregate's propensity for ASR reactivity. Accelerating ASR reactive conditions via alkaline solution immersion techniques are emerging as a viable ASR investigative tool. This study investigates the effect of boosted alkali binders and immersion solutions on the ASR mechanism. The effect on deleterious expansion, aggregate damage and ASR mechanisms are assessed.

Keywords: Alkali-Silica Reaction, Concrete, Durability, CPT, pore solution

1 Introduction

The alkali-silica reaction (ASR) is a deleterious reaction that affects concrete structures and poses significant durability concern worldwide. ASR induced damage reduces overall effective service life, requiring remediation or replacement of affected structures, incurring economic and environmental costs. ASR requires alkali metal cations in the pore solution which are primarily introduced in the form of sodium and potassium oxides from the cement binder. The alkali reacts with reactive (e.g. silica strained quartz, amorphous opal) in the aggregate resulting in dissolution [1]. The dissolved silica then polymerize in solution and precipitate to form ASR gel. The ASR gel sorbs available water from the pore solution which causes the gel to expand and induce mechanical stresses within the concrete leading to cracking. To reduce the prevalence of deleterious ASR, a number of mitigation strategies are implemented. These include the restricted use of aggregate materials known to be reactive, the minimization of available moisture and the control of available alkali. Alkali control is implemented by limiting the total amount of alkali in a concrete in order to minimize potential expansion, the exact limit varies by region, in Australia, the total alkali limit in concrete is $2.8\text{kg/m}^3 \text{Na}_2\text{O}_{\text{eq}}$ [2]. This limit is maintained by restricting the cement

alkali content to a low level; in Australia the maximum allowed alkali content of cement is 0.6% $\text{Na}_2\text{O}_{\text{eq}}$ [3].

An alternative approach to applying alkali limits is the balanced alkali model where the alkali limit for a specific concrete defined by the reactivity of the aggregate used and the consequence of the development of deleterious ASR; the suggestion being that alkali limits could be raised for non-reactive aggregates and/or low-risk applications.

To assess viability of a balanced alkali approach to the application of alkali limits, the threshold alkali limit for an aggregate to produce deleterious ASR must be investigated. The globally accepted test method for assessing aggregate reactivity to ASR is the concrete prism test (CPT). The test relies on subjecting concretes of a standard grading and water content to accelerated reaction conditions of 1.25% boosted alkali in a humid (95-100% RH) environment and a temperature of 38°C. The accelerated CPT conditions can produce ASR diagnosis in a period of 1 year by method of an expansion threshold that has been set based on field correlated studies. CPT's history of validation and practical reliability allows it to be a foundation for threshold testing. However CPT has an issue of alkali leaching which has been shown to contribute to the misidentification of aggregate reactivities [4]. Alkali leaching is the process by which dissolved alkalis from the pore solution are carried away by water movement within the humid reaction container, reducing the internal alkali concentration of the pore water over time. In the context of threshold determination, the leaching of alkalis would affect concretes of different alkali contents to different degrees, possibly reducing a lower alkali mix's expansion potential to a greater extent than a higher alkali mix, leading to misleading results. To reduce leaching, experimental strategies such as prism wrapping and solution immersion techniques have been proposed and implemented.

This study employs an alkali immersion technique that aims to address the alkali leaching deficiencies of the CPT test method while providing a potential alternative threshold testing method to investigate ASR.

2 Methods & Materials

Concretes were produced using a general-purpose (GP) Portland cement (0.47% $\text{Na}_2\text{O}_{\text{eq}}$), a reactive dacite aggregate (predominantly quartz and feldspar) and an unreactive natural river sand. Analytical grade NaOH was used in addition to potable water for the mixing procedure.

All concrete prism specimens were produced as per Australian Standard AS1141.60.2; the water to cement ratio for each mix was within 0.42-0.45 range, the cement content was 420kg/m³ and the slump targeted was 80 mm. The alkali contents of the mix were varied from 0.5% to 1.25% (Table 1); the respective alkali levels were achieved by boosting the mix with NaOH addition.

Two storage environments were used to investigate expansion; CPT as outlined in AS1141.60.2 and simulated pore solution testing. CPT prisms were stored under 95-100% relative humidity after an initial curing period of 24 hours. Immersion testing was carried out by complete immersion of the prisms in simulated pore solution baths

prepared using analytical grade KOH, NaOH and potable tap water. The prisms aged in immersion baths were first cured for 28 days in a humid environment at 23°C prior to immersion. Representative pore solution concentrations were determined by mechanically expressing the pore solution from equivalent paste samples cured for 28 days using a steel pore solution extraction device and a UX2000 compression machine, applying 800kN force for 8 minutes. Solutions were collected and analysed using an Agilent MP-AES to determine the sodium and potassium ion solution concentrations.

Prism expansion at 38°C was determined via the standard method outlined in AS1141.60.2; a Mitutoyo horizontal digital comparator was used with an accuracy of 1 micron. Measurements were taken after the initial curing period and after placement in their respective storage environments at 1, 7, 28 and every 28 days thereafter.

Table 1. Key Concrete Variables.

Concrete identifier	Alkali content, % Na ₂ O _{eq}	Simulated pore solution bath concentration	
		NaOH (mol/L)	KOH (mol/L)
D1	0.5	0.1	0.3
D2	0.7	0.2	0.3
D3	0.9	0.4	0.3
D4	1.1	0.5	0.3
D5	1.25	0.6	0.3

3 Results and Discussion

Expansion results for concrete prisms in CPT conditions up to a period of 196 days are displayed in Figure 1a. along with the standard Australian standard expansion limit for CPT denoted by the dashed line of 0.03% expansion. Figure 1b displays the pore solution immersion test prism expansion. Both test were carried out at 38°C.

Expansion is observed for both the CPT and the immersion test environments and both appear to have the same induction period prior to expansion. For the standard alkali content (1.25% Na₂O_e), the degree of expansion demonstrates reactivity of the aggregate. The degree of expansion is a little less for the CPT measurements. This may be ascribed to leaching of the alkali during the CPT. The pore solution immersion test maintains the pore solution concentration of alkali in the concrete prisms.

In both storage environments, mix D4 containing 1.1% Na₂O_{eq} follows an expansion curve very similar in rate and magnitude to that of D5, containing 1.25% Na₂O_{eq}. Investigation into difference in gel composition may provide the cause of this effect and will be carried out in further tests.

Below a content of 1.1 % Na₂O_e, there is significant divergence between the two test methods. An incremental decrease is observed for the immersion test whereas a significant decrease is observed for the CPT test. It is not certain that leaching is responsible for this sudden decrease in the CPT test. The variation is the subject of continued investigation. The inconsistent decline in expansion behaviour for the CPT

test specimens either indicates a threshold in alkali content or, more likely, that leaching is resulting in variable results. The consistent expansion behaviour of the immersion test suggest that this is a more viable test for studying threshold content.

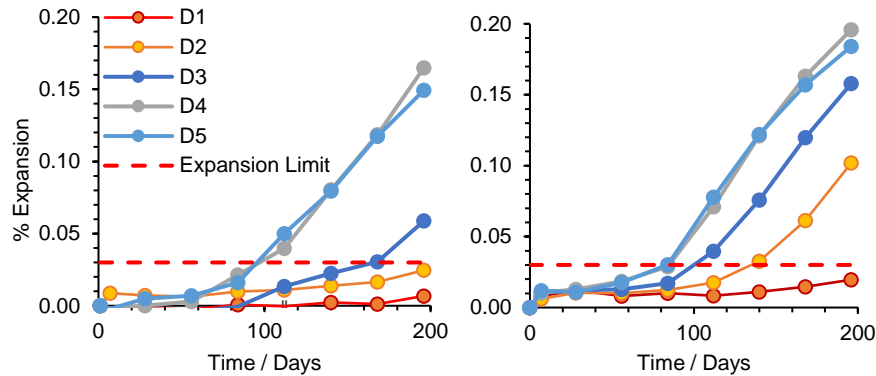


Fig. 1. (a) Percentage expansion over time (days) of concrete prisms in CPT conditions, 95-100% RH at 38°C (b) Percentage expansion over time (days) of concrete prisms immersed in simulated pore solution at 38°C. The expansion limit listed for deleterious ASR expansion is that of AS1141.60.2.

4 Conclusions

- Both CPT and immersion test show interesting expansion results above 1.0% Na_2O_e likely due to the properties of the silica gel produced which is the subject of further study.
- Significant difference between CPT and immersion test at lower Na_2O_e contents suggest leaching is an impediment for the use of the CPT for threshold determination.

References

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