

Evaluation of the effect of alkali bath concentration on ASR development in AMBT

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Abstract: The Alkali silica reaction's (ASR) expansive properties and its subsequent deleterious potential in concrete is a serious problem in infrastructure durability. The alkali content available to ASR influences its deleterious properties, therefore analysing the effect of alkali concentrations on reactivity and expansion is important for developing concrete with long term durability. This investigation aims to assess the effect of alkali concentration on mortar bar expansion in an accelerated reaction environment to provide a basis for future phase development studies. Mortar prisms are prepared with a reactive natural river sand and are subject to a range of alkali solution concentrations for 28 days at 80°C. The procedure follows the Australian Standard Accelerated Mortar Bar Test (AMBT), with modified storage solution concentration of 0.4, 0.7 & 1.0M NaOH and saturated Ca(OH)₂. The effect of common supplementary cementitious materials on ASR development with the incorporation of fly ash and ground granulated blast furnace slag is also investigated under modified AMBT conditions. Expansion results are reported in this study and are correlated with literature investigations.

Keywords: ASR, AMBT, durability, alkali, reactivity

1. Introduction

The alkali-silica reaction is a deleterious reaction between alkali hydroxides and reactive silica in concrete. The expansive properties of ASR gel and its subsequent deleterious potential in concrete is a serious problem in infrastructure durability. ASR can result from any cementitious system provided that three reaction components are available, alkali, reactive silica and water. The reaction precedes with the dissolution of reactive silica from aggregate materials and, in the presence of calcium, precipitates with available alkali ions in the pore solution [1]. This results in the precipitation of an expansive alkali-silica gel, the ASR gel. The ASR gel has the propensity to absorb water which causes it to expand and exert mechanical stress on the concrete which results in cracking. In order to reduce the potential for deleterious ASR, a number of mitigation strategies are employed. Common mitigation strategies include the use of non-ASR reactive aggregates, limitations on the available alkali in the concrete mix, incorporation of supplementary cementitious materials (SCM's) or a combination of multiple strategies.

A number of standardised test methods are available to determine an aggregate's potential reactivity to ASR. These test methods, such as the concrete prism test, AS1141.60.2 (CPT) and the accelerated mortar bar test AS1141.60.2 (AMBT), are carried out under accelerated conditions designed to provide aggressive environments to promote ASR gel development [2, 3]. These accelerated test methods are useful in their intended use as a binary indicator for ASR reactivity. Both have their limitations; AMBT is rapid but conservative, CPT is more reliable but is carried out over significantly longer periods.

The rapid nature of the AMBT test is desirable for rapid screening of aggregates and is the focus of this investigation. The categorisation of aggregate reactivity is based on expansion limits as outlined in Table 1. However, there have been examples of "false negatives" where aggregates classified as non-reactive that have been seen to cause ASR damage in field exposed structures [4]. It has also been shown that, due to the aggressive reaction environment, that some aggregates can be classified as reactive while showing no ASR damage in the field providing a "false positive" [5].

False positives and false negatives can be ascribed to the reaction conditions. Mortar expansion has been demonstrated to depend on solution concentration, aggregate mineralogy, and test duration [6]. The accelerated reaction environment in AMBT has also been reported to produce ASR-gels that are not consistent with those produced in concretes, with AMBT induced gels consisting of high sodium content gels compared to concretes of similar composition due to the constant supply of alkali from the 1 M NaOH bath [7]. False negatives are more concerning than false positives however are not as common. In many respects, these false positives and false negatives are addressed by carrying out the longer term CPT test, however, the AMBT test remains a reliable test method for rapid screening of

aggregates [8]. The benefit of assessing aggregate reactivity using the AMBT is that it enables a rapid evaluation of an aggregate's reactivity within a 21-day timeframe. These rapid timeframes are extremely valuable to industry regardless of gel compositional discrepancies and this warrants additional investigation into the test and the properties of the ASR gel it produces. This paper therefore focuses on the alkali concentration of the bath solution in modified AMBT experiments and reports the initial outcomes of expansion tests for reactive aggregates as a function of the bath solution concentration.

The AMBT has also been used to assess the efficacy of SCMs. SCM blended cements have been tested under AMBT conditions to evaluate the test method in identifying levels of SCM required to mitigate ASR for a particular aggregate [8]. SCMs have been shown to be effective in ASR mitigation through a number of mechanisms [9]. As AMBT has shown promise in identifying the efficacy of SCMs in mitigation of ASR, this paper also report the initial outcomes of expansion test for mortars containing reactive aggregates mixed using blended cements containing fly ash (FA) and ground granulated blast furnace slag (S).

Table 1. Reactivity classification for the AMBT as defined by AS1141.60.1.

Mean mortar bar expansion %		AS 1141.60.1 aggregate reactivity classification
Duration of specimens in 1M NaOH 80 °C		
10 days	21 days	Non-reactive
---	$E < 0.10^*$	
$E < 10^*$	$0.10 \leq E < 0.30$	Slowly reactive
$E \geq 0.10^*$	---	Reactive
---	$0.30 \leq$	Reactive

* The value for natural fine aggregates is 0.15%.

2. Materials and Method

2.1 Mortar

In this study a natural river sand chosen as the initial primary aggregate of focus as this aggregate had been classified as reactive by AS1141.60.1. The reactive river sand has been found to contain 10.7% moderately strained quartz, 2% heavily-strained quartz and 1.3% finely microcrystalline quartz within fragments of indurated meta-greywacke/siltstone and acid volcanic rock.

Three binder materials were used in the preparation of the AMBT prisms: GP Cement, fly ash (FA) and ground granulated blast furnace slag (S). The cement used is a Portland type GP cement that meets the specified requirements of AS 3972, with an alkali content of 0.47% Na_2O_e . For FA and S incorporated mixes, cement replacement percentages of 25% and 65%, respectively, were chosen as they are representative to common replacement levels in industry.

To mix the mortar, the procedure outlined in AS1141.60.1 was used. Gauge studs are placed within the mould prior to mixing and calibrated to have a gauge length of 250 ± 1 mm. Fine aggregate was prepared in its natural unaltered grading by oven drying at 110°C before cooling for mixing. Water used for mixing was that of potable tap water. The mortar prisms were cured in three gang moulds for 24 hours before demoulding and placing in tap water at room temperature. The baths were then heated to 80°C and kept at temperature for 24 hours for equilibration prior to zero day length measurement and subsequent immersion in respective alkali baths equilibrated at 80°C .

2.2 Alkali Baths

Four separate alkali baths were used as immersion baths for the mortar bars. Immersion concentrations consisted of bath solutions at 0.4, 0.7 and 1M NaOH and a bath of saturated $\text{Ca}(\text{OH})_2$ solution. Distilled water was used to prepare these solutions. The baths were kept heated at 80°C throughout the duration of the test. Mortar bars were vertically oriented within the bath, supported by a stainless steel grid so that no contact with the gauge pins occurred.

2.3 Expansion measurements

All comparative expansion measurements were conducted on a steel frame comparator equipped with a Mitutoyo digital micrometer. All expansion measurements are in reference to a 295mm invar reference

bar which is placed with identical positioning for each measurement and checked on a regular basis between mortar bar measurements. Mortar bars comparative length measurements were recorded at time periods of day 0 (immediately after removal from 80°C water bath), then at 1, 3, 7, 10, 14, 21 and 28 days following immersion in alkali baths. For expansion measurements, mortar were removed from the alkali baths, were lightly dried with a cloth then placed in the comparator for recording to 1 hundredth of a millimetre. These comparative length measurements were carried out within 10 seconds of removal from the bath and were measured in the same orientation within the comparator at each age.

3. Results

Expansion results for each mix reported in the plots below. Figure 1 displays the expansion curves for each binder composition over time while immersed in their respective alkali immersion baths listed. An overlay of the GP cement mortars (no SCM) is included in Figure 2. The concentration of the solutions in each bath were measured by titration and the pH calculated and listed in Table 1. Also listed in Table 2 is the expansion for each GP cement mortar (no SCM). A brief description of notable observations are listed below.

- a) Expansion is a strong function of the alkali content of the solution concentration. Little or no expansion is observed over the timeframe for the saturated $\text{Ca}(\text{OH})_2$ solution. Expansion for the alkali solutions increases with increasing bath concentration over the time frame of the experiment.
- b) An induction period is apparent in the 0.4M NaOH where the expansion is negligible up to 14 days followed by a notable increase in the expansion. Expansion appears to be increasing at 28 days. Further measurements will yield a limit for the expansion and discriminate concentration effects on ASR.
- c) No expansion is observed for these reactive aggregate mortars for mortars prepared with blended cements containing fly ash or slag. These SCMs appear to completely mitigate ASR within the timeframe of the experiment. Measurements to extended ages will identify whether this is the result of complete mitigation or if the expansion free region is an induction period where the SCM acts as an inhibitor (i.e is simply delaying the onset of expansion once consumed in the pozzolanic reaction).

In summary, the expansion increases with increasing NaOH solution concentration, this demonstrates that reactivity increases with increased availability of alkali. Additionally, the rate of expansion (slope of the expansion curves) is observed to increase with increasing alkali concentration in the bath solution. As the data presented here is limited to 28 days, the maximum expansion cannot be determined, hence the extent of the influence of bath concentration cannot be identified. Further measurements at greater ages will be carried out to identify the long term influence of alkali solution concentration on expansion.

The incorporation of SCMs in the mortar mix has a significant effect on expansion. This effect indicates mitigation, but further measurement is required to ensure that the SCMs are not simply delaying the alkali-aggregate reaction.

Table 2: Percentage expansion of mortar bars at an age of 28 days for 100% GP cement binder and calculated pH for each alkali immersion bath.

Alkali Bath	Saturated $\text{Ca}(\text{OH})_2$	0.4M NaOH	0.7M NaOH	1M NaOH
pH (calculated)	12.45	13.6	13.85	14
% Expansion of GP mix at 10 days	0.0340	0.3148	0.0480	0.3348
% Expansion of GP mix at 21 days	0.0248	0.6016	0.2364	0.7960
% Expansion of GP mix at 28 days	0.0356	0.3772	0.6936	0.8952

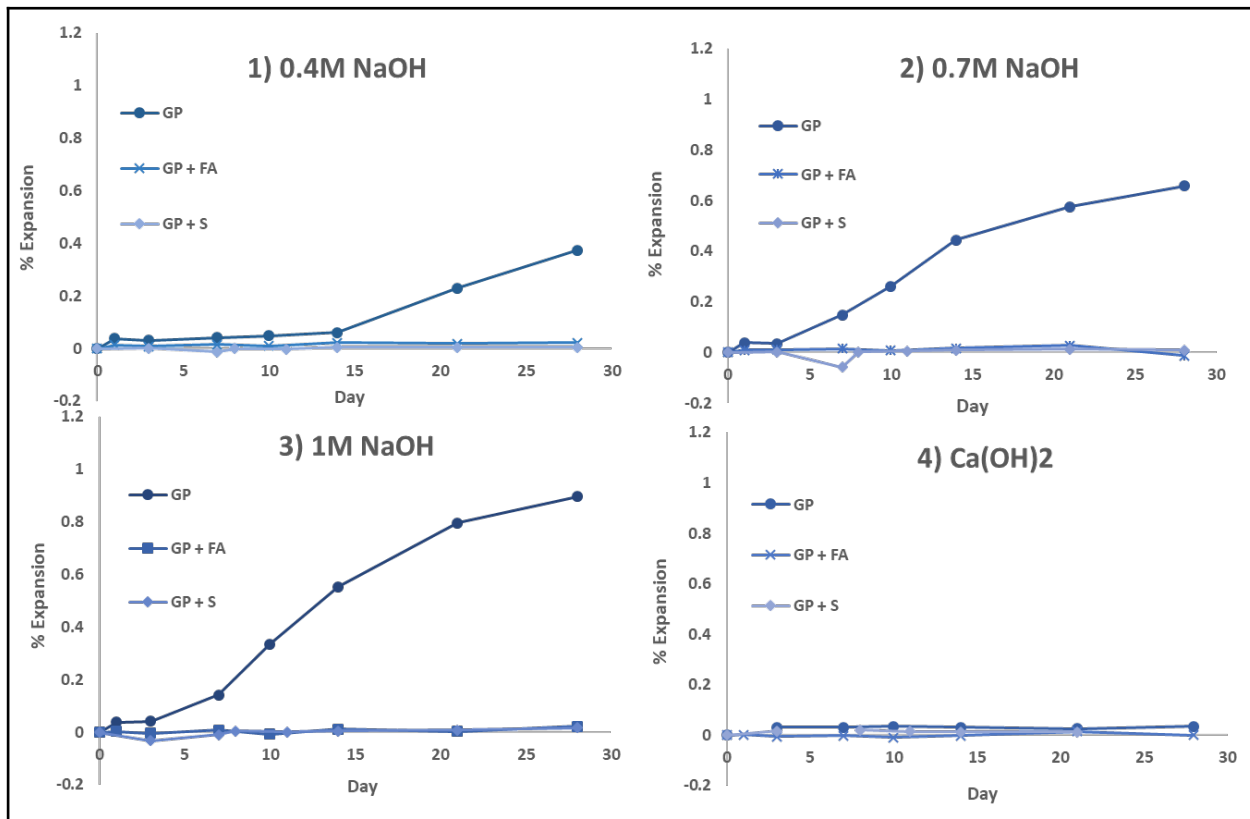


Figure 1: Expansion of mortars submerged in NaOH solution at 80°C for 28 days (a) 0.4 M, (b) 0.7 M, (c) 1.0 M and (d) saturated Ca(OH)_2 .

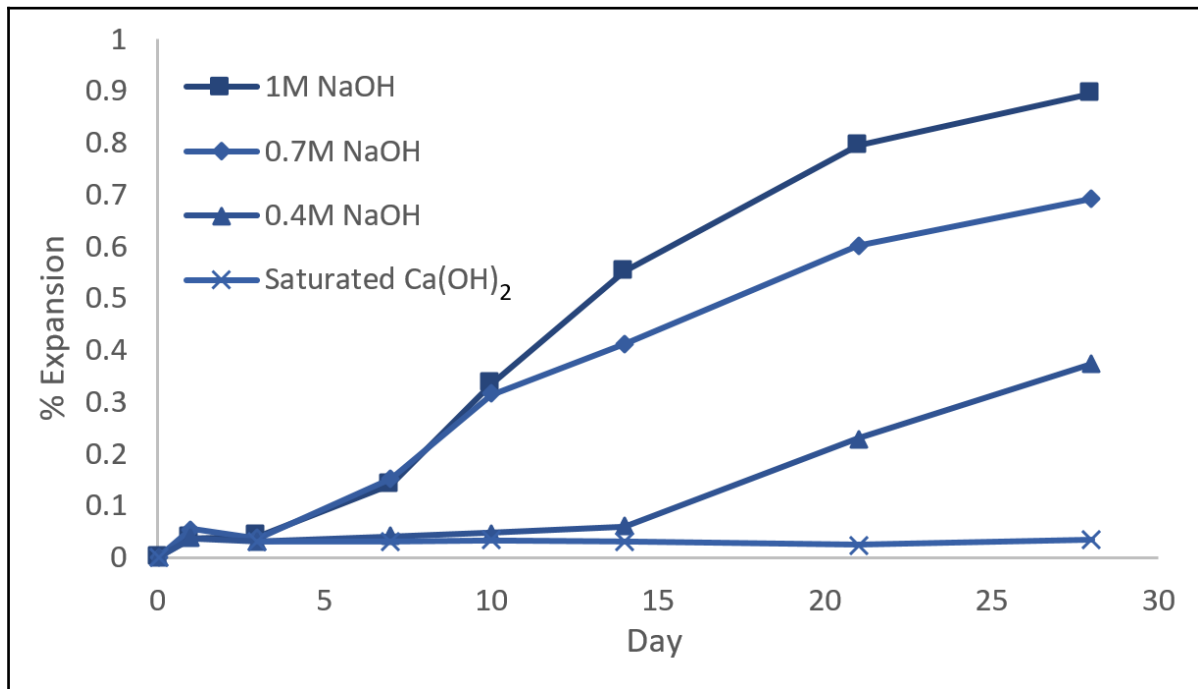


Figure 2: Percentage expansion of Type GP cement natural sand mortar bars immersed in 0.4M, 0.7M and 1.0M NaOH solutions and saturated Ca(OH)_2 solution over 28 days.

4. Conclusions

This study provides a foundation for future research on the ASR reaction system in AMBT and notes the role of alkali concentration in measured expansion; as alkali solution concentration increases, mortar bar expansion increases. This indicates a relationship between alkali availability and ASR reaction severity. The timeframe of the expansion data is limited for the data reported in this paper and further

examination of the expansion with age will clarify the relationship between alkali concentration and extent of the ASR reaction with time.

The test also indicated that fly ash and slag mitigate ASR induced expansion in aggressive accelerated reaction environments within the timeframe of the experiment. Similarly, an extended reaction period is required to demonstrate the relationship between SCM addition and solution concentration.

In order to deconvolve the relationship between ASR and bath solution concentration, further study is planned including further expansion measurements at greater ages and a microstructural and phase analysis of the ASR products. This investigation will be continued by analysing the effect these systems have on ASR gel composition in order to further the understanding of the relationship between gel composition and expansion.

5. Acknowledgements

This research is funded through an Australian Research Council Research Hub for Nanoscience Based Construction Materials Manufacturing (NANOCOMM) with the support of the Cement Concrete and Aggregates Australia (CCAA). The authors are grateful for the financial support of the Australian Research Council (IH150100006) in conducting this study. This research is supported by an Australian Government Research Training Program Scholarship.

6. References

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