Assessment of ASR expansions using an ultra-accelerated test

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Abstract: Alkali-silica reaction (ASR) is a potential source of long-term deterioration for reinforced concrete structures, particularly after 15 to 25 years of construction. Currently, an ultra-accelerated autoclave test, is being developed at the University of Technology Sydney, to study the effect of ASR expansion on plain, reinforced and prestressed concrete elements. This paper discusses the results obtained on plain concrete prisms under ultra-accelerated conditions in an autoclave. For autoclave tests, similar to CPT tests, boosting of specimens is required and up to 5% alkali boosting (by mass of cement) has been used by many researchers. Expansion results obtained on concrete prisms, with alkali boosting levels of 3-5% (by mass of cement), are reported in this paper. For comparative ASR expansion studies, 3 cycles of autoclaving at a maximum temperature of 130^{o}C was used.

Keywords: alkali silica reaction (ASR), expansion, accelerated tests, autoclaving

1. Introduction

Alkali Silica Reaction (ASR) can lead to extensive cracking in bridge superstructure as shown in Figure 1. There have been concerns about the residual load capacity of structures due to ASR damage in the concrete and structural integrity.

Figure 1. Cracking of bridge beams due to ASR

A greater understanding of the cause of ASR, the extent of damage and the consequent influence on the residual load carrying capacity of the concrete members is needed. Currently, research relating to ASR deterioration of bridge girders is carried out at the University of Technology Sydney.

ASR is one of the major durability issues affecting concrete structures in the world (1). Alkalis in concrete basically initiates ASR, mostly from Portland cement as well as other internal and external sources which causes high concentration of alkalis within the pore solution. The alkalis initially attack some siliceous phases in aggregates and produces an expansive gel, consequently causing expansion and cracking of concrete which ultimately reduces the mechanical properties (2). In the existing two laboratory test methods, namely AS 1141.60.1 accelerated mortar bar test (AMBT) and AS 1141.60.2 concrete prism test (CPT), AMBT can produce results within 21 days. CPT, however, takes 1 year for OPC concrete mixes and 2 years for mixes with supplementary cementitious materials. In both methods, aggregates are graded or crushed and recombined to give specific grading. Also, AMBT test requires handling NaOH solution at 80°C.

In order to test concrete mixes as used in the field and also to study reinforced and prestressed concrete elements, an ultra-accelerated test method using an autoclave has been investigated. Autoclave test methods for ASR have already been adopted by several researchers (3-10). Table 1 summarises the various autoclave tests carried out by different researchers.

Table 1. Autoclave accelerated tests for ASR expansion by various researchers

Test Parameter	Chinese Autoclave Method (8)	GBRC (7)	LAVAL/ CANMET (3)	Nishibayashi *et al* (6)	Ultra-accelerated (UACPT) (4)
Duration (from mixing)	3 days	3 days	3 days	Not known	4 days
Duration of autoclaving	6 hours	2 hours	5 hours	4 hours	24 hours
Specimen type	Mortar	Mortar	Mortar	Concrete	Concrete
Specimen size (in mm)	10x10x40	40x4x160	25x25x285	75x75x400	75x75x285
w/c	0.3	Unknown	0.5	0.54	0.42
Na_2O_{eq} (mass of cement)	1.5%	2.4%	3.5%	3%	3%
Max. Temperature	150°C	111°C	130°C	133°C	133°C
Conditioning	In 10% KOH solution Inside autoclave	In boiling water inside pressure vessel	Inside autoclave	Inside autoclave	Inside autoclave
Proposed expansion limit	-	-	0.15%	-	0.08%

In these autoclave tests, the mixes were boosted with alkalis between 1.5 to 3.5% by mass of cement and maximum temperatures used by different researchers varied between 111°C and 150°C. Duration of autoclaving varied between 4 to 24 hours for concrete prisms and 2 to 6 hours for mortar bars. In all these tests only one cycle of autoclaving was carried out.

Based on the information available, an innovative multi-cycle autoclave test method for ASR was investigated at UTS. The maximum temperature was maintained at 130°C for a duration of 5 hours for each cycle and three cycles were applied over a period of 3 days. Measurements were taken after each cycle and the details of this procedure are presented below.

2. Materials and Experimental Procedure

2.1 Materials and specimen preparation

Two aggregates (aggregates B and C) were chosen for these experiments. Aggregate B is considered as most reactive. In contrast, aggregate C was found to be slowly reactive by AMBT but found to be non-reactive by CPT. All coarse aggregates are crushed aggregates having a maximum size of 20mm. A non-reactive fine aggregate (Sydney Sand) was used in this study. Two GP cements with similar equivalent alkali contents (Na_2O_{eq}) of 0.52% (cement 1) and 0.50% (cement 2) by mass of cement were used. Equivalent alkali content was calculated as $Na_2O+0.658K_2O$. The cement oxide compositions are provided below in Table 2.

Table 2. Cement oxide compositions

Oxide Composition	Weight Percentage (%)	
	Cement 1	Cement 2
CaO	62.78	64.18
SiO_2	19.66	19.67
Al_2O_3	5.11	4.78
Fe_2O_3	3.04	3.10
SO_3	2.68	2.37
MgO	1.14	0.91
TiO_2	0.26	0.22
P_2O_5	0.12	0.06
Mn_2O_3	0.07	0.12
Na_2O_{eq}	0.52	0.50

To boost the Na_2O_{eq} to higher levels, sodium hydroxide (NaOH) pellets (with purity level of 98%) were added to the mixing water 24 hours prior to the mixing as dissolution of NaOH generates heat. Two type of coarse aggregates were tested. Non-reactive sand (Sydney Sand) was used as fine aggregate. The alkali levels were boosted to equivalent Na_2O levels of 3% and 5% by mass of cement. An un-boosted mix was also cast and tested for comparison. Concrete prisms of 75x75x285mm in size were prepared to determine ASR expansion. Nine concrete prisms were cast for each mix and the mix proportions are shown in Table 3.

Table 3. Concrete mix proportions

Material	Concrete mix		
	Un-boosted (kg/m^3)	With 3% Na_2O_{eq} boosting (kg/m^3)	With 5% Na_2O_{eq} boosting (kg/m^3)
20mm Aggregate	1134	1134	1134
Sand (non-reactive)	610	610	610
Cement 2	440	440	440
Water	175	175	175
NaOH added	--	14.491	26.083
Na_2O_{eq} (Calculated)	2.2	13.2	22.0

After casting and demolding (the following day) the specimens, each batch (9 specimens) was cured in water at a temperature of 23.0 ± 2.0°C for 3, 7 or 28 days of age (3 identical specimens were cured for a specific age).

2.2 Autoclave test procedure

The autoclave expansion tests were carried out on saturated prisms at 3, 7 and 28 days of age. At the age of 3 days, after initial length measurements, a set of 3 concrete prisms were placed in the autoclave (Figure 2). The temperature cycle shown in Figure 3 was applied. The maximum temperature and pressure were maintained at 130°C and 170 kPa, respectively, for 5 hours. The autoclave chamber had sufficient water at the base during the test and the specimens were kept in a saturated vapour environment in the pressurised chamber of the autoclave. When the specimens were cooling down, the relative humidity of the chamber was kept at 100%. The following day, the specimens were removed from the autoclave and the length reading were recorded while the specimens were in a saturated condition. The specimens were then returned to the autoclave and further 2 cycles were applied over the 2 consecutive days. After each cycle the length readings were recorded. Also the specimens were examined for cracks. The entire 3 cycles were applied over 3 successive days. The same procedure was repeated for another 2 sets of specimens, commencing at the ages of 7 and 28 days.

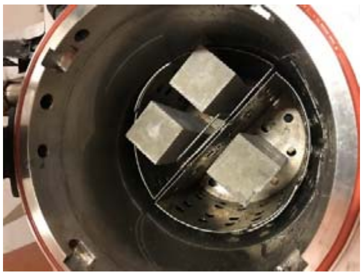

Figure 2. Test specimens in an autoclave

The temperature-time relationship and the pressure-time relationship for one cycle of autoclaving is shown in Figure 3.

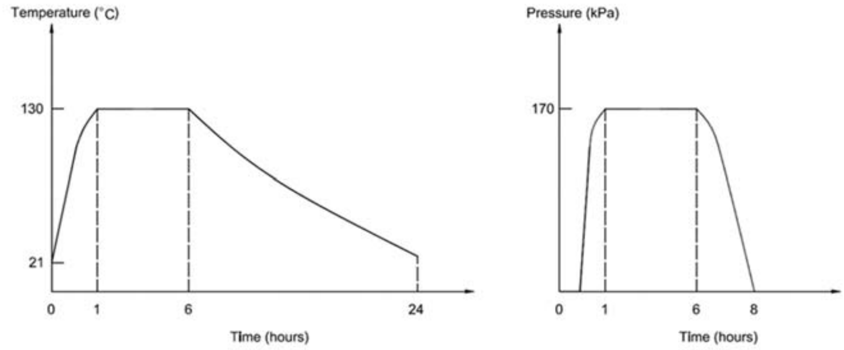

Figure 3. Temperature-time and pressure-time relationships for one cycle of autoclaving

3. Results and Discussion

Figures 4(a), 4(b) and 4(c) show the expansion of concrete prisms (average of 3 specimens) cast with reactive aggregate B and boosted to 3% and 5% Na_2O_{eq} by mass of cement after autoclave testing at ages of 3, 7 and 28 days, respectively. The expansion of specimens of aggregate C, with 3% and 5% alkali boosting, is currently under investigation.

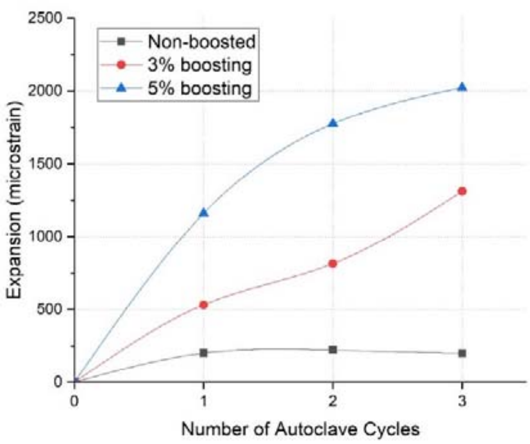

Figure 4 (a) Average expansion (of 3 specimens) at the age of 3 Days

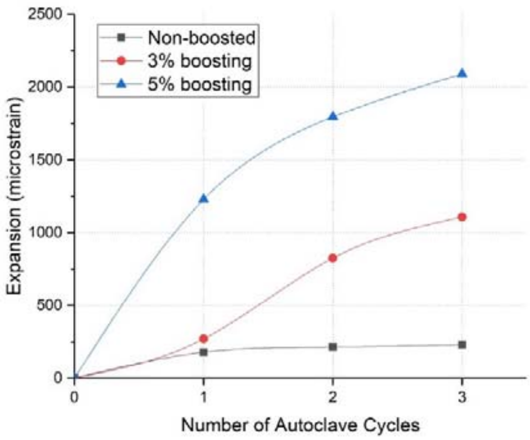

Figure 4 (b) Average expansion (of 3 specimens) at the age of 7 Days

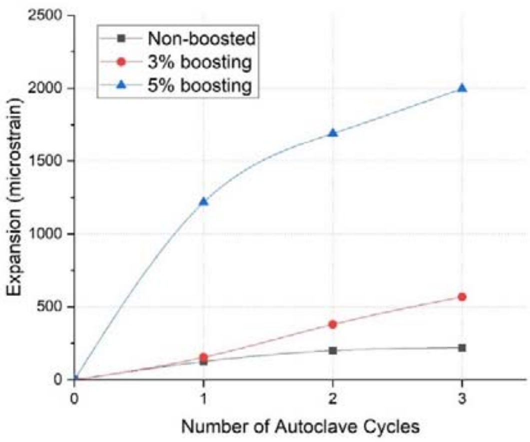

Figure 4 (c) Average expansion (of 3 specimens) at the age of 28 Days

Concrete mixes with non-boosted alkali levels showed little expansion (about 200 micro-stains). Therefore it is not possible to test and compare non-boosted concrete specimens, even under ultra-accelerated conditions. However, significant expansions were recorded at all ages with boosted specimens with 3 cycles of autoclaving. For concrete prisms cast with aggregate B and boosted to 3% Na_2O_{eq} by mass of cement, average expansion of 3-day specimens (after 3 cycles of autoclaving) reached 1311 micro-strains. The average expansion of 7-day specimens was 1108 micro-strains and the average expansion of 28-day specimens showed the smallest expansion of 567 micro-strains. The reduction in expansion with increasing age is mainly due to the strength development of the concrete with age. The 3-day and 7-day compressive strengths were found to be 60% and 77%, respectively, of the 28-day strength. However, for concrete prisms boosted to 5% Na_2O_{eq} by mass of cement after 3 cycles of autoclaving at ages of 3, 7 and 28 days, average expansions of the specimens were 1997, 2090 and 1997 micro-strains, respectively. It can be seen that with alkali boosting to 5% Na_2O_{eq} by mass of cement, specimens of 3, 7 and 28 days showed similar levels of significant expansion.

For concrete made with both aggregates B and C, without additional alkali boosting, the expansion of the specimens (after 3 cycles of autoclaving) were very small (about 200 micro-strains). Hence un-boosted concrete specimens may not show sufficient levels of expansion with only 3 cycles of autoclaving. Effect of more number of cycles are investigated now.

The crack patterns of prisms made of aggregate B, with 3% Na_2O_{eq} boosting (after 3 cycles of autoclaving) at ages of 3, 7 and 28 days are shown in Figure 5. Similar crack patterns were observed for prisms with 5% Na_2O_{eq} boosting. To discern differences in the crack patterns, crack widths and crack lengths a method such as Digital Image Correlations (DIC) is currently being investigated.

3 Days of age 7 Days of age 28 Days of age

Figure 5. Crack patterns of reactive aggregate B prisms with 3% Na_2O_{eq} boosting after 3 cycles of autoclaving at ages of 3, 7 and 28 days

Further tests on deterioration of mechanical properties due to ASR under autoclave accelerated testing conditions are currently being investigated. It is well established that as the boosting levels increase to 3% or 5%, there are substantial reductions in compressive strength and modulus of elasticity. Hence to compare concrete specimens of similar strength grades, an optimum boosting level of 1.25% is more appropriate. Current investigation focuses on specimens boosted to 1.25%, made of actual concrete mixes of Grade 40 concrete, with a maximum aggregate size of 20mm. Concrete mixes made of a highly reactive type of coarse aggregate is compared with those made of a non-expansive type of coarse aggregate.

4. Conclusions

The ultra-accelerated autoclave test, on prisms of actual concrete mixes, is able to simulate expansion and cracking caused by ASR within a short period of time.

Significant expansions and ASR damage were observed which simulate long-term ASR deterioration effects in the field.

An innovative multi-cycle autoclave test method appears to be suitable for investigating ASR deterioration of actual concrete mixes within a short period of time.

5. Acknowledgement

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6. References

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