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ALKALI–SILICA REACTION IN AUSTRALIAN CONCRETE STRUCTURES

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1. ABSTRACT

This research investigation has placed significant emphasis on collecting field information of alkali-silica distressed structures and using this data to calibrate laboratory tests for predicting safe cement/aggregate combinations. It was determined that alkali-silica reaction has occurred in concrete bridges, a wharf structure and an off shore bulk loading facility. The age of the structures investigated ranges from 8 to 29 years with a corresponding period of construction from 1959 to 1980. Documentation is provided showing that the occurrence of alkali-silica reaction may not always cause destructive expansion in the associated concrete matrix. Two structures were analysed and shown to exhibit alkali-silica reaction without any associated destructive cracking of the concrete structures. Four additional structures were shown to display similar alkali-silica reaction, however, in these cases associated destructive cracking of the concrete matrix had occurred. The reactive aggregates in the structures examined were identified as an extrusive volcanic source and a river gravel. It has been concluded from this project that the degree of alkali-silica reaction within a structure is dependant on environmental factors and can be magnified by an inadequate design concept. Details of an accelerated test for alkali-silica reaction on concrete samples are provided for use in determining safe cement/aggregate combinations.

2. INTRODUCTION

This research project has identified 100 structures suffering alkali-silica reaction (ASR) distress [1]. The type of structural element exhibiting distress in the majority of cases has been high strength (45 MPa), prestressed, steam cured bridge beams. Only three cases of ASR in reinforced concrete structures were identified. Within these cases only one structure showed external concrete distress due to ASR. Although the reaction was identified in the other two reinforced concrete structures no resultant concrete distress due to ASR was observed. Of the 100 structures identified suffering ASR only 8 showed severe signs i.e. crack widths greater than 0.6 mm. The balance of the structures displayed moderate to minor distress. The age of the structures investigated ranged from 8 to 29 years. This field survey has determined that distress due to ASR has been occurring for a substantial period of time and largely remaining undetected or incorrectly diagnosed by inspecting personnel. It is fortuitous that while a large number of bridges exhibit ASR distress only a small number display severe distress. Other researchers have previously identified ASR in a dam structure [2] in 1981 and a concrete bridge in Perth

[3] in 1986. This survey has substantially increased the recorded incidence of ASR in Australian concrete structures built during the period 1950 to 1985.

3. FIELD INVESTIGATION

3.1 Structures with ASR but without Resultant Concrete Distress

Two reinforced concrete structures were examined and ASR was detected in the thin section analysis, however, no exterior concrete distress due to ASR was observed in these structures.

3.1.1 Townsville harbour facility Concrete cores were extracted from part of this wharf structure built in 1959. Site inspection in 1986 revealed some areas of gel exudation on the soffit of particular slab elements. Petrographic analysis of the cores revealed the coarse aggregate to be medium grained granite and finely devitrified acid tuff. The sand component was composed of quartz, feldspars, hornblende, biotite, opaque oxides and granitoid fragments. This structure displays cracking due to chloride induced corrosion of the reinforcing steel. There was no map cracking consistent with ASR distress. Fig. 1 shows an electronmicrograph of a gel deposit within one of the cores. Table 1 details chemical analyses of this gel deposit showing it to be of the alkali-silica type.

3.1.2 Herbert river bridge This bridge was constructed in 1978. Inspection of the concrete substructure in 1986 revealed 1.0 mm wide vertical cracks in the pier columns. Examination of concrete cores extracted from these zones showed the chloride ion content of the cover concrete to be 1.5 percent by weight of cement. Hence, the vertical cracking following the main reinforcement was consistent with chloride induced corrosion of the reinforcing steel. Petrographic analysis of the concrete revealed the coarse aggregate to be of acid tuffaceous derivation and the fine aggregate to consist of mildly strained quartz, feldspars, biotite and hornblende. Fig. 2 shows an electronmicrograph of a gel deposit and Table 1 describes the chemical composition of this gel. Both the above structures were made from 20 MPa grade concrete. From an examination of the structures the lack of map cracking as a result of ASR is considered due to the reaction product entering the available pore space without filling this volume and causing disruptive expansion of the concrete. The acid tuff was identified as the reactive component in both the Townsville harbour facility and the Herbert river bridge.

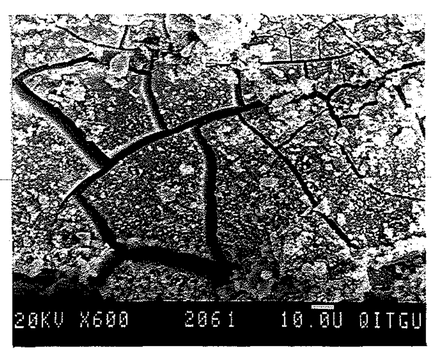

Fig. 1 Townsville harbour gel deposit

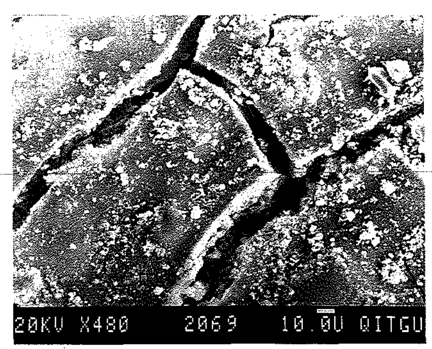

Fig. 2 Herbert river bridge gel deposit

Table 1. Chemical composition of gel deposits

Structure	Sample	Composition (percent)						
		NA	Al	SI	CL	K	CA	FE
Townsville	1	1	2.2	63.4	-	11.7	18	3.7
Harbour	2	1.1	0.4	53.5	1	8.2	29.8	3.4
Facility	3	1.6	3.6	56	1.1	6.2	27.4	4.1
Herbert River Bridge	1	2.9	0.5	66.7	-	14.4	12.1	3.5

3.2 Structures with ASR and Resultant Concrete Distress

Four structures are detailed which have suffered severe ASR i.e. crack widths in excess of 0.6 mm. All of these structures are bridges and the distress was observed in the prestressed, steam cured bridge beams. The design strength of this concrete was 45 MPa at 28 days. A river gravel and an extrusive volcanic aggregate were identified as the reacting components.

3.2.1 River gravel source The Sandy Creek bridge in Warwick and the Susan River bridge in Maryborough were both made from a river gravel source and displayed severe cracking due to ASR. The petrographic analysis of this aggregate is detailed in Table 2.

Table 2. Petrographic analysis of river gravel

	Component	Percentage
(a)	Coarse Aggregate	
	. quartzite	17.4
	. chert	10.2
	. sandstone	4.0
	. slate	2.2
	. miscellaneous (epidote quartzite, greenstone and feriginous rock)	1.2
	Total of Coarse Aggregate	35.0
(b)	Sand Components	
	. quartzite	12.0
	. quartz	6.4
	. feldspar	1.6
	. chert	1.4
	Total of Sand Aggregate	21.4
(c)	Cement and Gel	
	. cement components	39.0
	. porosity	2.0
	. silicate gel	2.6
	Total of all Components	100.0

The coarse aggregate used in these bridges was derived from a river gravel source consisting of strained metamorphic quartzite, chert, sandstone, slate and other minor rock types. The sand component contains comparable quartzite and chert. The measured undulose extinction angle of the strained quartz varied from 16° to 23° indicating it was deleterious [4]. Both these structures were cast in 1977 and the maximum observed crack width in 1986 was 1.8 mm in the Susan River bridge. Fig. 3 and Fig. 4 show details of the crack pattern and reacting chert particles.

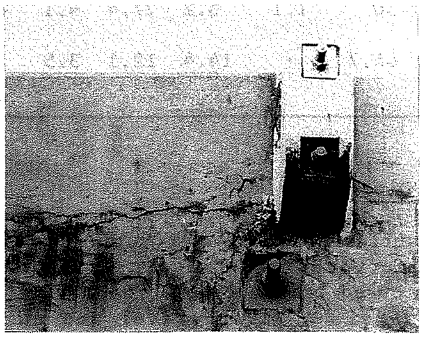

Fig. 3 Cracking in exterior beam

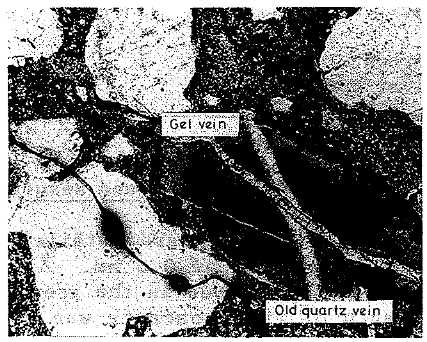

Fig. 4 Gel vein cutting chert particle (field of view 2.5 mm)

3.2.2 Extrusive volcanic source The Brinagee Creek bridge and the Tom Aitken bridge in Townsville were both constructed from an extrusive volcanic aggregate source. These bridges were built in 1978 and 1980 respectively. A petrographic analysis of a concrete core from the superstructure concrete is detailed in Table 3. Analysis of the core proved the reactive component to be the fine silica (grainsize 0.005 mm) within the rhyodacitic tuff of the coarse aggregate. The maximum crack width in the affected concrete was 1.0 mm in both structures.

Table 3. Petrographic analysis of extrusive volcanic aggregate

Component		Bottom Half of Core (%)	Top Half of Core (%)	Average (%)
(a)	Coarse Aggregate			
	tuff	16	38	27
	andesite	18	5	12
	trachyte		1	<1
(b)	Sand			
	quartz	9	8	9
	feldspars	7	4	6
	granite	15	8	12
	others	2	–	1
(c)	Cement	20	30	30
(d)	Silicate gel and cracks	3	6	5
	Total	100	100	100

Fig. 5 and Fig. 6 show details of the crack pattern and reacting tuff particles.

Fig. 5 Cracking in exterior beam

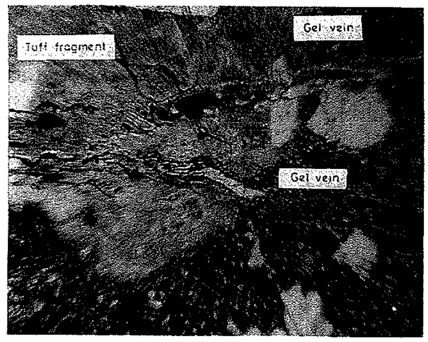

Fig. 6 Gel veins cutting tuff fragment (field of view 2.5 mm)

4. ACCELERATED TESTING

The predominant aggregate producing ASR in concrete structures in Queensland was determined to be the extrusive volcanic source described in Table 3. An accelerated test on concrete was required to predict the reactivity of this aggregate especially in steam cured prestressed concrete.

4.1 Test Procedure

Concrete test specimens 75 x 75 x 250 mm were chosen to enable the concrete mix to be used without grinding of the coarse aggregate to sand size as required by the mortar bar test. A minimum of two concrete samples were cast for each mix. The alkali level of the cement was adjusted by adding sodium hydroxide to give an equivalent Na_2O level of 1 percent by mass of cement. After casting the specimens they were steam cured in a factory steaming cycle for prestressed concrete elements. This involved gradually raising the ambient temperature to 80°C and maintaining this temperature for about 8 hours. After cooling of the specimens to a standard temperature they were measured and then stored at 50°C and 100 percent RH. Some specimens were stored in natural salt water by plastic wrapping. This was an attempt to simulate marine conditions. Three aggregates were tested, two innocuous river gravels and the known deleterious extrusive volcanic aggregate. Fig. 7 details the results obtained showing rapid expansion of the volcanic aggregate. Salt water dipping has doubled the observed expansion indicating the sensitivity of the aggregate to marine conditions.

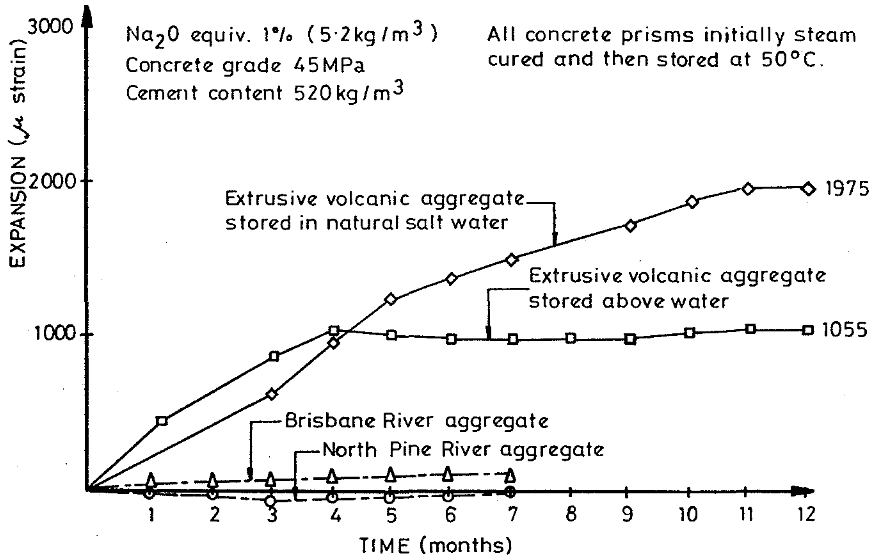

Fig. 7 Accelerated test on concrete for ASR

5. CONCLUSIONS

This research project has identified ASR in 100 concrete structures. However, only eight of these structures show severe distress (crack widths in excess of 0.6 mm). The occurrence of ASR does not necessarily mean disruptive expansion of the concrete. Two cases of ASR in 20 MPa grade concrete structures have been described which show no characteristic map cracking. The conclusion inferred is that the silica gel detected has exuded into the available pore space. The predominant structural element showing distress is 45 MPa grade concrete in steam cured prestressed bridge beams. The aggregates causing reaction have been identified as a river gravel and an extrusive volcanic source. An accelerated test on concrete using a normal steam curing process has been developed to simulate conditions the structure concrete will have to endure. The test clearly shows the extrusive volcanic aggregate to be reactive. Additional testing is required to determine a general criterion for aggregate classification as deleterious or innocuous.

REFERENCES

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