

New Test Methods for Alkali-Silica Reaction

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INTRODUCTION

It is now universally recognised that alkali silica reaction (ASR) can, under certain conditions, lead to excessive expansion and disruptive cracking of the cementitious system. Such cracking, in extreme cases, may in turn prevent the satisfactory functioning of plain concrete sections, reinforced and prestressed concrete structural members. Although the occurrence of such reaction is not wide-spread, when it does occur its effects can pose a serious engineering problem of structural stability and serviceability.

There are currently three test methods used to assess aggregates for alkali silica reactivity, although none of these tests provide quantitative information on the degree of reactivity to be expected or tolerated in service. Petrographic examination, the rapid chemical test on the potential reactivity of aggregates and the mortar bar expansion test are all recognised to be useful, but they also possess individual limitations. The chemical test for example, can lead to misleading classification of aggregates whilst the mortar bar test can sometimes be unreliable and not be sufficiently sensitive to identify slow but progressive reactivity; in any case no single test can be depended upon to give reliable data on the susceptibility of an aggregate to alkali silica reactivity.

From an engineering point of view, the most important drawback of all these tests is that none of them provide any quantitative data on the effect of alkali silica reaction on the engineering properties of concrete, and their influence on the structural performance of concrete affected by such reaction. Mortar bar test results are basically inapplicable in this respect, as these tests contain very high cement contents of 550-600kg/m³, far in excess of that generally used in concrete; further, the physical response of mortar and concrete to internal chemical reactions, stresses and external environments is quite different so that it is not valid to relate directly the results of mortar bar tests to concrete.

Much of the information on ASR currently available is based on the use of Beltane opal as reactive aggregate. However, opal has a very disordered structure, and as a result, the reaction with opal is too rapid to enable the effects of the expansion on the properties of concrete to be satisfactorily monitored. The use of crushed pyrex glass is not satisfactory either, for a variety of reasons, either to determine quantitatively the effects of ASR or to determine the effectiveness of mineral admixtures in preventing excessive expansion arising from ASR.

TEST APPROACH

In order to overcome these deficiencies and to establish test methods for alkali silica reactivity, the authors have investigated the use of various reactive aggregates in concrete. This paper summarises the results of some of these tests and presents suggestions for three test methods.

Test no 1: To establish the influence of ASR expansive reaction on the engineering properties of concrete.

Test no 2: To determine the effectiveness of mineral admixtures to control ASR expansion.

Test no 3: To determine the alkali reactivity of aggregates.

For tests nos. 1 and 2, the authors recommend the use of amorphous fused silica, a synthetic sand used extensively in the steel and refractory industries, as reactive aggregates to initiate ASR in the laboratory. The fused silica has a particle size distribution of 150-600 μ m, contains more than 99% of amorphous silica with practically no alkali in it. Both the amount and particle size distribution of the reactive aggregate influence the degree of reactivity. From the tests of the authors, it is therefore recommended that the fused silica be used to replace the fine aggregate in the concrete mix by an amount equal to 15% by weight of the total aggregate (Swamy and Al-Asali 1985).

For all three tests, the authors recommend 75x75x300mm prisms for measurement of expansion, made of concrete containing similar cement and aggregates in the same proportions and combinations that are specified for the concrete in question. Ideally it would be appropriate to use a high alkali cement. In the test results presented here the authors have used a high alkali portland cement (ASTM Type 1), with a percentage of alkalinity, expressed as percentage of sodium oxide equivalent, of just about 1% giving an alkali content in the concrete of just 1.0kg for every 100kg cement per cu.m. of concrete.

TEST FOR ENGINEERING PROPERTIES

Tests by the authors (Swamy and Al-Asali 1985, 1986) show that fused silica is an ideal artificial reactive aggregate to simulate expansion due to ASR in the laboratory. 15% replacement of fine aggregate by weight of the total aggregate creates the reactivity at a rate that provides a reliable and quantitative means of determining the effects of expansion on the properties of concrete. These tests have been carried out at 20°C, 96% RH, at 38°C in water, at cement contents of 250 to 520kg/m³ and when alkalinity is also present from external sources. To illustrate the effect of ASR expansion on the properties of concrete, some typical data are presented in Table 1 which show expansion, compressive strength, flexural strength and dynamic modulus of elasticity of control concrete and concrete affected by ASR. These results relate to concrete having a cement content of 520kg/m³ (i.e. an alkalinity of 5.2kg/m³) and containing 15% fused silica and cured at 20°C and 96% RH.

The results show that expansion does not increase steadily with age, and that concrete properties do not all decrease at the same rate or in proportion to expansion. The data also demonstrate that loss in compressive strength is not a good indication of ASR expansion. Probably the most important thing to note here is that ASR expansion is not only followed by cracking but also by dramatic losses of engineering properties of compressive strength, flexural strength and elastic modulus all of which would affect the practical performance of concrete elements.

Table 1. Effect of ASR expansion on concrete properties

Property	Mix	AGE - days			
		10	28	90	365
Expansion %	Control	0.001	0.003	0.017	0.021
	Fused silica	0.005	0.023	0.215	0.623
Comp.strength N/mm ²	Control	-	60.1	-	73.5
	Fused silica	50.2	52.45	51.35	44.5
Mod.of rupture N/mm ²	Control	-	5.25	-	5.58
	Fused silica	5.30	4.58	1.98	1.30
Dyn.mod.of elas.kN/mm ²	Control	41.1	42.5	44.1	45.4
	Fused silica	40.2	40.8	26.2	18.9

TEST FOR EFFECTIVENESS OF MINERAL ADMIXTURES

There are three possible methods of controlling ASR expansion in hardened concrete. Of these, the use of pozzolanic/mineral admixtures brings in not only cost benefits but also sound technical, environmental and energy-related advantages. The test method advocated earlier can also be used to assess the effectiveness of mineral admixtures to control ASR expansion (Swamy and Al-Asali 1986). To illustrate the application of this test method, Table 2 and Fig.1 are presented to show test results on the use of fly ash and silica fume as cement replacement materials. Table 2 presents data on a 1:1.966:4.166:0.64 concrete mix (cement content 300kg/m³) with 30% cement replacement by weight of fly ash, and subjected to 38°C water curing. The basic concrete mix A in Table 2 has a cement alkalinity of 2.1kg/m³. For mixes B and C, the alkalinity was increased to 3.0 and 6.0kg/m³ by adding dissolved sodium hydroxide pellets. By comparison with Table 1, the results show that the incorporation of PFA causes substantial reductions but not complete elimination of expansion. The PFA used in this test had an alkalinity of 2.4% sodium oxide equivalent compared to 1% of the cement. The implications of these are discussed elsewhere, but the emphasis here is to show the validity of the test method to evaluate the effectiveness of mineral admixtures both without and in the presence of external alkali.

Table 2. Effectiveness of PFA on ASR expansion.
30% PFA replacement

Age days	Expansion %		
	A 2.1kg/m ³	B 3.0kg/m ³	C 6.0kg/m ³
1	0	0	0
7	0.0033	0.0066	0.0053
23	0.0233	0.0460	0.0213
60	0.0673	0.1086	0.1246
134	0.1486	0.2166	0.2753
205	0.1926	0.2546	0.3266
272	0.2093	0.2720	0.3500
272+	0.2193	0.2773	0.3526

(+ specimens kept in salt water bath from 205 days age)

Fig.1 shows the effectiveness of 10% and 30% cement replacement by weight of silica fume. These results also relate to the same mix as before - 1:1.966:4.166:0.64 but the mix also contained a superplasticizer, 1.5% by wt. of cementitious materials. The 2.7 and 2.1kg/m³ alkalinity are the basic

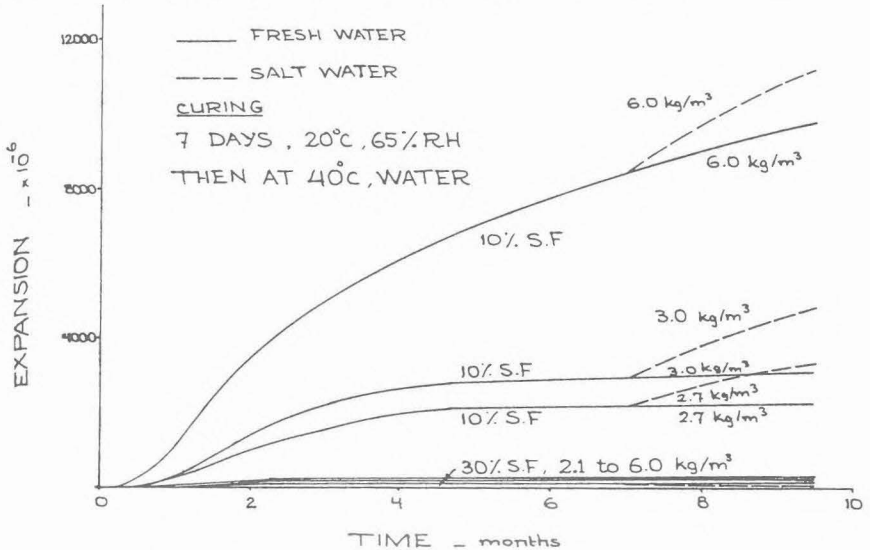


FIG 1 EXPANSION DUE TO ASR IN THE PRESENCE OF SILICA FUME AND SALT WATER

mixes, whilst those with 3.0 and 6.0kg/m³ alkalinities are mixes with externally added alkali. All the concrete mixes were initially cured at 20°C and 65%RH for 7 days and then exposed to 40°C with intermittent soaking in water. The test method again confirms its application to evaluate the effectiveness of mineral admixtures. At 30% replacement, silica fume is able to almost completely control the ASR expansion.

ALKALI REACTIVITY TEST

As pointed out earlier, none of the currently available test methods provide a reliable evaluation of the potential reactivity of an aggregate. Aggregates that exhibit slow but progressive expansion are not easily identified. One of the major obstacles in developing a fool-proof test method is the large number of parameters involved in ASR - cement content and cement alkalinity, volume fraction and particle size distribution of the reactive aggregate, contribution from alkalis in aggregates and external sources, environmental conditions etc. It can be readily seen that there are severe difficulties in developing a test method that takes into consideration all these parameters.

However, tests by the authors show that one sure ingredient that is likely to show up and accelerate the potential reactivity of an aggregate is the presence of salt at elevated temperature. This is illustrated in Fig.1 where some of the concrete prisms with 10% and 30% silica fume replacement were exposed at 7 months, to 40°C in a salt water bath. The results show an increase in expansion at all alkalinity levels with 10% replacement. At 30% silica fume replacement, the increases in expansion were only marginal, confirming other published data on the effectiveness of silica fume at this replacement level to exclude chloride ions.

Further evidence is provided in Fig.2 which shows the expansion of two reactive aggregates, opal and fused silica, when exposed to 40°C in fresh water or a salt bath after 28 days initial curing at 20°C, 65%RH. The effect

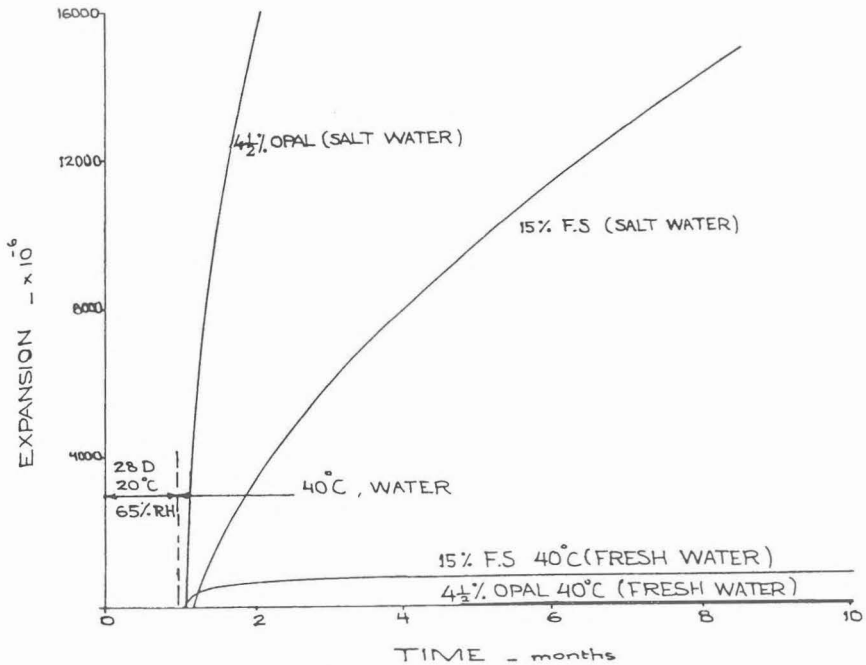


FIG 2 EFFECT OF SALT WATER ON EXPANSION

of the availability of chloride ions at elevated temperatures in the presence of reactive aggregates is unmistakable, confirming the data in Fig.1. To identify the role of chloride ions in accelerating ASR expansion, the mix used for the data in Fig.2 is a weak mix with 250kg/m³ cement content and a medium alkalinity cement with 0.823% sodium oxide equivalent giving a concrete alkalinity of about 2.1kg/m³

The test method recommended by the authors is thus clear. It is a 75x75x300mm concrete prism test, containing the cement and aggregates in the same proportions and combinations as specified for a particular application, and then exposed to 40°C in a salt water bath. The results should provide a clear idea of the overall potential reactivity of an aggregate. This test is likely to be of much shorter duration than currently available tests.

CONCLUSIONS

The paper suggests test methods to determine alkali reactivity, effect of ASR on concrete properties and to evaluate the effectiveness of mineral admixtures in controlling ASR expansion. Test evidence is presented to support the validity of the proposed test methods.

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