

A MECHANISM FOR ALKALI-SILICA REACTION IN CONCRETE ROADS

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ABSTRACT

A mechanism for alkali-silica reaction in concrete roads has been developed from observations made during a survey of concrete roads in Great Britain. The roles of cracks, reactive-silica aggregate, water and salt are each discussed and then brought together in a suggested four-stage process. It is suggested that two important conditions contribute to alkali-silica reaction: first, water has to penetrate the concrete, and second, alkali solution has to be able to reach any reactive-silica present in the aggregate. In British conditions, de-icing salt is seen as a likely additional contributor of alkali. Well constructed and sealed joints together with the minimum use of de-icing salt consistent with the safety of road users should reduce the likelihood of alkali-silica reaction in concrete roads.

1. INTRODUCTION

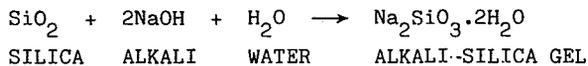
In Great Britain alkali-silica reaction has not hitherto been reported in concrete roads although it has been found in concrete highway structures (Winney, 1980 and Dumbleton, 1986). However, concrete road pavements are wet for long periods of time and are treated with sodium chloride as a de-icing measure during winter: therefore they are in the 'high risk' category (Cement and Concrete Association, 1987). Because of this concrete roads in Great Britain are being examined to see if there is any evidence of the occurrence of alkali-silica reaction in them. The early results of this survey (West and Sibbick, 1988) showed that of the fourteen road samples then examined, two gave evidence of alkali-silica reaction. The survey has also provided evidence of a possible mechanism by means of which alkali-silica reaction could take place in concrete roads; it is this aspect of the work that is reported here.

The method of assessing the concrete samples obtained during the road survey was to prepare 75mm x 50mm thin sections from resin-impregnated blocks and then to examine them with a polarising microscope. Alkali-silica reaction was identified as having occurred in the sample if a potentially reactive aggregate, microcracks and alkali-silica gel were all found to be present in the thin section. Examination of the thin sections also revealed the condition of the concrete in the later stages of the alkali-silica reaction which led to the postulation of the mechanism described below.

1.1 Chemistry of alkali-silica reaction

Alkali-silica reaction takes place in concrete when an alkali solution,

originating either from pore solutions in the cement paste or from some other source, reacts with certain types of silica in the aggregate to form alkali-silica gel. If the alkali solution comes from the cement paste the process can be represented in a straightforward manner by the following chemical reaction:



Theoretically, if the alkali solution comes from the infiltration of road de-icing salt into the concrete, then a reaction must first take place between the salt (sodium chloride, NaCl) and any portlandite (calcium hydroxide, Ca(OH)₂) that is present in the cement paste. This reaction, somewhat simplified, can be represented by:



By whichever method it is formed, the gel has the ability to absorb water, swell and exert a pressure that can crack both the aggregate particles and the surrounding cement paste. This process ultimately can damage the concrete.

For the alkali-silica reaction to take place in practice, there must be reactive silica present in the aggregate, a source of alkali -- either internal or external -- and a supply of water. In addition, there must be some way for the alkali solution to come into close contact with the reactive silica. We will now look at how these requirements can come together in concrete roads.

2. OBSERVATIONS

2.1 Reactive aggregate

In both concretes from the survey that were found to have evidence of alkali-silica reaction the coarse aggregate was Cretaceous flint gravel. On examination these flint gravel aggregates were found to contain particles showing a range of colour from black through grey and brown to cream and white. The water absorption of the different kinds of particle in one sample of gravel was measured for 20mm and 10mm nominal-sized aggregate by a standard method (British Standards Institution, 1975) with the results shown in Table 1.

TABLE 1. Results of water absorption tests

Type of particle	Water absorption (%)	
	20mm aggregate	10mm aggregate
Black flint	0.57	0.78
Brown flint	1.48	2.69
White flint	6.12	9.76

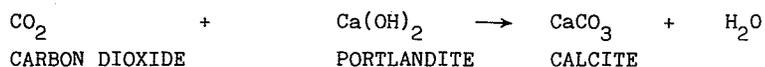
These measurements show that while the black flint is of very low porosity, the brown and particularly the white flints are considerably more porous. Flint

itself is cryptocrystalline silica, but it is clear from the water absorption measurements that the availability of the cryptocrystalline silica for reaction with alkali solution will depend on the type of flint particle, being greatest for the white flints with the highest porosity. As the particle size of the aggregate decreases, so the water absorption and the proportion of white flints increase.

2.2 Cracks

Many of the samples of concrete examined in the survey contained micro-cracks and some concrete pavements could be seen to be cracked on their upper surfaces, usually in the vicinity of the joints between slabs. On one site the visual cracks took the form known from its characteristic appearance as 'D-cracking'. These visual cracks in the concrete pavements have been attributed to causes other than alkali-silica reaction. It is important to note that both microscopically and visually many of the concrete roads had cracks near the joints. These cracks are seen as a means whereby surface water can penetrate deeply into the concrete in the vicinity of the joints; in winter this surface water will carry with it some of the salt used for de-icing.

In the thin sections from the concrete road survey, carbonation of the cement paste was sometimes seen along the microcracks. This was additional evidence for the penetration of water into the concrete, because the carbonation arises from water carrying dissolved carbon dioxide from the atmosphere reacting with portlandite in the cement paste to give calcite:



2.3 Water

It has been estimated that in Great Britain the road surface in winter is wet for about 60% of the time and in summer for about 15%. Also, British roads are salted in winter at an annual rate varying from 1-2 tonnes per km in regions where frosts are light to over 10 tonnes per km in areas of severe frosts (County Surveyors' Society, 1985).

One of the concretes from the survey was found to contain gel lining the cavity of a void in the cement paste, into which it had flowed along micro-cracks leading from a reactive particle of coarse aggregate. The gel was observed to have a marked layered structure suggesting periodic accumulation, depending upon the availability of water and perhaps also salt, and possibly also due to variations in the rate of reaction.

3. SUGGESTED MECHANISM

We are now in a position to outline a suggested mechanism for alkali-silica reaction in concrete roads.

Stage 1. Over a period of years cracks develop in a concrete pavement, mainly concentrated near the joints. This damage is due usually to a combination of factors; these may include traffic stresses, thermal expansion, frost action, low concrete strength, large particles of aggregate near joint faces, and the inadequacies of the joints.

Stage 2. Water then enters these cracks, particularly during the winter

months when it will be laden with de-icing salt. In theory, this salt can react with portlandite in the cement paste to produce an alkali solution, adding to the alkali already present in the pore solution of the cement paste.

Stage 3. If there is a porous reactive-silica aggregate such as white flint in the concrete, the alkali solution diffuses into the aggregate particles. A chemical reaction then takes place between the alkali solution and the porous reactive-silica to form alkali-silica gel. Once formed, the gel, which is hygroscopic, takes in more water and expands in volume.

Stage 4. The continued formation and swelling of the alkali-silica gel produces an internal pressure which eventually cracks the aggregate particles together with the surrounding cement paste. That this cracking is of an expansive type can be seen by the open nature of the cracks and by the displacement of fragments of aggregate. The alkali-silica gel is now able to flow out of the aggregate particles and into the cement paste along the microcracks that have formed as a result of the expansion. The development of more gel and further expansion leads to further cracking. Evidence for the pressure produced by the gel can be seen in the cement paste adjacent to the microcracks, where the cement paste is seen to be heavily stained as a result of the injection of gel into it in a process analogous to grouting.

3.1 Evidence for mechanism

Stage 1 of the suggested mechanism for alkali-silica reaction can be seen by the visual inspection of older concrete road pavements where cracking has occurred near the transverse joints. Stages 2 and 3 cannot be detected readily as the changes are chemical rather than physical. Stage 4, however, can be seen by examining thin sections of suspect concrete.

Figure 1 is an example, viewed in plane polarised light. On the left of the photomicrograph is a large coarse aggregate particle of flint and on the right an area of cement paste with fine aggregate particles. The large aggregate particle has cracked in a bifurcated manner considered typical of alkali-silica reaction damage. Much of the central portions of these cracks are now filled with the resin added to the concrete during the preparation of the thin section. Within the aggregate particle itself the alkali-silica gel is now absent or remains only as a fringe deposit. At the boundary of the aggregate particle and the cement paste, the gel completely fills the crack, and shows very fine, and as yet unexplained, laminae. In the cement paste the gel is again found as a fringe deposit in the microcracks, which have now developed into a complex network surrounding fine aggregate particles. The cement paste bordering these microcracks is highly stained, probably as a result of the high pressure injection of gel.

The gel develops in the centre of the reactive flint particles, causing expansive cracking; once this cracking has occurred the gel then migrates from the reaction site into the microcrack network, leaving only remnants of gel in the flint particles. The microcrack networks in the cement paste can be traced back to porous white flint particles, which are considered to be the sites of the original reaction.

3.2 The role of voids

Since the severe winter of 1962-63, air-entrainment has been used in Great Britain to reduce the frost susceptibility of road pavement concrete. Sometimes the microcracks intercept the air-entrainment voids in the concrete and these can then act as reservoirs for alkali-silica gel. This mitigates the effect of

the alkali-silica reaction.

4. DISCUSSION

For alkali-silica reaction to be a problem, alkali solution has to gain access to reactive silica. It is thought that cracks play an important part by allowing ingress of surface water, which in winter carries de-icing salt with it. Salt is seen as a possible contributor to the alkali-silica reaction as has been recognised recently by Nixon et al (1988), albeit in another connection, namely that of salt in the concrete at the time of construction.

The mechanism of alkali-silica reaction postulated in this paper is one in which the concrete is considered to have cracked to some extent before the reaction commences, the alkali-silica reaction being secondary to some other primary cause of damage. Ingress of water near joints in the concrete is seen to be a vitally important factor in the mechanism.

In order to reduce the likelihood of alkali-silica reaction occurring in concrete roads, it is important to use non-reactive aggregate and a low-alkali cement and to ensure that joints are soundly constructed, sealed and well-maintained so that the concrete does not crack. Air-entrained concrete does provide voids into which the gel can expand, reducing the pressure and the consequential cracking. Also, the amount of de-icing salt used in the winter should be kept to the minimum consistent with road safety.

5. ACKNOWLEDGEMENT

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director. Crown copyright. The views expressed are not necessarily those of the Department of Transport.

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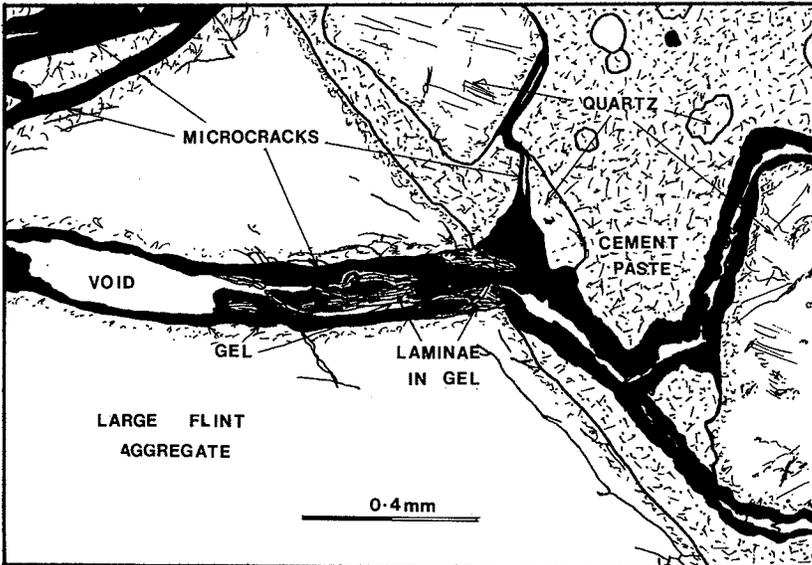


Figure 1. Large flint aggregate in cement paste showing microcracks and associated gel.