ASR—Inside Phenomena and Outside Effects (Crack Origin and Pattern)

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ABSTRACT

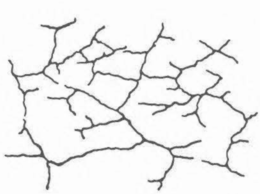
Explanations of the processes involved in alkali-silica (and silicate) reactions have been proposed during the last four decades and a great deal is known concerning the internal phenomena associated with the origins of expansion and cracking as revealed from laboratory experiments and petrographic studies.

Stresses so produced result in macro strains in concrete structures but the actual effects depend on internal and external restraints and constraints operating on the concrete. These influences account for the sometimes baffling outside appearances of affected structures especially the wide variance in modes of cracking and staining of plain, reinforced and prestressed concretes.

Despite the considerable amount of published information on alkali reactions in concrete there remains much misunderstanding on the practical effects and time dependancy of expansion phenomena. This paper re-emphasises the need for careful evaluation of all aspects of the problem.

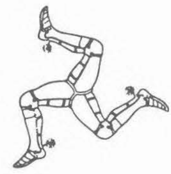
INTRODUCTION

Alkali-silica reaction is viewed by the general public as being capricious and pernicious, an attitude encouraged by reports in the popular press of "the scourge of the construction industry", "concrete burst apart by alkali-aggregate reaction", "concrete decay", "foreign disease", "the crunch", "concrete cancer" etc. [Headlines, 1980-86].



Such articles have frequently been accompanied by illustrations of map-cracked concrete [New Civil Engineer, 1977 and 1980] and more authoritative advice has also tended to give prominence to the type of cracking produced in unrestrained concrete [Building Research Establishment, 1982]. Thus the impression has been created that any kind of random crack pattern must be used by deleterious alkali-silica reactions - even to the extent that the nspecting Engineer for a newly constructed concrete bridge recently required rigorous checks for alkali-aggregate reaction when crazing of surface laitence was revealed by water-mist spraying.

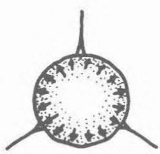
"Manx" or "Isle of Man" three-branched cracks are often produced by expansive alkali reactions [Figg, 1975]. Other surface expressions of internal expansion are pop-outs, bulging or tilting of concrete members, as well as cracking although the crack configuration depends on the extent and form of movement constraint to which the concrete is subjected.



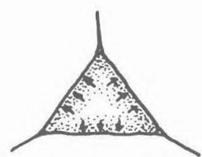
Concretes affected by ASR sometimes also exhibit other characteristics including presence of viscous (resin-like) exudations, staining/streaking from cracks, reduced surface erosion associated with impregnated areas beside cracks and damp blotches/slow-drying areas on the outside surface.

INSIDE PHENOMENA

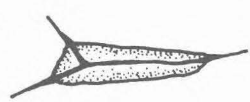
The expansive forces within concretes affected by ASR are generated by hydraulic pressures created in siliceous aggregate particles. These pressures are produced by the net water inflow resulting from the cleavage of silanol linkages in the aggregate by hydroxyl ions, in the presence of sodium (or potassium) ions, when the affected particle is surrounded by cement paste (containing a high concentration of calcium ions) [Chattergi et al., 1986]. It appears that in such circumstances the aggregate/cement paste interface behaves as an osmotic membrane facilitating pressure development caused by swelling of the gel reaction product.



Alkali silicate gels have been demonstrated to be capable of producing osmotic pressures well in excess of 10 MPa significantly greater than the tensile strength of conventional concretes.



Swelling of an altered homogenous spherical aggregate particle causes pressure to be exerted on the surrounding cement paste which is equal in all directions. The minimum number of cracks required to accommodate the volume increase is three and very often a concrete section will show such cracks about 120° apart. The tendency to form three cracks is encouraged by angular or irregular aggregate shapes and even elongated or flattened pebbles will frequently be found to result in triple cracks.

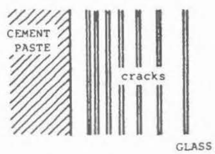


The changes occurring within aggregates and the influences of aggregate composition and morphology on dimensional changes, crack development and propagation may be followed by microscopic examination (optical and SEM) of concretes suffering from ASR. An excellent series of such observations has been recorded by Idorn [1967].

Polymictic (polymineral) rocks and aggregates containing veins o. vughs of secondary reactive material may exhibit a more asymetric expansion and correspondingly more complex cracking.

Other internal phenomena commonly found with ASR include zones of alteration at the aggregate periphery. Such alteration zones may or may not result in volume change and care must be taken to distinguish them from the weathered surface or cortex often present with gravel aggregates.

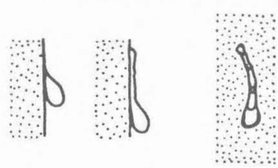
Most cracks emanating from reacted aggregate particles will contain some of the alkali silicate gel, distinguished by its isotropic optical character, often accompanied by signs of drying shrinkage (caused by the method used to prepare the examination specimen). Gel development may be very sparse with slowly reacting aggregates.



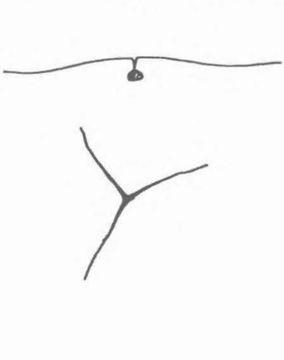
Glassy aggregates (artificial glasses) may show a series of gel-filled cracks more or less parallel to the outside surface, produced by alkali-silica diffusion/reaction. In some cases these cracks comply with the Spacing Law for rhythmic reactions analogous to Liesegang Rings produced by diffusion/precipitation [Blanchard et al., 1985].

OUTSIDE EFFECTS

Where copious quantities of alkali-silicate gel are produced, for example with opaline silica - containing aggregates, some of the gel may exude from cracks or pores in the concrete to form a resin-like accumulation on the surface. Initially clear, viscous and slippery to the touch the alkaline gel soon becomes carbonated on exposure to the atmosphere and changes in appearance to a translucent to opaque white, matt substance (often difficult to distinguish from 'carbonated' leachate from the concrete).

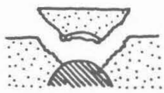


Where the gel is of lower viscosity it may accumulate in the concrete surface pores forming a deliquescent area (readily observed in a damp atmosphere) slowly carbonating to a white stain. Damp spots and "snail trails" are a useful diagnostic indicator of ASR with cores drilled from affected concretes [Palmer, 1977].



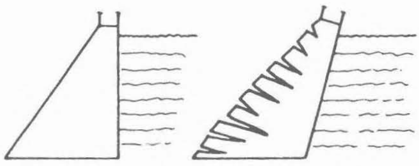
Although concrete members may exhibit overall expansion as a result of alkali-silica reaction, in reality expansion is very uneven due to the random distribution of reactive aggregate particles. The resultant differential volume change exacerbates cracking.

Reactive aggregate particles close to the outside surface may produce a bulge, and concomitant Manx cracking, or a small conical plug of concrete may be pushed out of the concrete surface as a pop-out.



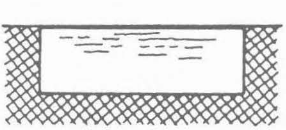
Pop-outs appear to be especially associated with rapidly reacting and swelling aggregates or accelerated (steam) curing of concretes containing reactive materials. Internal swelling pressure has been demonstrated to reproduce pop-out damage [Bache and Isen, 1965].

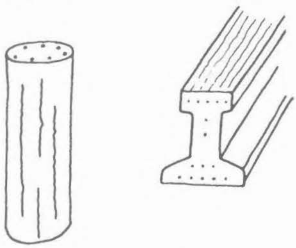
The origin of the Manx cracking is in part the presence of reactive aggregate near to the surface, but also the resultant surface pattern of a number of partial pop-outs produced by several reactive particles. The cracks meet at angles which tend towards 120° and in unreinforced, unrestrained concretes the eventual effect is of classical map-cracking.



Large concrete structures, even when no reinforcement is present, do involve some inequality of condition involving constraint to movement which is greater in one direction than another. Gravity dams are such a case where expansion is easiest in an upward direction (rather like the opening of a book) hence cracking tends to be predominantly horizontal.

Similarly ground slabs constrained by more massive construction may show cracking more or less parallel to the free edge.

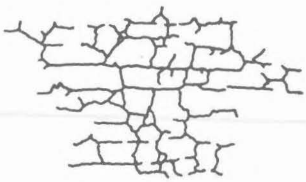




ASR in reinforced concretes which have the main steel oriented in one direction (such as beams and columns) tends to be expressed as linear cracking approximately parallel to the steel. This effect is particularly marked with prestressed concretes (which give many fine cracks) but conventionally reinforced elements show the same crack configuration but with fewer and wider cracks.

ASR expansion should cause the cracks to occur between the steel, unlike cracking due to corrosion of reinforcement where the cracks coincide with the corroding steel.

Structures containing more evenly distributed steel (walls, bases, abutments etc.) may show a roughly rectangular crack pattern as a result of ASR. A far remove from the anticipated random map cracking.



CONCLUSIONS

It is important that engineers should realise that deleterious ASR is a time-dependent volume-change phenomenon, with maximum expansion occurring at lower temperatures than maximum rate of reaction.

Authenticated cases of ASR (except for autoclave cured concretes) all involve considerable elapsed time after casting before damage ensued (measured in years rather than weeks).

For an internally expanding concrete the actual direction of movement depends on the restraint imposed on the concrete member. Random cracking can only be expected in unreinforced unconstrained concretes.

Whilst ASR may result in Manx or map-cracking the opposite, that random cracking is due to ASR, is certainly untrue. Only where cracks have been shown to originate from reacted aggregate can ASR be definitely diagnosed.

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