ALKALIS IN CONCRETE: A MATTER OF EDUCATION FOR ENGINEER AND RESEARCH SCIENTIST

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ABSTRACT

The idea that certain aggregates together with alkalis in concrete may produce deleterious reactions which will disrupt concrete structures in a matter of years is now well known. However, the view of what is important concerning alkali-aggregate reactivity in concrete depends very much upon the position of the observer. The research scientist will be concerned with the chemical mechanisms of the reaction processes, the various factors that influence the reaction itself and the physical effects which are produced as a result of it. The engineer, on the other hand, will be primarily concerned with the physical effects of cracking and expansion, the rate of which these progress and the ways in which the reaction may be avoided or stopped if it is already in progress. It is important that the engineer should understand that, if satisfactory answers to his questions are to be obtained, it is essential that first the reaction mechanisms and their controls be fully understood. The scientist in his turn must understand the difficulties and constraints faced by the engineer on the construction site and his need to predict accurately the future behaviour of the concrete.

As a result of interaction between engineers and research scientists, much practical and useful information can now be provided concerning the factors which control the alkali-aggregate reaction and the tests and limits which may be specified to avoid the use of reactive materials in concrete. However, at the present time, careful and intelligent interpretation of the research and test results are required, with all the probabilities duely considered so that both unjustifiable expense and unjustifiable risk conditions can be avoided. There is still an urgent need for education concerning the interpretation and application of these results, a task perhaps best accomplished in short courses and conferences where adequate opportunity exists for discussion.

Further researches, particularly into the areas of control of the reactions and the changes in the mechanical properties of concretes that are undergoing reaction are now in progress. The results of this work, if properly interpreted and correctly applied by engineers and scientists working together, should be of great value in reducing the incidence of deleterious reactions and in improving the precision of prediction for the future behaviour of concrete structures.

1. INTRODUCTION

Although lime was used to cement blocks in the pyramids and the Romans made use of concrete, Portland cement used in concretes which are so common as a construction material in the world today were born of the Industrial Revolution with the work of Frost 1822 and Aspdin who patented 'Portland Cement' in 1824. It was used by Sir Isambard Brunel to build a tunnel under the Thames in 1838 and to the construction industry of the time, must have appeared a 'wonder material' sufficiently exciting for a block of concrete to be displayed at the Great Exhibition in London in 1851.

The use of Portland cement concretes has continued to expand and develop since that time with technological advances such as steel reinforcement increasing the scope and usefulness of concrete as a construction material until today the sales of concrete world-wide lie between 200 and 300 billion dollars annually /1/. It is human nature not to seek out problems unnecessarily so it is unlikely that much consideration was given to the alkali content of Portland cements until concrete failures focused the attention of engineers and scientists on the curious chemical reaction between alkalis from the cement and certain aggregate particles which could produce such spectacular physical effects within a short span of engineering time.

It is perhaps instructive to consider some of the more important stages in the study of this deleterious reaction before considering how engineers and scientists have attempted to deal with the problem. Until the 1930s alkali-silica reactions in concretes if they occurred went undrecognised and indeed modern examinations of old concrete which still exist fail to identify this type of reactivity though other features of deterioration are often observed. Stanton's work /2/,/3/, was the first major step in identifying the reaction, its mechanisms and its effects. It is interesting that a number of concrete structures built in Europe during the Second World War when examined today are seen to be suffering from alkali reactivity. By 1957 problems had been reported not only in connection with alkali silica reactivity but also from reaction between alkalis and argillaceous carbonate aggregates /4/. The problems associated with alkali aggregate reactivity in concretes were perhaps first brought to the full attention of Europeans with the publication of Idorn's thesis in 1967 /5/. Britain was fortunate in not having to consider the problem until in 1971: the Val de la Mare Dam was discovered to be showing signs of premature deterioration and by 1976 examples of reactivity were being recognised in South West England. Today over 40 cases have been reported in the U.K. Examined in a wider context alkali silica reactivity in concrete has been identified in most of the developed countries of the world as is shown by Fig. 1.

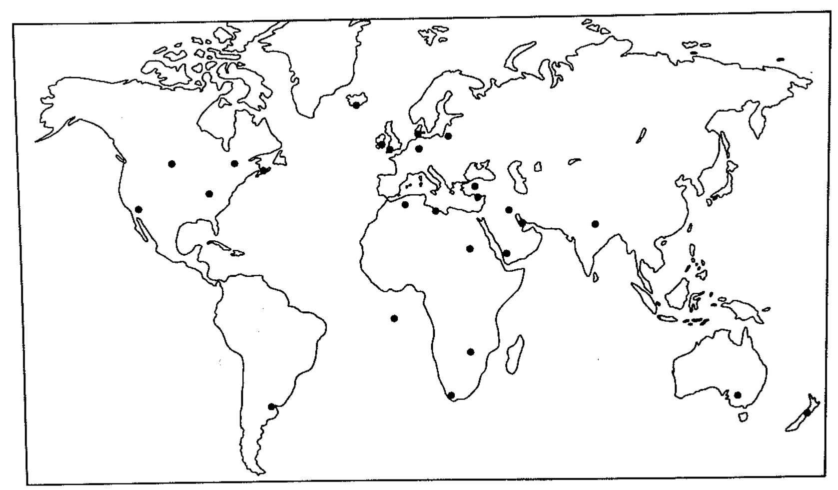

Fig. 1 Reported cases of alkali silica reactivity 1982

In parallel with this unfolding history there has been continuing research effort directed towards understanding the processes involved in the reactions, and towards avoiding the problem or minimising its effects. This research appears to have received fresh impetus and urgency in recent years doubtless because of the increasing concern felt by the construction industries of the world and the costly nature of any failure. Certainly increasing numbers of people are becoming aware of the problem as is reflected by numbers of delegates attending conferences like this one. Table 1 below clearly indicates an increased and widening interest in this materials problem.

Table 1 Delegates attending this series of international conferences

Conference		Number of delegates
Reykjavik	1975	26
U.K. London	1976	48
U.S.A. Purdue	1978	57
South Africa Cape Town	1981	156

It is true to say that the vast majority of concrete structures built do not and will not suffer from alkali silica reactivity and will perform satisfactorily for their full design life. However, if you have a responsibility for a structure which is suffering from alkali silica reactivity, it is small comfort to know that the percentage of structures with this problem is very small.

2. ENGINEERING ASPECTS OF THE PROBLEM

Doubtless Brunel faced and solved many problems in connection with the construction of his Thames Tunnel but, unlike today's engineer, the problems of durability associated with alkali aggregate reactivity was not one of them. The materials engineer is, depending on circumstance, faced by one of two problems, with a new concrete structure he must avoid materials that are potentially deleterious or take steps to negate or at least minimise the effects of the reaction. The second type of problem arises with the existing structure that is suffering from the effects of alkali aggregate reactivity. In this situation the engineer will seek to arrest or at least slow down the reaction and attempt to calculate rate of deterioration and hence determine the life of the structure. In order to assist the engineer in solving his problems for a new concrete structure he will require information concerning:

1. the nature of the reacting materials,
2. the limiting concentrations of reactants,
3. the effects of the environmental conditions on the reaction,
4. a satisfactory screening test for the materials,
5. a realistic test for checking performance of the materials to be used,
6. methods of modifying a concrete so as to reduce reactivity to acceptable levels.

Ideally tests 4 and 5 need to be rapid, reliable simple and cheap. Item 6 only becomes important if there are no alternative inactive materials available for construction.

If the engineer is dealing with an existing structure then again he will require information as listed under 1, 2 and 3 above but he will also require information on:

1. reaction rate under given environmental conditions,
2. the effects of the reaction on structural strength,
3. methods of arresting or slowing the reaction,
4. methods of repair.

The engineer expects the research scientist to provide this information and hopes that in all respects it will be simple and unambiguous. At the present time this is clearly not the case largely because the problems are very difficult to solve, but perhaps partly because engineer and research scientist, having different objectives and constraints do not always work together as closely as they should.

3. THE RESEARCH SCIENTIST'S POSITION

To the research scientist concrete is a complex and variable material and, in order to obtain representative material for study, large samples need to be used. The alkali-aggregate reactions fall within the province of chemistry, mineralogy and materials science and, in order to simplify the research problems in the laboratory, very simple systems are often used under very carefully controlled environmental conditions. Thus there are obvious difficulties when attempts are made to scale up effects observed in these simple experiments to full scale concrete structures.

A second approach to the research study of alkali-aggregate reaction in concretes is the sampling and study of real structures that have suffered from the reaction. This type of study overcomes the difficulty of scale but suffers in its turn from a lack of detailed information concerning original manufacture and the environmental conditions over the life span of the structure.

Since education can be defined as the systematic acquisition of useful knowledge, perhaps it is instructive to look first at the objectives of the research scientist and at the progress made toward them, and then see how useful this information is to the engineer who has to solve the practical problems that arise.

3.1 The Reactants and the Reaction Mechanism

In general terms the reaction mechanism is well understood with poorly crystalline forms of silica reacting with alkali solutions from the cement producing an expansive alkali silica gel. However, when research results are examined in detail, a number of difficulties are at once apparent.

1. It proves very difficult to identify reactive forms of silica and estimate them quantitatively particularly when they are mixed with quartz or other materials.
2. The concentration of reactants controls reaction rate and reaction effect. Detailed information concerning the effect of concentration is limited and determination of these concentrations is very difficult in a real situation.
3. Reaction rate is also controlled in a complex way by environmental conditions. Only the most general conclusions concerning the effect of environment can be applied to real structures.
4. The visible effects of the reaction in real structures are cracking and displacement (expansion). Very limited information is available concerning expansion to be expected and little or none concerning reductions in strength resulting from this type of cracking.

3.2 Tests for Potential Reactivity

Various tests have been devised to identify and quantify the potential reactivity of materials to be used in concrete. Clearly,once the alkalinity of the cement to be used has been specified, attention is focused on the aggregates; hence most tests are concerned with the aggregate, though a few do involve both cement and aggregate. The tests can be grouped under a series of general headings as indicated in Table 2. All these tests have limitations. 1 and 2 do not always provide unambiguous results. Extrapolation of results from tests with mortar to real structures may not be satisfactory, while large concrete blocks though more realistic may take a long time to develop symptoms of deterioration.

Table 2. Some Tests for Alkali-Aggregate Reactivity

Test Type	Principal Use	Comment
1. Petrographic Examination	To screen for potential aggregate reactivity.	Can also be used to identify AAR in concrete.
2. Aggregate Dissolution tests, e.g. ASTM C 289	To screen for deleterious and potentially deleterious aggregates.	Some inert U.K. flints are designated deleterious by this test
3. Mortar Bar tests e.g., ASTM C 227	To measure rates of expansion for cement/aggregate mixtures.	Expansions are often slow - test lasts 6 months.
4. Concrete Block tests	To determine effects of reactivity and rate of reactivity in concrete.	Concrete can be used - effects will take time to develop.
5. Service Record	Practical information concerning the likely durability of the structure.	The value depends on similarities between old and new structures and the ages of existing structures.

3.3 Remedial Measures

The alkali-aggregate reaction can only proceed if alkali solution and reactive aggregate is available; moisture is an essential component in this reacting system and it has been observed that the weather faces of concrete structure suffer more severely than protected faces. Short of replacement of the affected structures, most attempts at arresting the reaction have centered round sealing the surfaces to prevent ingress of moisture. Such methods would be successful if moisture levels within the concrete could be fixed or reduced sufficiently to prevent reaction proceeding, though it must be remembered that reaction would restart once the surface barrier was breached.

There appears to be very little research data presently available concerning change of strength of concrete units as cracking proceeds,and only recently /6/, /7/ have systematic attempts been made to monitor crack development with time on existing structures. Figure 2 illustrates part of a crack pattern map prepared for a concrete panel by Comberbach in 1981. Until the pattern of deterioration and change in strength with time can be established, it remains impossible to offer more than a guess as to the remaining life of a structure suffering from the reaction.

4. THE MUTUAL RE-EDUCATION OF ENGINEER AND SCIENTIST

The engineer will perhaps be correct in his opinion that test results are often ambiguous and slow to obtain, that information concerning rate of progress of the reaction and its effects particularly concerning expansions and strength is very limited and that information concerning effective remedial measures is almost non-existent.

The scientist will with reason point to the difficulties of identifying the reactive elements in an aggregate, the difficulties of monitoring the reactive system, the problems associated with a multivariate system and the difficulties of accurately scaling up from laboratory results to full size structures.

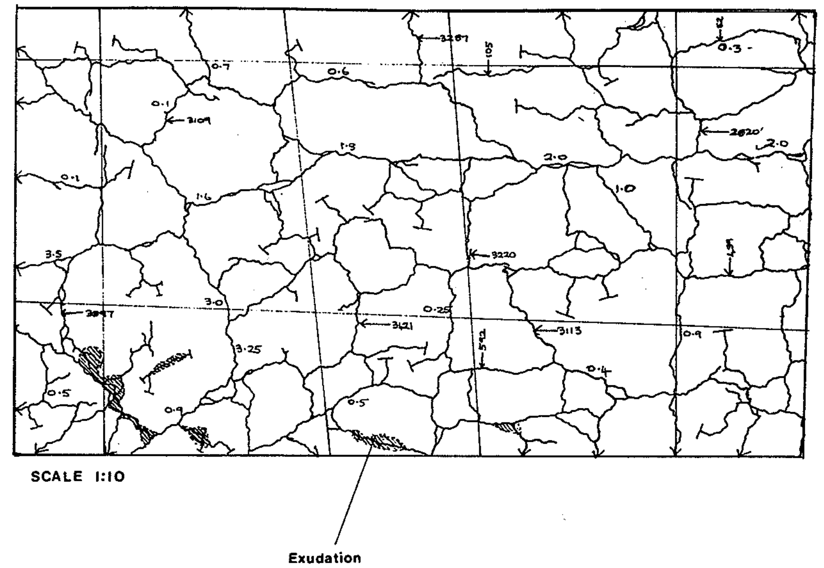

Fig. 2 Part of a crack pattern map of a concrete panel

However, if the scientist and engineer examine current research findings with the mutual objective of solving the two principal practical problems of avoiding deleterious material for new structures and dealing with a structure already deteriorating, then at least the directions of additional future research become clear.

Firstly a rapid and effective screening test for materials is required. A possible fruitful area for research here is to use petrographic or chemical techniques to identify the first signs of alkali-aggregate reactivity. A realistic test is also required to evaluate the durability of particular concretes; this can only be accomplished by using the concretes in the test, these must then be treated in some way to accelerate any deleterious effects so that they occur within a reasonable time scale. This objective requires more quantitative information to be obtained concerning effects known to accelerate reaction, for example the use of excess alkalis, elevated temperature or cyclic conditions. In order to assess the rates of deterioration of existing structures, it will be essential to monitor the development of cracks and changes of strength with time which will be a costly and slow process. With regard to remedial measures, the removal or fixing of water within the concrete fabric would seem to be the most satisfactory method of arresting the reaction process. This in its turn requires research into methods of removing or fixing the water, and information relating to the effect of moisture concentrations and movements on the reaction process itself.

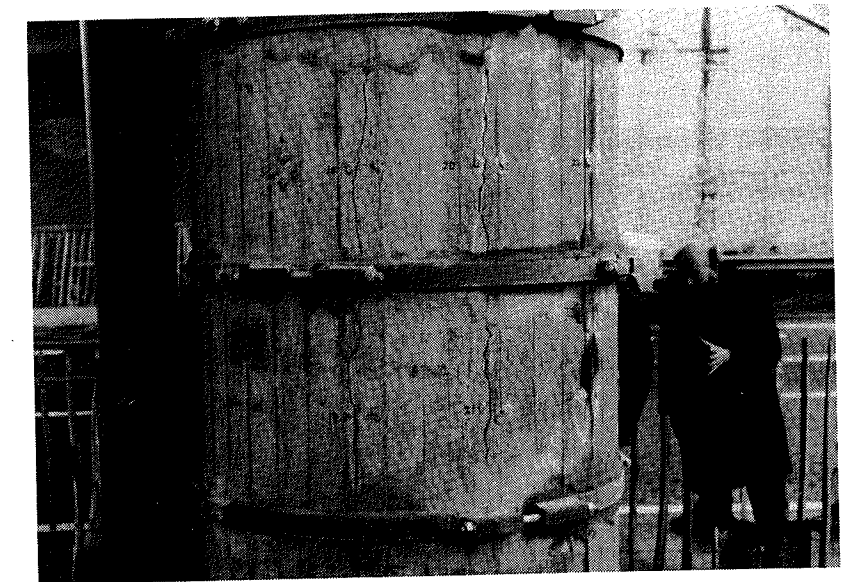

Fig. 3 A solution to the problem?

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