8th
ICAAR
1989
KYOTO
8th Internationl Conference
on Alkali–Aggregate Reaction

# ALKALI–AGGREGATE REACTION IN SOUTH AFRICA : SOME RECENT DEVELOPMENTS IN RESEARCH

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## 1. INTRODUCTION

The first review paper on alkali-aggregate reaction in South Africa was presented at the Fifth International Conference on Alkali-Aggregate Reaction in Concrete (ICAAR) held in Cape Town, South Africa in 1981 [1]. Papers on specific aspects of research into the problem in South Africa have been presented by a number of authors at every ICAAR since 1976 and many have been published in journals and textbooks. This paper will therefore not review all research in South Africa to date, but will rather refer to three aspects of the alkali-silica reaction (asr) currently being investigated.

## 2. MINERAL ADMIXTURES

Different mineral admixtures have been examined for their effectiveness in inhibiting asr in concrete and, based on the results both of laboratory experiments and long-term outdoor exposure of large concrete specimens, the following have been recommended as partial replacements for high-alkali cement to prevent deleterious expansion when using an alkali-reactive aggregate:

- an approved fly ash: 20% by mass;
- milled granulated blast-furnace slag (MGBS): 30% by mass; or
- condensed silica fume (SF): 10% by mass.

The above percentages should be increased in proportion to any increase in the $Na_2O$ equivalent of the cement above 0,90% [2].

However, at the 7th ICAAR in Ottawa in 1986, the effectiveness of SF and MGBS (inter alia) in preventing asr when replacing high-alkali cement in large concrete cubes exposed outdoors was discussed [3]. Although replacing 5% OPC by 3,5% SF (by mass) initially delayed expansion, when compared with the control made with high-alkali OPC without any replacements, after about 1 200 days expansion exceeded the value of 0,05%, which is regarded as deleterious. The question was asked whether, after a longer period the same would not apply to the replacement of 10% OPC by 7% SF (by mass). The most recent results are shown in Figure 1 and the details of the cubes are given in Table 1.

In this particular series of experiments (MGBS and SF), the OPC was replaced by an amount of admixture equal in volume to the mass of cement replaced. Thus, for example:

$$10\% \text{ by mass OPC} = 10/3{,}15 = 3{,}18 \text{ cm}^3 \text{ OPC} = 3{,}18 \times 2{,}18 = 7 \text{ g SF}$$

In the case of the specimens indicated with a + sign, the dilution of the available alkali in the OPC by the substitution of the admixture was calculated (the alkali content of the admixture was ignored) and alkali hydroxide added in the proportion of the $Na_2O$ and $K_2O$ in the OPC, so that the available alkali content was the same, as if OPC alone had been used. This was done to establish what role the diluting of the OPC alkalis by the admixture plays in inhibiting expansion.

(a)

(b)

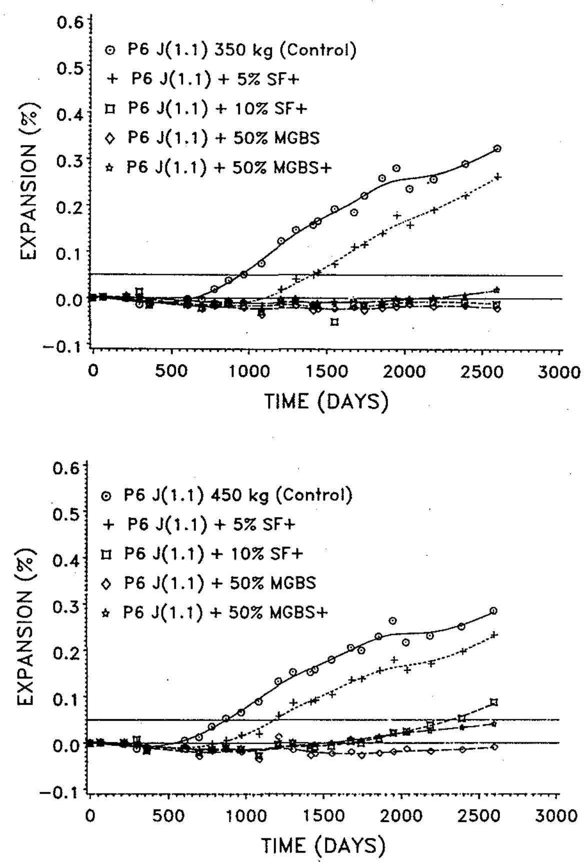


FIGURE 1: Graphs showing the effect of silica fume and milled granulated blast-furnace slag on the dimensional change of 300 mm concrete cubes made with alkali-reactive aggregate where the cement content was (a) 350 kg/m³ and (b) 450 kg/m³

For the concrete made with 350 kg OPC per m³, the control exceeded an expansion of 0,05% after 950 days. With 3,5% SF addition expansion exceeded 0,05% 450 days later. This amount of SF therefore does not prevent deleterious expansion if the active $Na_2O$ equivalent of the concrete exceeds 3,87 kg/m³. It is clear from the results of the MGBS that a 50% replacement will prevent deleterious expansion; this effect is not due merely to dilution by the MGBS of the OPC alkalis and it occurs even though the total alkali content increases with the addition of the MGBS, because the total alkali content of the slag is higher than that of the OPC.

For the concrete made with 450 kg OPC per m³, the expansion of the control exceeded 0,05% after 870 days. The concrete with 3,5% SF exceeded this expansion after 1 200 days and that with 7% SF exceeded it after 2 300 days. Therefore, at an active alkali content of 4,97 kg/m³ even the replacement of 10% OPC by 7% SF cannot prevent deleterious expansion in the long term. From the trend of the curve in Figure 1(b), it appears that even the concrete with a 50% replacement of the OPC by MGBS could exceed 0,05% expansion in the long term, at the above active alkali content.

TABLE 1: Details of the 300 mm concrete cubes

| Cube identification number | Cement/cement plus admixture combination | | CONCRETE | | | Days to 0,05% expansion |
|---|---|---|---|---|---|---|
| | $Na_2O$ equiv. % | | Cement + admixture | $Na_2O$ equiv. kg/m³ | | |
| | Total | Active | kg/m³ | Total | Active | |
| P6 J(1,12) 350 kg | 1,12 | 1,10 | 350 | 3,92 | 3,85 | 950 |
| P6 J(1,12) + 5% SF* | 1,15 | 1,12 | 345 | 3,98 | 3,87 | 1 400 |
| P6 J(1,12) + 10% SF* | 1,19 | 1,14 | 340 | 4,03 | 3,88 | |
| P6 J(1,12) + 50% MGBS | 1,69 | 0,52 | 335 | 5,69 | 1,74 | |
| P6 J(1,12) + 50% MGBS* | 2,33 | 1,15 | 335 | 7,81 | 3,85 | |
| P6 J(1,12) 450 kg | 1,12 | 1,10 | 450 | 5,04 | 4,95 | 870 |
| P6 J(1,12) + 5% SF* | 1,15 | 1,12 | 444 | 5,12 | 4,97 | 1 200 |
| P6 J(1,12) + 10% SF* | 1,18 | 1,14 | 437 | 5,19 | 4,99 | 2 300 |
| P6 J(1,12) + 50% MGBS | 1,19 | 0,52 | 431 | 7,31 | 2,23 | |
| P6 J(1,12) + 50% MGBS* | 2,33 | 1,15 | 431 | 10,03 | 4,95 | |

## 3. LONG-TERM EXPANSION OF CONCRETE IN A DAM

The Churchill Dam is one of the water supply sources of the City of Port Elizabeth in the Eastern Cape province of South Africa. It was constructed between 1940 and 1943, and consists of ten inclined arches with 17 m spans, bearing at an angle of 60° to the horizontal against a series of concrete buttresses. The arches are circumferentially reinforced in both faces, but carry only nominal reinforcement in the vertical direction and taper in thickness from 3,2 m at the base to approximately 1,8 m at the crest. Originally the buttresses were approximately 3,4 m thick at the crest, increasing to 5,8 m at the base. The overflow crest height is 36,5 m.

In 1957 extensive cracking was observed in the downstream face of one of the arches and in the adjoining buttresses. The cracking was mainly horizontal along construction joints, but in parts of the arch it was irregular in pattern. An investigation conducted by the National Building Research Institute of the CSIR between 1959 and 1962 revealed that cracking was present in all the arches and buttresses. It was concluded that the cracking had been caused by shrinkage of the concrete and thermal changes, but particularly the former. In 1963 the buttresses were strengthened with concrete extensions to their downstream side. Monitoring to detect movements of the structure was begun in 1960 and has been continued up to the present [4, 5].

The level readings on top of the arches and buttresses show a consistent increase in the height of the structure, the maximum recorded being a 26-mm rise of one of the arches in 20 years. This represents a total expansion of 0,07% and an average rate of expansion of 0,0035% per year over a height of 36,5 m. Between 1960 and 1965 expansion was as high as 0,0065% per year, but it has progressively reduced and reached zero expansion at many of the monitoring points since 1984 [5]. It is not possible to determine the rate of expansion between 1943 when the dam was completed and 1960. Some typical level readings are shown in Figure 2.

Measurements of upstream-downstream movement have not shown a definite pattern; the top centres of some arches and the tops of some buttresses have tended to move up to 14 mm downstream. The top centres of other arches have remained stationary (apart from seasonal fluctuations), whereas the top of one buttress has actually moved upstream by some 4 mm.

As part of a safety inspection carried out by the consulting engineers Messrs Ninham Shand, cores were drilled from the dam in 1988 and submitted to the Division of Building Technology for investigation. Petrographic, X-ray diffraction and scanning electron microscope examinations showed typical signs of asr, the aggregate being a Table Mountain quartzite.

Results of compressive strength and elastic modulus tests carried out in 1960 and 1987 are compared in Table 2. There does not appear to have been a deterioration in the strength characteristics of the concrete of the dam; it should, however, be remembered that only sound cores were tested.

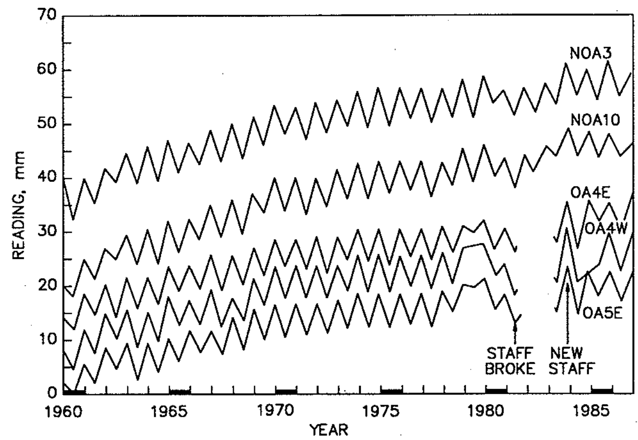


FIGURE 2: Some typical plots of long-term measurements taken on arches of the Churchill Dam

TABLE 2: Compressive strength and elastic modulus values determined on saturated cores taken from the Churchill Dam

| Year taken | Core diameter<br>mm | Equivalent cube compressive strength, Mpa | Elastic modulus<br>GPa |
|---|---|---|---|
| 1960 | 150<br>100 | 30 - 55<br>32 - 44 | 19 - 23<br>16 - 31 |
| 1987 | 142<br>100 | 28 - 50<br>31 - 45 | 20 - 33<br>20 - 29 |

## 4. CONCRETE SURFACE TREATMENTS

Previous research done in South Africa has shown that, of several coatings applied to large concrete beams made with alkali-reactive aggregate and high-alkali cement, silicone was the only one that effectively inhibited expansion, but it did so for a limited period only; weathering apparently destroyed its effectiveness [6]. The results are shown in Figure 3. Following on the above results, one of a pair of uncoated beams which had been cast from the same concrete mix, and which exhibited marked expansion and cracking as a result of asr, was coated with a solvent-based silicone after 26 months exposure. Shortly thereafter expansion ceased and shrinkage started. This was accompanied by a loss in mass. However, the coating apparently lost its protective value after about 10 months and expansion again took place (see Figure 4).

Following the rather promising results, research has commenced on a number of surface treatments to evaluate their performance in respect of depth of penetration, water transmission, water vapour transmission, resistance to chloride penetration and resistance to carbon dioxide penetration. The first three properties are regarded as relevant to asr.

The materials can broadly be classified as: silane, numbers 1, 2 and 7; siloxane, numbers 4, 5, 6 and 8; silane/siloxane, number 3; mixture of silane, siloxane, oils and resins, number 10; double-coat system of silane and methacrylate, number 9. The depth of penetration of each treatment, when applied to mortar substrates at different moisture contents, is given in Table 3.

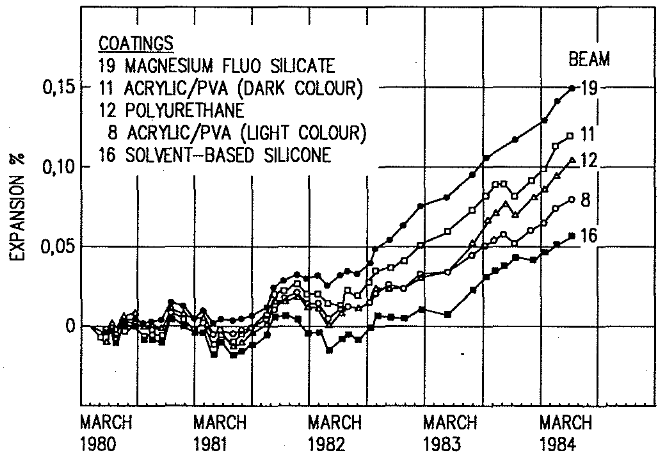


FIGURE 3: Dimensional change of large concrete beams made with alkali-reactive aggregate and high-alkali cement when exposed out of doors; different surface treatments had been applied about two months after casting

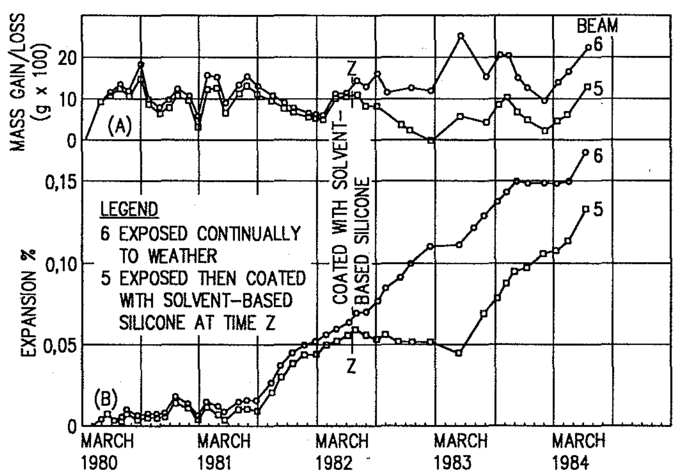


FIGURE 4: Effect of the application of a solvent-based silicone to a large concrete beam exposed outdoor and affected by asr with regard to (A) gain and loss of moisture, (B) dimensional change

TABLE 3: Depth of penetration for surface treatments at different moisture contents

| Moisture content % | Mean depth of penetration (mm) for surface treatment number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| <0,1 | 9,9 | 7,3 | 2,7 | 0,7 | 1,0 | 2,6 | 3,1 | 2,6 | 0,1 | 0,2 |
| 0,5 | 11,6 | 7,6 | 3,5 | 0,2 | 1,5 | 2,4 | 3,7 | 2,3 | 0,2 | 0,8 |
| 0,9 | 6,4 | 4,4 | 1,3 | 0 | 0,5 | 1,8 | 2,1 | 1,7 | 0,2 | 0,1 |
| 2,4 | 4,1 | 3,2 | 1,6 | 0 | 0,8 | 1,9 | 1,9 | 1,8 | 0 | 0,2 |
| 8,6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

It is seen that for increasing moisture contents, depth of penetration decreases. Treatment number 2 is a 50% dilution of treatment number 1; in this case, therefore, dilution did not improve penetration.

From Table 4 it is seen that seven of the treatments have low RWT values (e.g. less than 131 g/m²/day) compared with the untreated control; one has a medium value and two have values approaching that of the control. Since the ability to allow water vapour to move freely out of treated concrete, enabling it to dry out, is one of the properties one looks for in a surface treatment for concrete affected by asr, some of the materials may appear to perform poorly in the light of the above results. However, if RVT/RWT is greater than one, the chances are good that a concrete will dry out to at least ambient relative humidity. Treatments giving RWT/RVT values greater than 2,27, the value for the control, will result in treated concrete being wetter than untreated concrete at the same environmental conditions. The results in Table 4, indicate that some surface treatments can result in concrete drying out. If this is indeed the case, then such surface treatments should effectively inhibit deleterious asr. The more promising ones are now being tested on specimens suffering asr in practice.

TABLE 4: Rate of water transmission (RWT), rate of vapour transmission (RVT) and both RVT/RWT and RWT/RVT values for the different treatments applied to mortar discs

| Property | Value for treatment number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| RWT, g/m²/d | 1554 | 61 | 80 | 104 | 1430 | 1302 | 131 | 108 | 122 | 85 | 690 |
| RVT, g/m²/d | 685 | 101 | 111 | 211 | 608 | 356 | 61 | 215 | 84 | 22 | 245 |
| RVT/RWT | 0,44 | 1,66 | 1,39 | 2,03 | 0,43 | 0,27 | 0,47 | 1,99 | 0,69 | 0,26 | 0,36 |
| RWT/RVT | 2,27 | 0,60 | 0,72 | 0,49 | 2,35 | 3,66 | 2,15 | 0,50 | 1,45 | 3,86 | 2,82 |

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