# LONG TERM MOVEMENTS DUE TO ALKALI-SILICA REACTION AND THEIR PREDICTION

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## ABSTRACT

Expansion test results are reported for concretes made with a range of original alkali contents, 3 to 8 kg/m$^3$, and prepared using a number of U.K. siliceous aggregates, all but one of which contained chert and flint. The concretes were subject to three exposure regimes: moist storage at 38 °C, moist storage at 20 °C and external exposure in the South East of the UK. The duration of exposure for the concrete prisms stored at 20 °C and the concrete blocks stored externally is approaching 7 years. Expansion test results are also reported for concrete cores taken, at an age of between 36 and 55 months, from a number of the blocks, both cracked and uncracked, and then stored moist at either 20 or 38 °C. The prediction, from accelerated tests on laboratory stored concrete prisms and cores, of the unrestrained expansion-age relationships for externally exposed concretes is briefly discussed.
*Keywords*: Alkali-silica reaction, expansion, core testing.

## INTRODUCTION

A previous paper (Hobbs, 1992), presented expansion data obtained up to an age of 36 months on a range of unreinforced concrete blocks stored externally, together with expansion data obtained on concrete prisms stored moist at 20°C and 38°C. The concretes had alkali contents in the range 3 to 8 kg/m$^3$ and were prepared using a number of UK siliceous aggregates. The monitoring of these samples has continued and the present paper includes expansion data obtained on these concretes up to an age of 84 months, together with expansion data obtained on cores taken from a number of the concrete blocks which were expanding due to ASR. These latter tests were carried out to check whether the future unrestrained expansion of concrete could be predicted from core expansion tests.

## EXPERIMENTAL DETAILS

The cement used was a Portland cement with an alkali content expressed as equivalent sodium oxide content of 1.00 per cent by mass. The 14 sands and coarse aggregates used in the programme are listed in Table 1. Further details relating to the materials employed are given in the previous paper (Hobbs, 1992). Prisms, 75 x 75 x 250 mm in size, and blocks, 200 x 250 x 500 mm in size, were prepared from most mixes with alkali contents in the range 3 to 8 kg/m$^3$. The prisms were stored moist at 20 °C or 38 °C and the concrete blocks were stored externally in the South East of the UK. Periodically the expansion of the prisms and blocks was monitored. Further details relating to the concretes tested and the storage conditions to which they were subjected are given in the previous paper (Hobbs, 1992)..

*Table 1: Location of the aggregates*

| | Aggregate |
|---|---|
| 1. | A Trent Valley sand |
| 2. | A Trent Valley coarse aggregate, from the same source as 1 |
| 3. | A siliceous sand, South West England |
| 4. | A coarse siliceous aggregate, South West, from the same source as 3 |
| 5. | A Mendip limestone, crushed fines |
| 6. | A Mendip limestone, crushed coarse, from the same source as 5 |
| 7. | A siliceous sand, Southern England |
| 8. | A Thames Valley sand |
| 9. | A sea dredged sand, Southern England |
| 10. | A crushed quartzite coarse aggregate, South West |
| 11. | A sharp siliceous sand, Southern England |
| 12. | A Thames Valley coarse aggregate, 20-10 mm |
| 13. | A Thames Valley coarse aggregate, 10-5 mm |
| 14. | A Thames Valley sand, from the same source as 13 and 12. |

At an age of between 36 to 55 months, cores, 75 mm diameter and 250 mm in length, were taken from a number of the concrete blocks stored externally. Sets of demec studs were fixed to each core to provide Demec gauge lengths in each of three rows at 120° to one another around the core. The cores were then covered to minimize moisture loss and stored in a laboratory maintained at 20 ± 1 °C. The gauge length used was 100 mm. The first demec gauge length measurements were made within 24 hours after the cores had been extracted. Each core was wrapped in a moist towel surrounded by a plastic sleeve and a small section of the sleeve and towel was removed to expose each demec stud. The wrapped prism was then placed in a plastic bag and stored in a sealed container in a room maintained at 20 ± 1 or 38 ± 1 °C. Periodically additional water was added to maintain the towel in a wet condition and the six gauge lengths on each core measured. Measurements were completed as quickly as possible and the wrapped cores replaced into their closed containers, which were then returned to the storage rooms.

## RESULTS: PRISMS AND BLOCKS

### Ages to abnormal expansion

The approximate ages at which abnormal expansion (~0.05%) commenced for each exposure condition are given in Table 2. No concretes with alkali contents below 4.8 kg/m$^3$ have exhibited abnormal expansion. For storage at 38 °C, the age to abnormal expansion ranged from 2 to 12 months, for storage at 20 °C from 8 to 45 months and for external storage from 18 to 60 months. An examination of Table 2 shows that the ages at which abnormal expansion commenced for concretes stored moist at 38 °C, stored moist at 20°C and exposed externally are approximately in the ratio 1:4:7 or 1:4:8 respectively in agreement with previously published work (Hobbs, 1993).

### Expansion

The three most deleterious aggregate combinations were (3,6), (8,6) and (11,6). The expansion results obtained on concretes, stored at 20 °C, containing two of these aggregate combinations are shown plotted in Figs. 1 and 2. On the basis of these results it can be concluded that, for the particular aggregate combinations tested in this study, an original alkali content of about 4.8 kg/m$^3$ is necessary for deleterious expansion to result from ASR.

The expansions of the concretes at ages of 9 months for concretes stored at 38 °C, 3 years for concretes stored at 20 °C and the expansion of the top face of the blocks at 5 years for concretes stored externally are compared in Table 2 (i.e. at ages in the ratio 1:4:6.7). The expansions of each concrete are broadly similar, indicating that the alkali-silica reaction rates for concrete subject to the three exposure conditions, are approximately in the ratio 7:4:1. This is illustrated further in Fig. 3 to 5 where

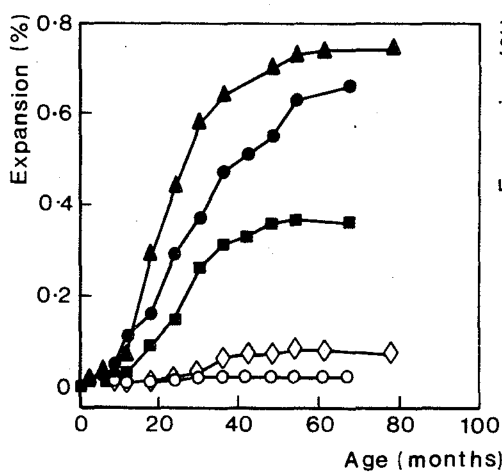



*Fig. 1 Relationship between expansion and age. 20 °C. Aggregate (3,6).*

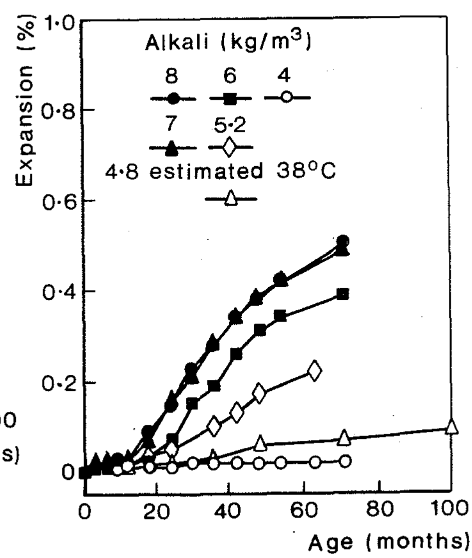
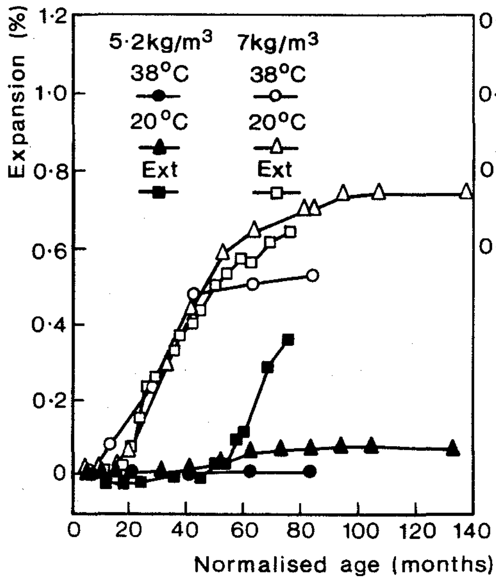



*Fig. 2 Relationship between expansion and age. 20 °C. Aggregate (8, 6).*

*Table 2: Expansions(%) at ages of 9 months (38°C prisms), 3 years (20°C prisms) and 5 years (external blocks) together with the approximate ages (months) to abnormal expansion. (uc = uncracked)*

| Aggregate combination | | Alkali content (kg/m³) and exposure 'temperature' | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.8 | 5.2 | | | 6.0 | | | 7.0 | | | 8.0 | | |
| Sand | Coarse | 38°C | 38°C | 20°C | Ext. | 38°C | 20°C | Ext. | 38°C | 20°C | Ext. | 38°C | 20°C | Ext. |
| 1 | 2 | - | 0.01 (uc) | 0.02 (uc) | 0.02 (uc) | 0.09 (7) | 0.15 (23) | 0.09 (52) | 0.16 (3.5) | 0.20 (18) | 0.13 (42) | 0.20 (3) | 0.21 (12) | 0.13 (26) |
| 1 | 6 | - | 0.02 (uc) | 0.03 (µc) | 0.01 (uc) | 0.03 (12) | 0.05 (36) | 0.08 (60) | 0.06 (7.5) | 0.09 (18) | 0.05 (56) | 0.06 (7.5) | 0.08 (18) | 0.09 (30) |
| 3 | 4 | - | 0.01 (uc) | 0.02 (uc) | -0.01 (uc) | - | | -0.03 (uc) | 0.02 (uc) | 0.03 (uc) | 0.03 (uc) | - | - | 0.03 (uc) |
| 3 | 6 | - | 0.01 (uc) | 0.06 (30) | 0.11 (54) | 0.21 (6) | 0.31 (14) | 0.46 (18) | 0.50 (2) | 0.64 (10) | 0.57 (18) | 0.28 (2.5) | 0.47 (8) | 0.59 (18) |
| 5 | 2 | - | 0.01 (uc) | 0.04 (45) | 0.01 (uc) | 0.03 (11.5) | 0.06 (30) | 0.06 (60) | 0.09 (4.5) | 0.13 (19) | 0.13 (50) | 0.03 (22) | 0.14 (12) | 0.14 (41) |
| 5 | 4 | - | - | - | - | - | - | - | 0.02 (uc) | 0.05 (uc) | - | - | - | - |
| 5 | 6 | - | - | - | - | - | - | - | 0.02 (uc) | 0.04 (uc) | 0.02 (uc) | - | - | - |
| 5 | 10 | - | 0.02 (uc) | 0.04 (uc) | 0.00 (uc) | 0.04 (12) | 0.05 (30) | 0.01 (uc) | 0.04 (uc) | 0.07 (18) | 0.02 (uc) | 0.04 (10) | 0.08 (10) | 0.03 (uc) |
| 7 | 6 | - | 0.02 (uc) | 0.03 (uc) | 0.01 (uc) | - | - | - | 0.04 (uc) | 0.06 (26) | 0.03 (40) | - | - | - |
| 8 | 6 | 0.03 (12) | 0.09 (7) | 0.10 (26) | 0.05 (59) | 0.26 (4.5) | 0.19 (21) | 0.26 (45) | 0.16 (4) | 0.28 (15) | 0.36 (28) | 0.32 (2) | 0.28 (13) | 0.32 (28) |
| 9 | 6 | 0.03 (uc at 26) | 0.04 (10) | 0.04 (uc) | 0.02 (uc) | 0.17 (3.5) | 0.17 (17.5) | 0.16 (44) | 0.23 (3.5) | 0.25 (13) | 0.23 (30) | 0.24 (3) | 0.24 (12) | 0.24 (36) |
| 11 | 6 | - | 0.02 (uc) | 0.04 (uc) | 0.01 (uc) | 0.09 (7) | 0.26 (18) | 0.29 (41?) | 0.30 (3) | 0.43 (12) | 0.34 (24) | 0.39 (3) | 0.48 (11.5) | 0.39 (24) |
| 14 | 12,13 | - | 0.02 (uc) | 0.03 (uc) | - | 0.02 (uc) | 0.03 (uc) | - | 0.02 (uc) | 0.06 (34) | - | 0.04 (uc) | 0.16 (21) | - |

expansion is shown plotted against normalized age for a number of the concretes prepared using aggregate combinations (3,6), (9,6) and (1,2), the assumption being made that the reaction rates, for the three exposure conditions, are in the ratio 7:4:1. In one instance the agreement is very poor (see Fig. 3). This poor agreement occurred at an alkali content of 5.2 kg/m$^3$ and is due in part to the high expansion occurring close to the trowelled face of the exposed end face of the block. If this expansion is excluded, then the mean expansion at 75 months falls from 0.36 to 0.24%. From Figs. 3 to 5 it can be seen or deduced that for concretes stored at 38 °C, 20 °C and externally, the ages at which expansion is largely complete are probably 9 to 15 months, 4 to 7 years and 8 to 15 years respectively.



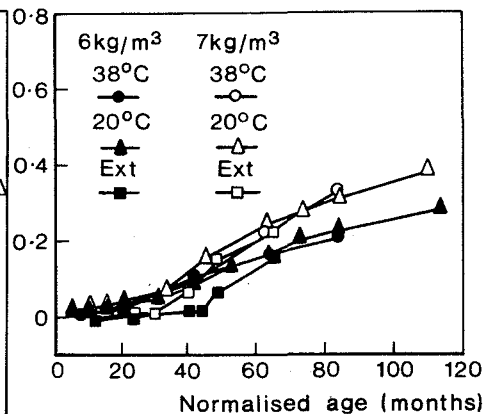
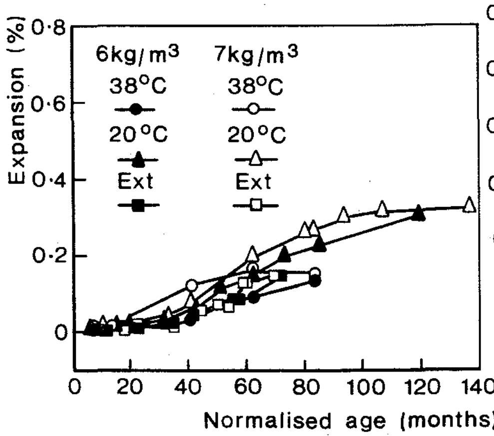




*Fig. 4 Relationship between expansion and normalized age. Aggregate (9, 6).*

*Fig. 3 Relationship between expansion and normalized age. Aggregate (3, 6).*



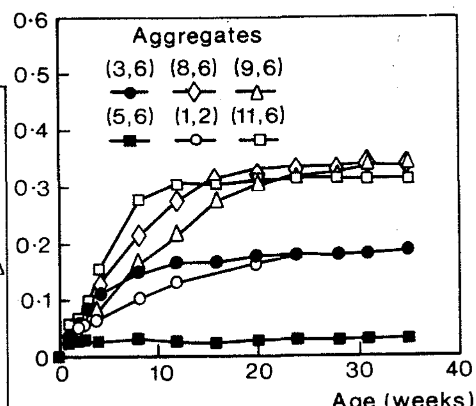




*Fig. 6 Comparison of core expansions. 38 °C. 7 kg/m$^3$.*

*Fig. 5 Relationship between expansion and normalized age. Aggregate (1, 2).*

## RESULTS: CORES

The mean expansion results obtained on cores taken from a number of the unreinforced blocks are shown plotted against test age in Figs. 6 to 8. In the case of the cores stored at 38 °C, no correction has been made for the thermal expansion induced by raising the core temperature from 20 to 38 °C (possibly 200 to 300 micro-strain). Monitoring of the cores stored at 20 °C and the blocks is continuing. An examination of Figs. 6 to 8 leads to the following observations:

1. At 38 °C, expansion is largely complete after 20 to 30 weeks. (Figs. 6 and 8).
2. Similar expansion is observed after 20 to 30 weeks storage at 38 °C and 90 to 100 weeks storage at 20 °C (Figs. 6 and 7).

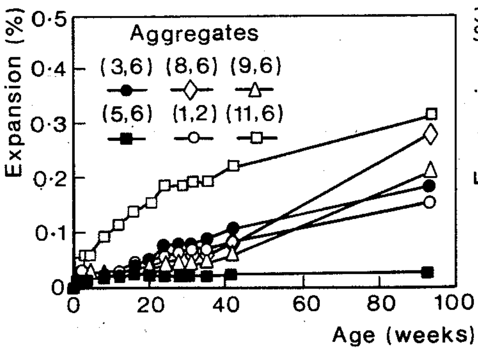



*Fig. 7 Comparison of core expansions. 20 °C. 7 kg/m³.*

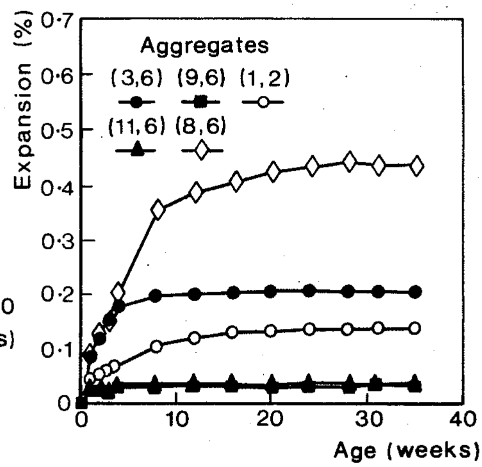



*Fig. 8 Comparison of core expansions. 38 °C. 5.2 kg/m³.*

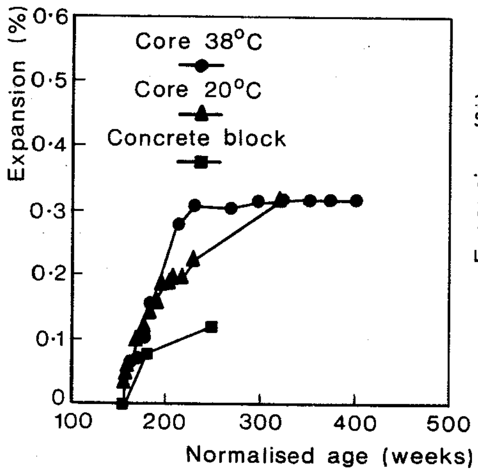



*Fig. 9 Expansion predicted from core testing and actual expansion. Aggregate (11, 6). 7 kg/m³.*

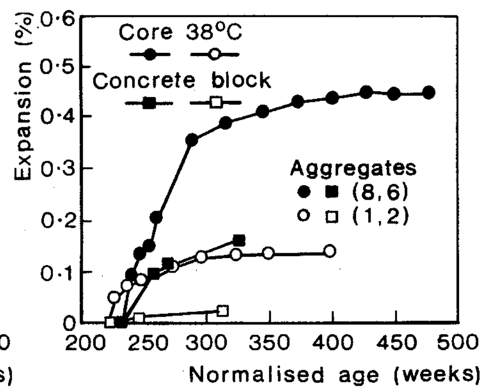



*Fig. 10 Expansion predicted from core testing and actual expansion. 5.2 kg/m³.*

## DISCUSSION

Assuming the rates of expansion for concretes stored moist at 38 °C, stored moist at 20 °C and exposed externally, are in the ratio 7:4:1, the test ages for the cores were normalized and the expansion compared with the expansion of the region of the block from which the cores were taken. Some of the comparisons are shown plotted in Figs. 9 and 10. It was found that the core expansions were substantially higher than the block expansions. In one instance the core exhibited abnormal expansion but the concrete block from which it was taken did not (Fig. 10). Two reasons may account for these disappointing results. Firstly, due to their higher surface area-volume ratio, the cores may have taken up more water than the blocks and secondly, the removal of the confining restraint may have allowed additional expansion to occur. This confining restraint is induced by the outer macro-cracked region of the blocks (Hobbs, 1988), and is removed when a core is taken.

When it was deduced that the normalized expansions were going to be substantially higher than those of the blocks from which they were taken, several blocks were selected for moist storage at 38 °C. Monitoring of these blocks has indicated substantially lower expansions than the relevant cores stored at 38 °C, indicating that removal of the confining restraint is probably the major factor resulting in enhanced expansion of the cores.

## CONCLUSIONS

The following conclusions are applicable to the particular aggregate combinations tested and to the data obtained to date:

1. The approximate age at which abnormal expansion due to ASR is induced for concretes stored at 38 °C, 20 °C and externally, are approximately in the ratio 1:4:7 respectively.
2. After expansion has been induced, the expansion rates for concretes stored at 38 °C, 20 °C and externally, are generally approximately in the ratio 7:4:1 respectively.
3. For concretes stored at 38 °C, 20 °C and externally, the ages at which expansion is largely complete are probably 9 to 15 months, 4 to 7 years and 8 to 15 years respectively.
4. The expansion monitored on cores stored moist at 38 °C and 20 °C can greatly over-estimate the unrestrained expansion of the concrete members from which they are taken.

## ACKNOWLEDGEMENTS

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