ALKALI AGGREGATE REACTIONS (AAR) IN NORWAY: THIN SECTION ANALYSIS AND EXPANSION MEASUREMENTS FROM A DAM AND A BRIDGE

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ABSTRACT

Two concrete structures with AAR have been investigated. The structures are a dam and a bridge, both approximately 30 years old. Both structures have a characteristic crack pattern on the surface of the concrete. Thin section analysis showed clear signs of AAR around aggregate particles consisting of quartzite, sandstone, and mehta rhyolite. To assess the remaining reaction potential of the concrete, expansion measurements were performed on drilled cores from the structures. The cores were stored in 40 °C and 100 % relative humidity. The results showed an initial swelling due to increased moisture content, but after that no expansion was measured up to 16 months. The implication of these results is that there is no more expansion potential in the concrete and consequently that repairs can be carried out. However, because of little experience with this method in Norway we feel there is a need for investigations with other methods as a supplement to these results.

KEY WORDS: concrete structures, deterioration, cracking, Alkali Aggregate Reaction (AAR), thin section analysis, rest reaction potential, expansion measurement, test methods

1 INTRODUCTION

Although reports on AAR have been made earlier in Norway /1/, it is only during the last 2 - 3 years that this area has received attention as far as increased research is concerned /2/, /3/, /4/, /5/, /6/. The present paper presents results from investigations of two concrete structures in South East Norway; a dam and a bridge both approximately 30 years old and damaged by deterioration due to AAR. The reactions have resulted in a characteristic crack pattern on the surface of the concrete.

The investigations were carried out to establish:

1) The cause of the damage
2) Whether the reaction has stopped so that repairs can be carried out.

The investigations have consisted of:

1) Thin section analysis
2) Expansion measurements on drilled cores

2 EXPERIMENTAL

2.1 Thin section analysis

Four thin sections were prepared from the dam and six thin sections from the bridge. Drilled cores from the structures were stored one week in 100 % relative humidity. The thin sections were then cut from areas of the cores with dark (moist) zones around aggregate particles. Visible moisture around aggregate particles indicate that there may be a hygroscopic reaction product (gel) from AAR.

The thin section analysis consisted of a qualitative investigation of:

- reaction products
- amount and width of cracks
- $Ca(OH)_2$ - content around aggregate particles
- identification of types of rocks assosiated with AAR

2.2 Expansion measurements

To assess the remaining reaction potential in the concrete and determine whether repairs may be carried out, expansion was measured on drilled out cores from the structures. The cores were drilled out and stored sealed for 1 month in the laboratory. Then knobs of stainless steel were attached to the cores with epoxy. The specimens where then stored in a chamber with 40 °C and 100 % relative humidity for 16 months. High temperature and moisture are expected to accelerate AAR. Six specimens of 7 - 13 year old laboratory made concrete with supposedly non-reactive aggregates were also stored in the chamber as reference specimens. All reference specimens were cylinders with diameter 100 mm and height 200 mm. Initial length measurements were performed on cold specimens.

Length change was measured with a length gauge with an accuracy of 0.001 mm at 0, 7, 42, 92, 140, 184, 267, 388 and 481 days (16 months). Weight was measured at the same time as length was measured. Length and weight were measured in a room with 50 % RF and 23 °C not more than 1/2 hour after the specimens were taken out of the chamber. In table 1 the number, diameter and length of the specimens are shown.

The moisture content and moisture history before the investigations started is unknown for all specimens. Also concrete compositions are unknown.

Table 1: Diameter and length of cores for expansion measurements.

Specimen	Diameter (mm)	Length (mm)
Dam 1	95	238
2	95	200
4	95	238
6	95	237
8	95	209
Bridge 1	85	238
2	85	238
3	85	214
4	85	236

In addition 6 reference sylinders of diameter 100 mm and height 200 mm were used.

3 RESULTS AND DISCUSSION

3.1 Thin sections

Gel from alkali aggregate reactions is seen in three of four sections from the dam, and in four of the sections taken from the bridge. Low Ca $(OH)_2$ content in some areas is observed in all thin sections.

Reactions in thin sections from the dam concrete seem to be connected with aggregate consisting of quartzite and metha rhyolite. Metha rhyolite and sandstone containing quartz seem to be responsible for the AAR in the bridge as well.

Qualitative results from thin section analysis of cracks, $Ca(OH)_2$ content, reaction products and types of rocks connected with AAR are summarized in table 2.

Table 2: Qualitative results from thin section analysis

	Dam	Bridge
Cracks	Several cracks observed in all sections. Size of cracks not measured. A few cracks are continous from the paste and through the aggregate, but most of the cracks are only in the paste.	Several cracks observed in all sections. Varying size of the cracks. The larger cracks have widths up to 0.5 mm, and the smaller cracks are less than 0.1 mm. Some of the cracks are continuous.
$Ca(OH)_2$	Areas with low content of $Ca(OH)_2$ are observed on all sections. These areas are around cracks and some places around aggregate particles.	Low $Ca(OH)_2$ content can be seen in parts of all sections.
Reaction products	In three of the four sections brown/yellow gel is observed in air voids. In one of these three sections all cracks are filled with the same type of gel. A picture of a typical reaction zone is shown in figure 1.	In four of the six sections reaction products are seen in cracks and air voids. The reaction products consist of ettringite and brown and colourless gel. Some cracks are observed in the gel, probably due to desiccation. An example is shown in figure 2.
Type of rocks connected with AAR	The gel seems to be connected to aggregate particles consisting mainly of quartzite and metha-rhyolite.	The gel seems to be connected mainly to aggregate particles of sandstone containing quartz and metha-rhyolite.

In figure 1 and 2 typical areas of the investigated concretes are shown.

Figure 1: AAR in the concrete from the dam. A continous crack is filled with gel.

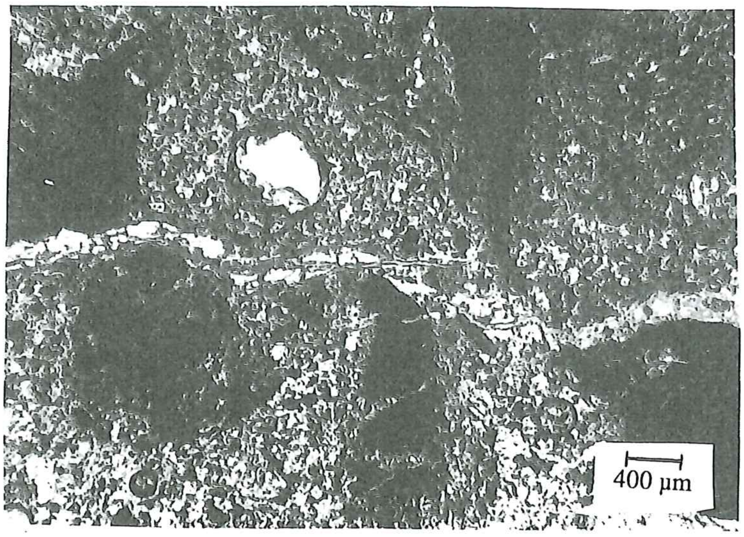
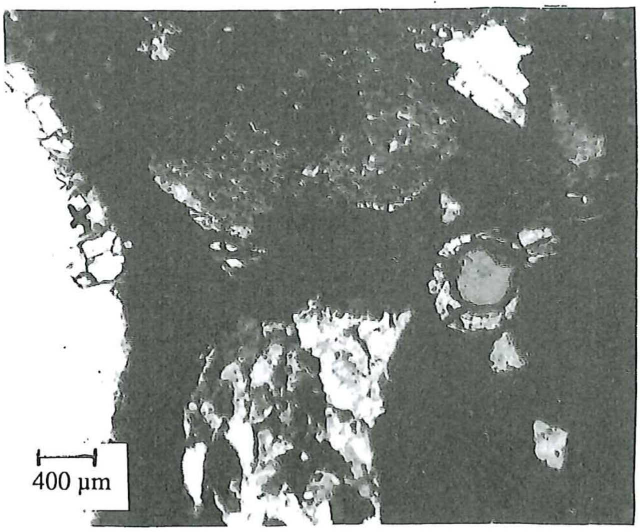


Figure 2: AAR in the concrete from the bridge. Gel from the AAR can be seen in two air voids and in a crack.



The observations on thin sections show that both concrete structures are deteriorated due to AAR. It is not possible from the observations on the thin sections to determine whether the reaction has stopped or will continue and lead to more cracks and expansion.

3.2 Expansion measurements

Expansion measurements are shown in figure 3 and in table 3. In figure 4 weight measurements are shown.

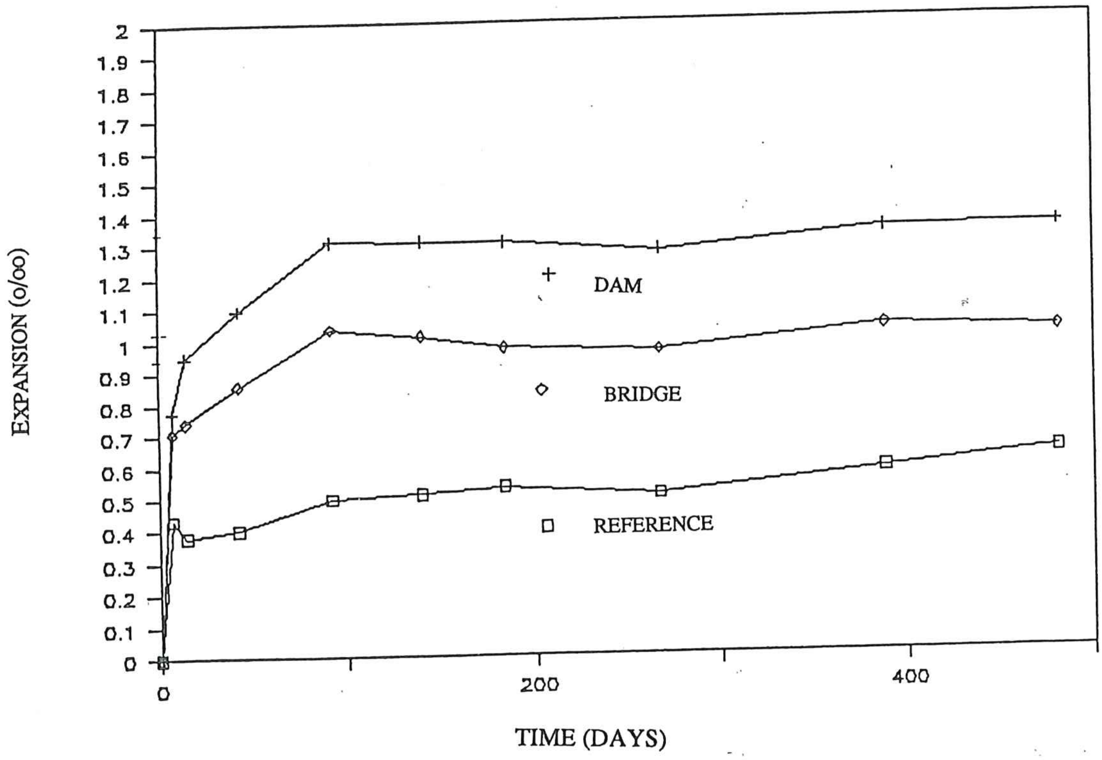


Figure 3: Expansion - time measurements, mean values for the dam, the bridge and the reference samples.

Table 3: Expansion, results for each specimen and mean values. (o/oo)

Spec.	Time of exposure (days)								
	7	14	42	92	140	184	267	338	481
Ref 1	0.39	0.33	0.37	0.47	0.53	0.52	0.50	0.57	0.60
2	0.43	0.38	0.43	0.51	0.60	0.65	0.61	0.76	0.88
3	0.38	0.31	0.33	0.45	0.42	0.47	0.43	0.46	0.48
4	0.43	0.34	0.37	0.46	0.47	0.46	0.47	0.51	0.50
5	0.47	0.43	0.41	0.50	0.50	0.47	0.48	0.53	0.70
6	0.50	0.48	0.50	0.60	0.53	0.60	0.52	0.61	0.61
mean	0.43	0.38	0.40	0.50	0.51	0.53	0.50	0.57	0.63
Dam 1	0.67	0.70	0.94	1.26	1.27	1.28	1.24	1.27	1.29
2	0.98	1.70	1.64	1.73	1.70	1.70	1.70	1.79	1.83
4	0.58	0.58	0.74	0.91	0.91	0.94	0.91	0.93	0.94
6	0.72	0.76	1.01	1.31	1.33	1.29	1.30	1.27	1.33
8	0.91	1.00	1.16	1.35	1.34	1.31	1.22	1.42	1.33
mean	0.77	0.95	1.10	1.31	1.31	1.30	1.27	1.34	1.34
Brdg 1	0.53	0.61	0.88	1.14	1.21	1.13	1.13	1.11	1.17
2	0.76	0.76	0.91	1.13	1.10	1.11	1.08	1.11	1.11
3	0.65	0.65	0.65	0.76	0.72	0.64	0.59	0.76	0.71
4	0.88	0.94	0.99	1.11	1.01	1.00	1.02	1.13	1.06
mean	0.71	0.74	0.86	1.04	1.01	0.97	0.96	1.03	1.01

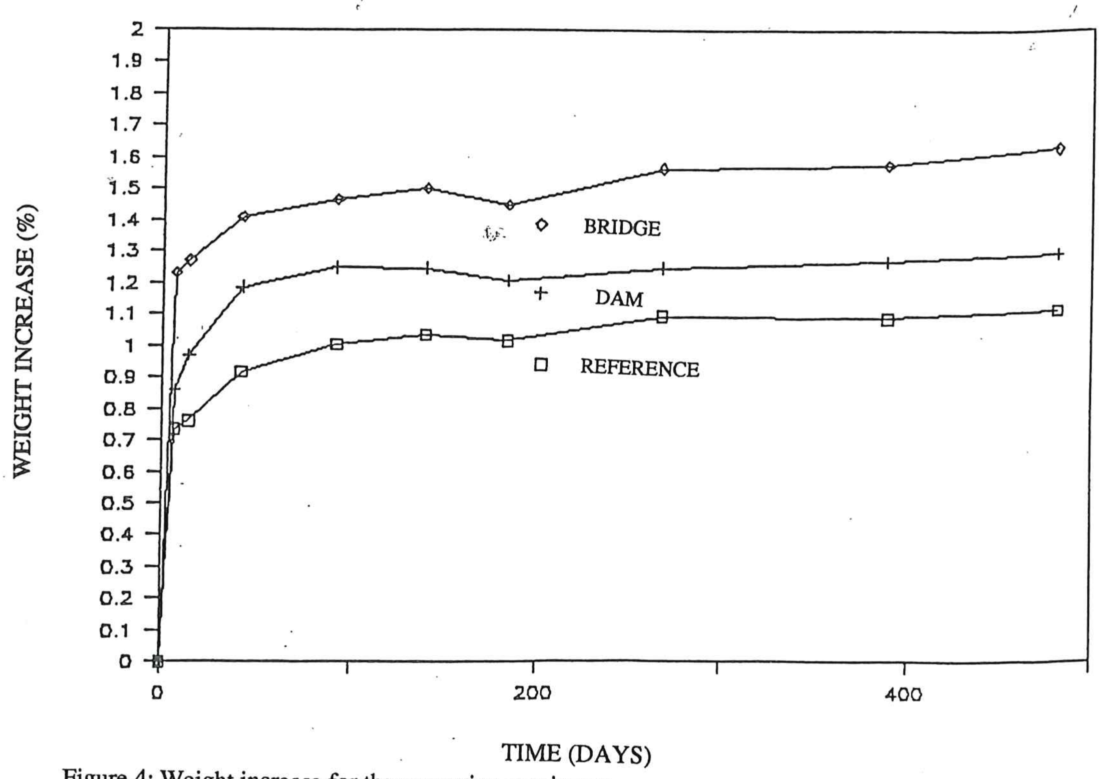


Figure 4: Weight increase for the expansion specimens

All specimens have a high initial expansion. However, after 92 days (3 months) hardly any expansion is registered for any of the series. The deviations between companion specimens are quite high, but as can be seen from table 3 each single specimen has a time-expansion relationship which follows a steady course without sudden increase or decrease. The results therefore give no reason to say that the exspansion increases from 3 to 16 months.

Expansion can be due to:

1) Alkali Aggregate Reactions (AAR)
2) Moisture uptake - swelling
3) Thermal expansion

AAR:

AAR would most likely lead to a steady increase in length as long as the reaction is continuing. After 3 months hardly any expansion is registered and this implicates that no AAR has taken place in this period. No signs of reaction (gel, further cracking) were observed in the test period.

Swelling:

By comparing figure 3 and 4 it can be seen that the initial expansion can be associated with the increase in weight due to moisture uptake. The individual differences in expansion between companion specimens and between the dam, the bridge and the reference samples are most likely due to different amounts of cement paste in the samples. The maximum aggregate size in the concrete from the dam and the bridge is 35 - 40 mm. This large aggregate size compared to the size of the specimens, results in an uneven distribution of aggregate and cement paste between the cores. This in turn leads to differences in moisture uptake. The reference specimens have a maximum aggregate size of 16 mm. Therefore the aggregate particles are more evenly distributed in the reference specimens. The deviation in length change between companion reference specimens is smaller than between companion dam and bridge specimens. In further tests the size of the drilled out cores from concrete structures with maximum aggregate sizes of 35 - 40 mm should have a diameter of 150 mm.

Also differences in cement content, W/C-ratio and initial moisture contents would lead to different expansions. These parametres are unknown and probably different for all three concretes.

Temperature expansion:

In addition to the swelling caused by moisture uptake, temperature has caused some of the initial expansion. This contribution is estimated to be maximum 0.3 o/oo.

4 CONCLUSIONS

Thin section analysis show clear signs of AAR. These are:

- Cracks and air voids filled with an amorphous gel.
- Areas of the concrete with reduced $Ca(OH)_2$ content (around cracks and aggregate particles)
- The reactions seem to be connected to aggregate particles consisting of sandstone, quartzite and metha rhyolite

Measurements of expansion on drilled cores from the structures show an initial expansion (3 months) due to moisture uptake and temperature increase. From 3 to 16 months hardly any expansion was measured. The implication of this result is that the alkali aggregate reactions have stopped and consequently that repairs can be carried out. However due to little experience with this method with Norwegian types of rocks (altered, Caledonian) we feel there is a need for other test methods to measure rest reaction potential as a supplement to the present results.

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