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POP-OUTS DUE TO ALKALI-SILICA REACTIONS - A MOISTURE PROBLEM?

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SYNOPSIS

Problems attributable to the alkali-silica reaction in Sweden are new and occur as pop-outs on certain structures, mainly concrete floors on the ground. The problems turn out to be linked to the presence of moisture since no pop-outs at all have been reported on out-door structures but only on 'moist indoor structures', that have had a history of moisture change.

A research project is now underway and investigations have so far concentrated on attempts to reproduce pop-outs in the laboratory, mainly through the control of climatic conditions.

SAMEVATTING

Probleme in Swede wat aan alkali-silikareaksie gewyt kan word is nuut en kom in die vorm van skietblasies op sekere strukture voor en hoofsaaklik in betonvloere op die grond. Die probleme blyk aan die teenwoordigheid van vog gekoppel te wees aangesien glad geen skietsblasies aan buitestrukture aangeteken is nie en slegs aan 'klam binnestrukture' wat 'n geskiedenis van vogverandering het.

'n Navorsingsprojek is tans aan die gang en ondersoeke is tot dusver toegespits op pogings om, hoofsaaklik deur die beheer van klimaatstoestande, skietblasies in die laboratorium na te maak.

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1. INTRODUCTION

Problems due to alkali-silica reactions (ASR) in Sweden are new and coincide with the introduction of a high-alkali cement in the south of Sweden where the aggregate contains reactive grains of opaline flint and sandstone. The problems occur only as pop-outs on certain structures and turn out to be very much a moisture problem since no pop-outs are known on outdoor structures even if they are wet. Problems only occur on 'moist indoor structures', that have had a history of moisture changes. In Figure 1 the most frequently affected structure is shown with its 'moisture history' indicated. More than 9 out of 10 problems with pop-outs due to the ASR are found on such structures.

A research project has recently been started to acquire enough knowledge about the ASR to be able to control it in the future.

The objectives of this project can be listed under three headings:

(i) Explain the cause and mechanism of pop-out damage.
(ii) Investigate the role played by moisture in the alkali-silica reaction.
(iii) Develop methods for testing concrete and test some inhibitors.

The experimental investigations have so far been concentrated on attempts to reproduce pop-outs in the laboratory, mainly by controlled climatic conditions. Some of the early results of these experiments are shown in this paper.

2. THEORETICAL DISCUSSION OF THE INFLUENCE OF MOISTURE

Moisture participates in many ways in the mechanism of the alkali-silica reaction, the swelling pressure generated causing over-all expansion and pop-outs. Water is a *solvent* for the dissolved ions taking part in the reaction. The ability of adsorbed water to act as a solvent is questionable as it has a thickness of just a few molecules. The capillary condensed water, usually with a negative pressure, can however act as a solvent. This means that not all the water in concrete acts as a solvent and that a diminishing moisture content results in an increasing alkali concentration. If the concentration in capillary saturated concrete is expressed as $[N^+_e]_{100}$, where 100 means 100 per cent RH (and assuming that all of the moisture in concrete is supposed to be a solvent) the concentration can vary with the pore humidity as in the example in Figure 2, based on data from

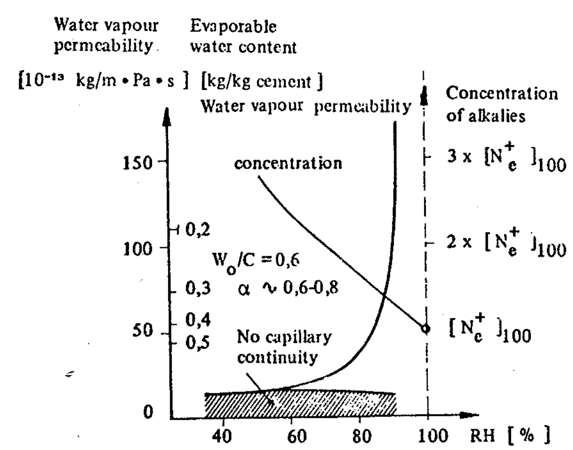

FIGURE 2 : Examples of the influence of moisture on some factors participating in the alkali-silica *reaction*. Data from Nilsson (1980).

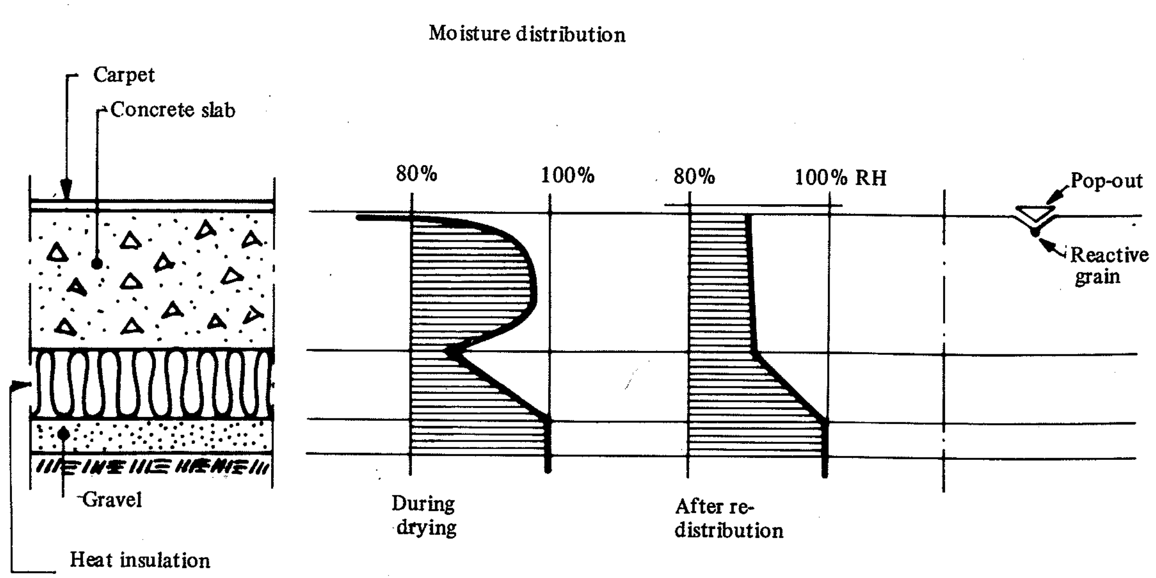

FIGURE 1 : Typical floor structure and moisture distribution of a concrete slab laid directly in the ground

'Slite Std-79', with an equivalent alkali content of 1,04 per cent. The aggregate was from 'Hassle-Bösarp' and contained 5-10 per cent opaline flint and sandstone in the fraction 1-16 mm. Both mortar and concrete specimens were mixed with w_0/c = 0,7 and aggregate/cement-ratio of 3,8. The surface was floated after a couple of hours and then steel trowelled. After curing at 20 °C, the specimens were dried under various conditions in a climate chamber at 20 °C. Finally the specimens were rewetted usually in two different ways. A generalised moisture history is shown in Figure 5.

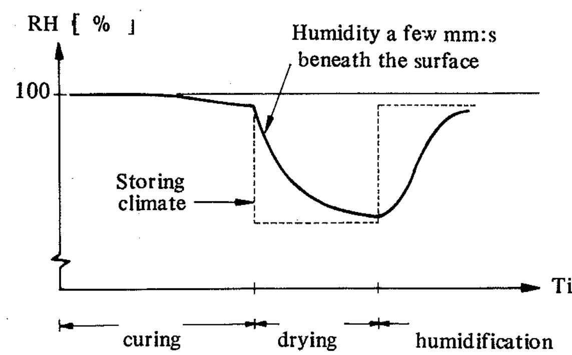

FIGURE 5: Approximate 'moisture history' for reactive grains close to the surface and the storing climate of the specimens

The moisture history of each specimen is shown in Tables 1 - 3 together with the results expressed in terms of the number and size of the pop-outs obtained. Figure 6 shows a specimen, sealed and cured for 16 weeks.

The number of reactive grains close to the surface is indicated by the gel extrusions.

The results can be summarized as follows. Storing under perfectly sealed or wet conditions gives a lot of gel extrusions but no pop-outs. A large amount of gel is produced as a result of the ASR, but the gel has too low a viscosity to affect the surrounding mortar. The gel instead penetrates the cement mortar as seen in Figure 6. In some cases the samples have not been perfectly sealed during curing and occasionally small pop-outs have been created.

Most of the pop-outs have occurred on specimens that have been dried at very high humidities, over 80 per cent RH. Pop-outs on specimens dried under somewhat lower humidity occur only after a rather protracted humidification when more gel is probably produced.

The moisture change regimes used in these experiments have, however, not given reproducible results. The mechanical properties of the surface, and the depth of the reactive grains, are probably not the same in each series due to differences in surface treatment. This means that dif-

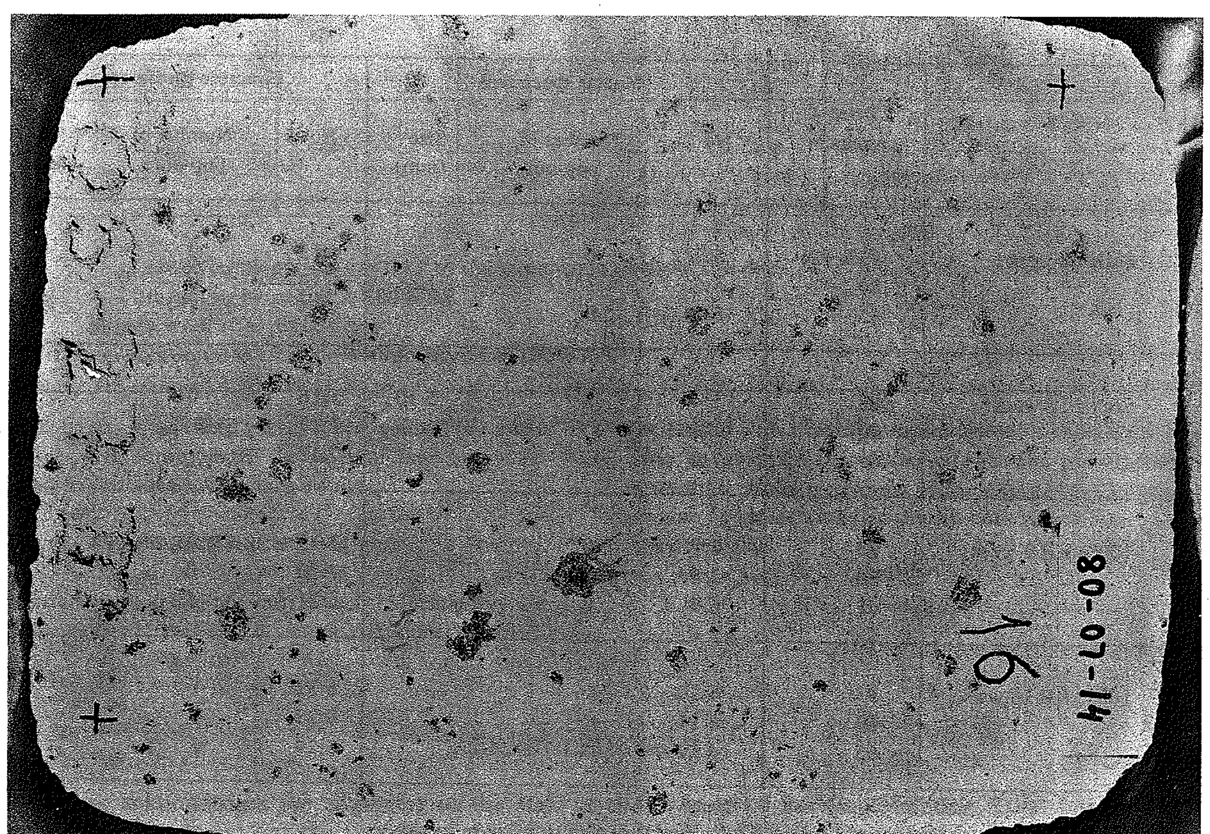

FIGURE 6 : Surface of a 200 mm x 300 mm specimen sealed and cured for 16 weeks, showing no pop-outs whatsoever but many gel extrusions

Nilsson[1]. If, as is more likely, only the capillary condensed water acts as a solvent, the concentration increase will be even greater than indicated in Figure 2.

Water is also a *transport medium* for the dissolved ions. The flow of water is affected by the pore humidity as shown in the example in Figure 2, indicating a very slow moisture transport by diffusion at lower humidities and an increasing flow rate with increasing humidity due to an increasing capillary continuity in the liquid phase. The flow of water, of course, causes an increase in the transport of dissolved ions, but the moisture flow in the form of diffusion at lower humidities acts as a 'capillary break', ie an *obstacle* to such transport. This is also what happens when no moisture flow takes place. The diffusion of ions in water is prevented at low humidities when no continuous liquid phase is present. Increasing humidity means an increasing number of paths for such flow.

The flow of water containing dissolved ions results also in an increasing alkali concentration at the evaporation zone where the ions in the liquid flow are deposited when the moisture flow continues as diffusion. A very high concentration increase is possible due to this effect, cf Nixon et al[2].

The *swelling* of the gel is affected by the surrounding pore humidity. Krogh[3] measured the absorption of water by synthetic gels and indicated a critical moisture condition in this respect of about 90 per cent RH. The gels act in the same way as a hygroscopic salt, cf Figure 3.

The damage caused by the swelling of the gel is also affected by moisture as it affects the viscosity of the gel, cf

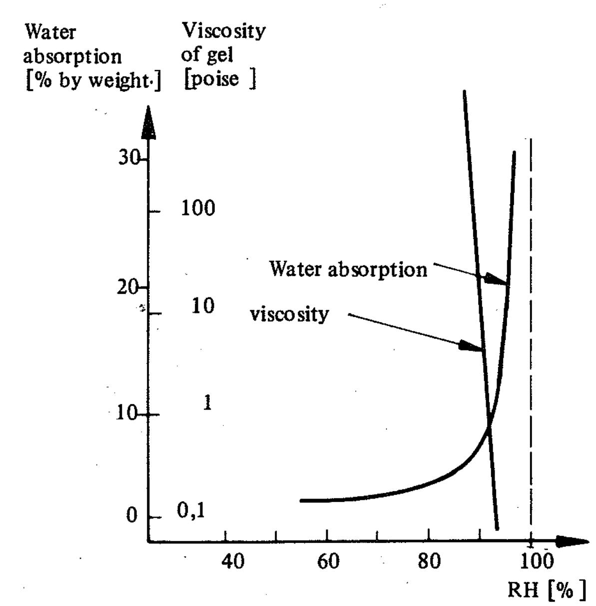

FIGURE 3: Examples of the influence of moisture conditions on the behaviour of an alkali-silica gel; absorption data from Krogh[3] and approximate viscosity data from Moore[4].

Moore[4] and Figure 3. A very small increase in the humidity of the gel may cause a decrease in viscosity which may in turn allow the gel to penetrate the surrounding cement matrix without causing any expansion.

The resulting moisture dependence of expansion due to the ASR has been determined in one case by Lenzner & Ludwig[5] and their results are shown in Figure 4. These indicate a critical moisture condition of about 85 per cent RH for the composition used.

The results shown in Figure 4, also indicate the amplified effect of moisture *changes*. Drying followed by re-exposure to a humidity above this critical value, causes greater expansion than storing continuously at the higher humidity. Similar results have been reported by researchers such as Hobbs[6].

The moisture condition affects the *reaction* and the *swelling pressure*, generated by the gel, in different ways. The critical moisture condition for the reaction to continue seems to be lower than the critical moisture condition for obtaining the maximum swelling pressure. The correct humidity close to a reactive grain can therefore result in the production of a rather dry gel with high viscosity. Subsequent humidification can then create a very high swelling pressure. In attempts to reproduce pop-outs experimentally, the aim has been to make use of this mechanism.

3. EXPERIMENTAL

Pop-outs, have been made experimentally by using a concrete composition close to that used in practice and exposing the surface to a standardised series of climatic conditions.

Mortar and concrete specimens, 0,35 x 0,25 m and 8 cm thick, have been made using a high-alkali Portland cement,

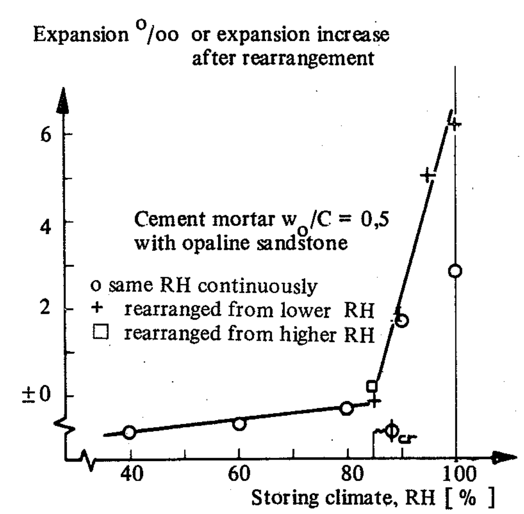

FIGURE 4: Effect of atmospheric humidity on expansion due to the alkali-silica reaction; data from Lenzner & Ludwig[5].

TABLE 3 : Specimens, series 8-11, cured 1 week (series 8 in 95-100% RH, series 9-11 sealed) dried in different climates and humidified in two different ways

Drying climate 1st week	Drying climate 2nd-5th	Rewetting	Mortar specimens No	Mortar Number of pop-outs	Mortar Size (mm)	Concrete specimens No	Concrete Number of pop-outs	Concrete Size (mm)
93% RH	80% RH	W+100% RH	8:1	0		8:13	0	
			9:7	10*)	5-10	9:19	2*)	5-8
			11:1	0		11:13	0	
80	65	W+100	8:2	0		8:14	0	
			9:8	0		9:20	0	
			11:2	0		11:14	0	
65	65	W+100	8:3	0		8:15	0	
			10:9	0		10:21	0	
			11:3	0		11:15	0	
93	80	100	8:4	1	7	8:16	0	
			10:10	9	3-10	10:22	6	5-7
			11:4	2	4-7	11:16	0	
80	65	100	9:5	0		9:17	0	
			10:11	9	3-10	10:23	3	4-7
65	65	100	9:6	3	4-7	9:18	0	
			10:12	5x)	4-10	10:24	1x)	5

W = rewetting by putting one third of the specimen in water for one day
100 = rewetting by storing in 100% RH
*) within a week after rewetting
x) pop-outs occurred after > 4 weeks storing in 100% RH

ferent levels of swelling pressure are needed to create pop-outs and consequently the reaction time before rewetting has not always been long enough.

4. FURTHER RESEARCH

The attempts to create pop-outs in a reproducible way are continuing with the use of other 'moisture histories'. Correlation with expansion measurements is being done in order to quantify the various effects. The participation of moisture in the mechanism of the ASR and the swelling pressure generated, is being studied both theoretically and experimentally.

ACKNOWLEDGEMENT

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TABLE 1 : Specimens, series 2-4 with different 'moisture histories'

Curing	Drying	Rewetting climate	Specimen	Number of pop-outs	Size (mm)
Sealed 1 week 95-100% RH 1 week	85% RH for 8 weeks	100% RH	2:1 mortar	$\sim$ 20x)	4-15
			2:2 concrete	$\sim$20x)	4-15
		93	2:3 mortar	$\sim$ 7x)	4-10
			2:4 concrete	$\sim$10x)	5-10
Sealed (not perfect) for 12 weeks	65% RH for 4 weeks	W+100% RH	3:1 mortar	3*)	7-15
			3:2 concrete	6*)	5-10
	93% RH for 4 weeks	W+100% RH	3:3 mortar	4*)	4-10
			3:4 concrete	4*)	4-15
95-100% RH for 3 weeks		condensation, then sealed	4:1 concrete	7	4-20

x) some smaller pop-outs occurred during drying
*) some smaller pop-outs occurred during curing
W = Rewetting by putting one third of the specimen in water for one day.

TABLE 2 : Specimens, series 5-7, with different curing conditions and drying climates. Rewetting by putting one third of the specimen in water for one day and then storing in 100% RH

Curing	Dried 4 weeks in	Mortar specimens No	Mortar Number of pop-outs	Mortar Size (mm)	Concrete specimens No	Concrete Number of pop-outs	Concrete Size (mm)
Sealed 8 weeks	93% RH	5:1	0		5:13	0	
	80	5:2	1x)	12	5:14	0	
	65	5:3	0		5:15	1x)	8
Sealed 16 weeks	93	5:4	2*)	5-10	5:16	0	
	80	7:5	-)		7:17	-)	
	65	7:6	-)		7:18	-)	
100% RH 8 weeks	93	7:7	0		7:19	0	
	80	7:8	0		7:20	0	
	65	6:9	0		6:21	0	
100% RH 16 weeks	93	6:10	-)		6:22	-)	
	80	6:11	-)		6:23	-)	
	65	6:12	-)		6:24	-)	

*) one small pop-out occurred during curing; the other directly after rewetting
-) not yet humidified
x) pop-outs occurred after $\sim$ 6 weeks storing in 100% RH

DISCUSSION

Mr R T L Allen (C & CA London) asked Prof Nilsson whether the reactive aggregate particles had been distributed throughout the size grading and whether pop-outs in the field were associated only with the larger particles. Did they occur in slabs that were not covered with carpet or vinyl, and was there any cracking.

Prof L-O Nilsson replied that he had not yet seen any cracks in Sweden. The pop-outs that occurred in practice varied greatly in size and were associated with particles that ranged from 2 mm to more than 8 mm in diameter. For the most part it was structures such as concrete floors that were covered with some vapour-tight floor covering, that were affected but they had had cases where pop-outs from kitchen ceilings, some of them rather large, had dropped onto the occupants.

Dr G Idorn (Denmark) said that pop-outs similar to those demonstated by Prof Nilsson were a common phenomenon in structural cases of the alkali-silica reaction in Denmark. They were associated with large aggregates and porous flint. Danish experience was that such pop-outs occurred in precast, steam-cured, concrete during the first day of curing.

Pop-outs in exposed concrete structures might be caused by freezing and thawing but were probably the result of a combination of factors.

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