product produced from a reacting aggregate particle at an early stage of reaction is very small, virtually all of the swelling pozzolan particle becomes deformable at an early stage and can be dissipated into spaces in the surrounding hydrated cement paste without unduly stressing or expanding the concrete.

The alkali-silica complexes are potentially unstable and are capable of reacting with additional alkalis. Their capacity to react with additional amounts of alkalis ensures that pozzolans and pozzolan reaction products will continue to protect reactive aggregate particles from undue reaction. Reactive aggregate therefore in the presence of pozzolan remains in an arrested reaction condition. It is most unlikely that alkalis in sufficiently large amounts could penetrate into concrete and cause a deleterious aggregate reaction.

Penetration of water or water vapour into concrete can occur but will tend to transform reaction product on the surfaces of reacted particles into deformable gel or sol which can dissipate, without causing undue concrete distress, into spaces in the surrounding cement paste. While large amounts of absorbed water increase the swelling of reacted aggregate and in turn increase concrete expansion, the presence of excess water promotes reaction product dispersion and sol formation. Dissipation of sol into spaces in the cement paste brings the alkali-silica complex into contact with calcium hydroxide and may promote the formation of calcium hydroxide-alkali hydroxide-silica reaction products which do not absorb water and cause concrete expansion but may improve strength and cement paste permeability. Such pozzolanic reaction processes could therefore assist in explaining the beneficial effects of pozzolans on the performance of blended cements.

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SORPTION PROPERTIES OF CONCRETE
WITH ALKALI-SILICA REACTIVE AGGREGATE

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ABSTRACT

The moisture binding capacity of concrete with alkali-silica reactive aggregate is discussed. The discussion includes practical measurements in a swimming pool wall. It is concluded that it is reasonable to suggest that the creation of alkali-silica-gel contributes to the selfdesiccation of the concrete.

Keywords: Moisture, relative humidity, measurements, alkali-silica-gel.

1. INTRODUCTION

Moisture analysis is an important tool to use in making a diagnosis of the damages in a structure, as water is necessary in most deterioration processes, including the alkali-silica reaction (a.s.r) /1/. In such an analysis it is necessary to know, which moisture level can be expected in a sound undamaged structure. This problem is treated below.

The principal idea in the treatment is that concrete curing without exchange of water with the surroundings dries due to the chemical reactions to a certain degree. This selfdesiccation is well known in connection with the cement hydration. But the chemical reactions also include a.s.gel, which has two effects. Firstly the amount of evaporable water is reduced as the gel contains some non-evaporable water /3/. Secondly the gel will contribute to the hygroscopic binding capacity of the concrete, so that the sorption curves will lie higher than those for a concrete without a.s.gel.

Concerning the concepts shortly: The sorption diagram shows the equilibrium water content by weight as a function of the relative humidity in surroundings. The material is able to contain more water, when it has dried out to the equilibrium state (desorption), than when it has taken up water to the same relative humidity (adsorption). It is only the desorption curves which are treated here. (The adsorption isotherms are previously treated in /2/).

In the following the calculation of the desorption curve of a concrete is discussed and the selfdesiccation effect of a concrete with a.s.gel is shown by an example.

*) From 1983-09-01: Building Materials Laboratory, Technical University, Lyngby, Denmark.

2. CONCRETE DESORPTION ISOTHERM

Hygroscopically bound water in concrete is hold by the cement paste, by the aggregate and, if it is present, by the a.s.gel, cf. fig. 1.

At each value of the relative humidity the water content may be expressed as

$$u_{concrete} = u_{cement\ paste} + u_{aggregate} + u_{a.s.gel} \tag{1}$$

where the letter u stands for the water content by weight.

2.1 Cement paste

The contribution to the desorption curve from the cement paste can be calculated on the basis of desorption isotherms measured by Pihlajavaara (fig. 2) in the following way.

The u_c^1-values are found on the curve for the w/c-ratio in question.

For each RH-value the moisture content by weight is calculated as

$$u_{cement\ paste} = u_c^1 \cdot \frac{C}{\rho} \tag{2}$$

where C is the amount of cement per m^3 and ρ is the dry density of the concrete.

2.2 Aggregate

Porous aggregates contribute to the water binding capacity. It may be practical to distinguish between fine and coarse aggregate. The contribution to the water content of the concrete is given by

$$u_{aggregate} = \frac{1}{\rho} (u_{sa}^1 \cdot Sa + u_{st}^1 \cdot St) \tag{3}$$

where u_{sa}^1 and u_{st}^1 are the ordinates of the desorption curve of the fine and the coarse aggregate, respectively, and Sa and St is the content of fine and coarse aggregate, respectively, in kg/m^3. Fig. 3 shows as an example a desorption curve of a fine aggregate.

2.3 The alkali-silica-gel

The contribution of the a.s.gel to the water binding capacity may principally be calculated as

$$u_{a.s.gel} = \frac{u_{a.s.gel}^1 \cdot G}{\rho} \tag{4}$$

where $u_{a.s.gel}^1$ is the ordinates of the desorption curve of the a.s.gel and G is the amount of a.s.gel in the concrete in kg/m^3. Meanwhile, these quantities are both unknown. They are both dependent on the amount of alkali, the amount of reactive material and the internal stress situation.

Our present knowledge of the composition of a.s.gel (e.g. /3/ and /5/) does not give any rule of how much gel is created under certain circumstances. Neither can anything about the water binding capacity be found in the literature. The adsorption properties of synthetic gels are studied in /5/, but these results can not be used in the present work, because the compositions of the gels are different from practical ones, because adsorption and not desorption is studied and last, but not least, because the adsorption curves are measured in free swelling.

Fig. 1. Principal sketch of the desorption isotherm of concrete showing contribution from cement paste, aggregate and alkali-silica-gel.
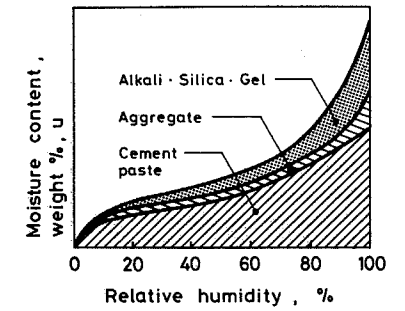

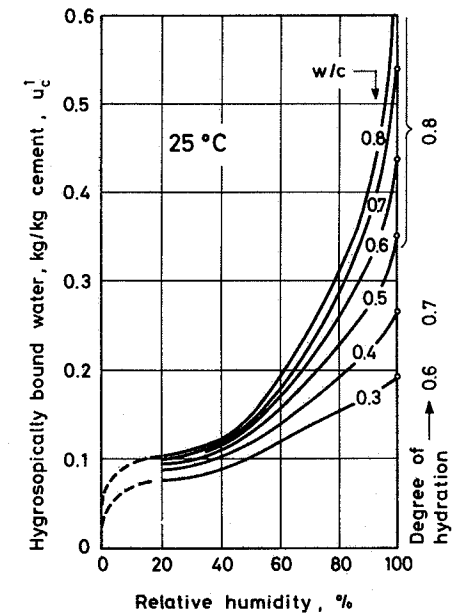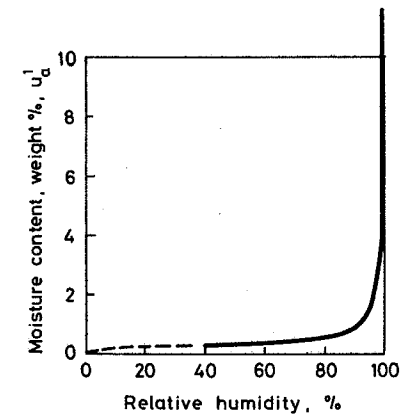Fig. 2. Desorption curves of cement paste in concrete acc. to Pihlajavaara and /6/.

Fig. 3. Desorption curve of fine aggregate (0-8 mm) containing 5-15% reactive particles. Nymølle 1983.

The internal stress situation is very important for the water uptake of the gel. In the same way as a sponge surrounded by a rubber band will not be able to absorb as much water as a sponge without rubber band, so an a.s.gel swelling in an uncracked concrete will not take up as much water as an a.s.gel in a cracked concrete. In wood science this is previously studied /4/, but within the concrete research this field is completely untreated.

In the example below values of the $u_{a.s.gel}$ have been judged to fit to measurements taken on uncracked concrete.

3. MEASUREMENTS

A swimming pool constructed in 1978 started to crack on certain spots in 1982 due to a.s.r. As part of the investigations in this connection an undamaged part of the pool wall was examined. The examination was made 4 years after the concreting. On samples cut out dry the relative humidity in the pores and the moisture concent by weight, u, were measured /1/. The results are shown in fig. 4.

The rather big scatter of the u-values is due to the rather small samples. The RH-results are rather high on the water side of the wall due to water diffusion. The curve has a very distinct plateau between layer 4 and 7. Calculations show that this plateau can not be explained as drying out towards the gallery. It must be understood as a result of the selfdesiccation of the concrete. The effect of drying is seen only in the outermost 50 mm of the wall.

In fig. 5 connected values of u and RH are shown. The mean value and the scatter of u and RH for the plateau between layer 4 og 7 are calculated and shown as a single area in the diagram. This point is especially important as 0,613 kg of concrete enters the calculation og the u-value.

In fig. 5 also the desorption contributions of the cement paste and the fine aggregate for this very concrete are shown. The distance from the resultant curve of these two constituents to the measured points must be interpreted as the effect of the alkali-silica-gel. It is seen that the gel contribution, dependent on the RH-value is about 25% to 100% of the cement paste contribution.

The amount of a.s.gel in the process may be guessed in the present case:

The concrete in the layers 4 to 7, which may be considered as seal cured are treated. The measured mean value here is u_{4-7} = 4,1%. The dry density of the concrete is ρ = 2240 kg/m³, i.e. that the evaporable water is w_e = $\rho \cdot u$ = 2240 · 0,041 = 92 kg/m³.

The cement content is said to be C = 300 kg/m³. With a degree of hydration of α = 80% this cement will bind chemically w_n = C · α · 0,25 = 300 · 0,8 · 0,25 = 60 kg/m³.

The w/c is measured microscopically according to the routine on the TI-laboratory to w/c = 0,45. So the added water has been at least w_c = C · (w/c) = 300 · 0,45 = 135 kg/m³. The water bound in the aggregate at mixing may have been w_a = 35 kg/m³.

The following balance can be made:

Water at mixing, added	w_c = 135	
Water at mixing, in aggr.	w_n = 35	170 kg/m³
Non-evaporable in cement	w_n = 60	
Evaporable, measured,	w_e = 92	152 kg/m³
Non-evaporable in a.s.gel	$w_{n,a.s.g}$ ~	18 kg/m³

Fig. 4. Measurements 1982 of the moisture conditions in a swimming pool wall constructed 1978. /7/.

Top: Distribution of relative humidity.

Bottom: Distribution of moisture content by weight. The great scatter here is due to the small samples.
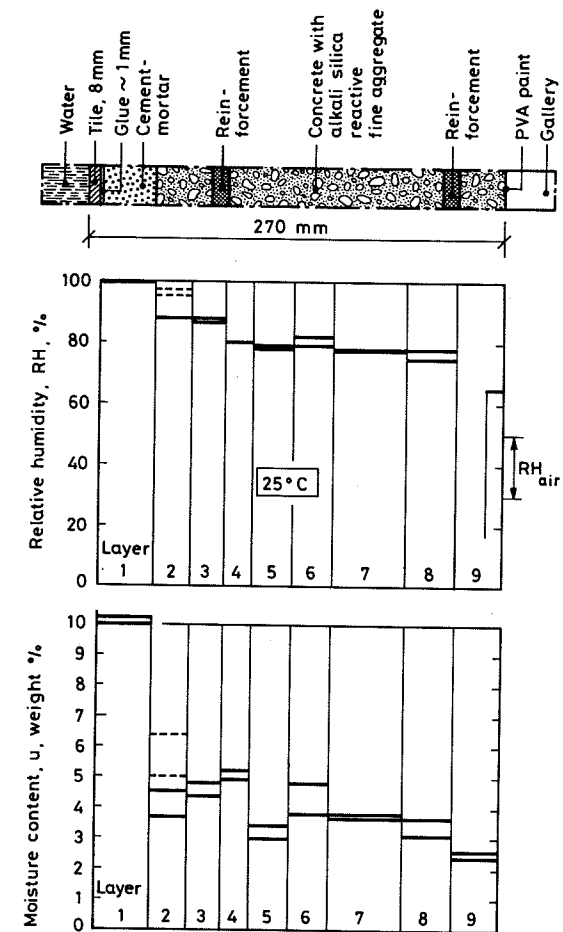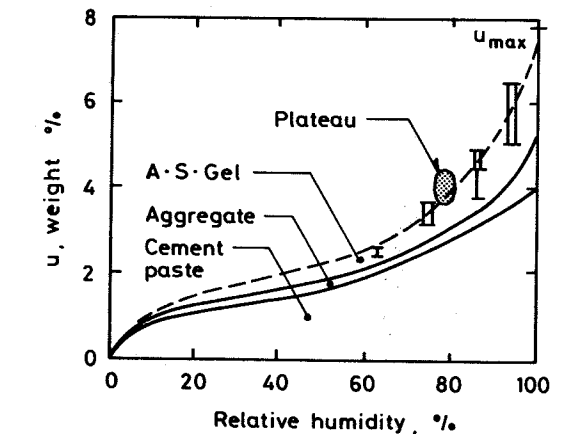

Fig. 5. The measurement from fig. 4 plotted as u versus RH. The contributions to the desorption isotherm for the cement paste and the aggregate in the concrete used in the wall are shown.

It is suggested on the basis of /3/ that $w_{n,a.s.g}$ is about 30% of the dry weight of the a.s.gel. Then the amount of gel should be $G \sim 18 \cdot 0,3 = 60$ kg/m^3.

Another guess of the magnitude of G can be made from the amount of reactive material. The fine aggregate makes 760 kg/m^3. About 10% of this is reactive particles, i.e. 76 kg/m^3. Part of this material may react and together with calcium and water create gel of the same order of magnitude as calculated above.

4. CONCLUSIONS

Measurements of connected values of relative humidity and water content by weight make it reasonable to assume that alkali-silica-gel contributes essential to the selfdesiccation of seal-cured concrete with alkali-silica reactive aggregates.

Further research is needed to clear out the rules of calculation for the desorption curve of the alkali-silica-gel.

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MOISTURE EFFECTS ON THE ALKALI-SILICA REACTION

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ABSTRACT

The moisture effects on the alkali-silica reaction have been studied by measurements of moisture distributions on some damaged structures and by several laboratory experiments with varying climatic conditions. Relative humidities of the concrete close to 90 % RH, at different temperatures, have been shown to be "critical", causing the most popouts.

A test method for popouts has been developed using the "moisture history" as an aid to reproduce the damages in the laboratory. The effect of some potential inhibitors has been studied with the test method, with promising results.

Key-words: popouts, moisture, relative humidity, test method

1. INTRODUCTION

Problems due to alkali-silica reactions in Sweden are new and coincide with the introduction of a high-alkali cement in the south of Sweden where an ordinary concrete aggregate contains reactive grains of opaline flint and sandstone. The problems occur only as popouts on certain structures and turn out to be a definite moisture problem as popouts have never been found on outdoor structures even when they are wet. Problems arise only on "moist indoor structures", that have had a certain history of moisture changes. The most frequently affected structure is concrete slabs on the ground. More than 9 out of 10 problems with popouts due to ASR are found on such a structure /1/.

Moisture effects on the alkali-silica reaction causing popouts have been studied in practice and in experiments. In this paper some damage investigations are summarized and some results of the laboratory work are shown. The pessimum effect of moisture is pointed out.

2. SOME DAMAGE INVESTIGATIONS

The moisture effects have been studied by measuring the moisture distribution on some damaged structures. The results from two cases are summarized below.

2.1 Case 1: An epoxy painted basement floor

Several large popouts (up to 60mm in diameter!) have occurred on an epoxy painted concrete floor in a basement. In different parts of the basement, the moisture distribution through the floor slab has been determined by measuring the relative humidity (RH) on samples taken at different depths, cf. /2/. Some results are shown in Figure 1.