Alkali-Silica Reactions in Reinforced Concrete Beams with Particular Reference to Bearing Capacity

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ABSTRACT

This paper contains a brief description of a laboratory research program on alkali-silica reactions (ASR) in reinforced concrete beams (4300x180x360 mm), concrete prisms (600x100x100 mm), and concrete test cylinders (Ø100x200 mm).

For several years research on ASR has been carried out at the Danish Engineering Academy and the Technical University of Denmark, and as the Danish Road Directorate wanted to start research on ASR damages which have been found on a great number of road bridges, it was natural to start an investigation. The purpose of the investigation was to clarify a connection between a visual evaluation of damage of a beam and the shear and anchorage strength. In the laboratory thin sections and polished concrete slabs from the test beams have been investigated.

Three weeks after casting and subsequent wet curing some of the beams were stored in a saturated NaCl solution at 50°C. During the storage period longitudinal and transverse expansions were measured. After different storage periods, the extent of damage in the beams was evaluated, and the load carrying capacity of the beam in shear was tested in a test set-up.

Registration as regards a damage grading scale from 0-4 comprises the concrete surface as well as the interior of the concrete. The number, extent, appearance of AS gel deposits, popouts and cracking of the surface are registered. The interior of the concrete is evaluated on the basis of a microstructural description of reacting sand particles, the crack system, and interior AS gel deposits. To date 13 concrete beams have been cast, and some of the preliminary results will be presented.

INTRODUCTION

In recent years severe damage has developed in several concrete structures, especially road bridges in Denmark. The major part of the damage has been caused by AS reactivity, particularly in the sand fraction (Danish Road Directorate 1978, 1980). In light of this, some individual projects were started in 1984 at the Danish Engineering Academy (Thorsen et al., 1986). A brief summary of this investigation from 1984 is given below. The investigation (Thorsen et al., 1986) was meant to form the basis of an evaluation of the effect on concrete prisms made with ASR sand using different amounts of reinforcement and quantities of silica fume.

The cast prisms (78 pieces) were stored in a 10% NaCl solution at 50°C; after about two years of storage, the following preliminary conclusions can be given (Thorsen et al. 1986):

- Reinforcement (steel bars) reduces the expansion by a factor of about 2.5 compared to the reference prisms.
- Stirrups have little effect on longitudinal expansions, but some effect on transverse expansions.
- Addition of about 5-10% silica fume reduces the expansion by a factor of about 5 compared to prisms without silica fume.

The investigation described in this paper was started in 1984 in close cooperation with the Danish Road Directorate, AEC Consulting Engineers, Ltd., Denmark, the Structural Research Laboratory at the Technical University of Denmark, and the Physics and Materials Science Department at the Danish Engineering Academy.

The project was prompted by the fact that a great number of Danish road bridges had been attacked by ASR, but none had collapsed for this reason. The results of this project are meant to form the basis of an evaluation of the load carrying capacity of these road bridges.

EXPERIMENTAL PROGRAM

Reinforced concrete beams, concrete prisms, and concrete test cylinders were made with alkali-reactive sand (approx. 17% porous flint), innocuous marine gravel, 300 kg/m^3 of RPC (approx. 0.8% equiv. Na_2O), and w/c = 0.5.

The beams, prisms, and some of the test cylinders were exposed to accelerated ASR for a study of the impact of the reactions on the shear strength of the beams.

The testing plan for the concrete beams included two different types of beams:

Type A: shear tests, relaxed reinforcements
Type C: anchorage tests

The geometry and reinforcement of the beams can be seen from Figure 1.

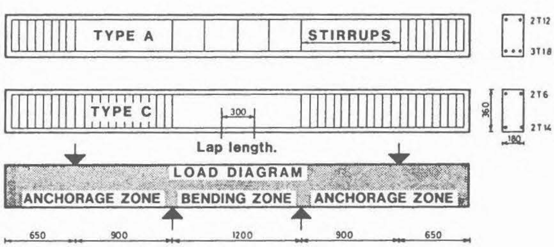

Figure 1. Test beams, geometry, reinforcement, and load diagram

Table 1 shows the different storage conditions of the test specimens.

After various periods of storage, the load carrying capacity of the beams was tested according to the load diagram (Figure 1). Compression and tensile splitting tests have been made on cylinders which have been stored normally and in an NaCl solution corresponding to the storage used for the beams.

Table 1

Storage Condition	Temperature °C	Beams 4300x180x360	Prisms 600x100x100	Cylinders Ø 100x200
Total Number		13	30	105
Saturated NaCl Solution	50	11	14	+
100% RH		0	8	-
Outdoors	Var	0	8	-
Danish Standard DS 423.21	20	2	0	+

MIX DESIGN AND EXPERIMENTAL TECHNIQUES

Table 2 shows the different data from the mix design and some data from the casting of beams.

Table 2. Data from the concrete mix, properties of the fresh concrete, and specification of the specimens in the investigation. Sikament FF, Sika-Air, and Frobe were used as admixtures.

	Mix Design [kg/m^3]		Initial Fresh Concrete Data				Specimen			Added NaOH + KOH
	Aggregate		Slump [mm]		Air					
	Fine	Coarse	Wanted	Actual	Wanted	Actual	Beams	Prisms	Cylinders	
I Mix June 1984	805	1105 sea gravel re-active	90	75	4-6	10	1A, 2A	6	18	+
II Mix Oct. 1984		1105 granite non-reactive (8-16 mm)		58	0	2.6	A6, A10	6	18	-
				110	4-6	5.6	A1, A5	6	18	-
				45	0	2.5	A3, A7	6	18	+
				58	4-6	3.3	A9	6	9	-
III Mix Nov. 1985				74	4-6	3.7	A11	-	6	-
				94		3.1	A12	-	6	-
				98		4.5	A0	-	6	-
				95		4.2	A13	-	6	-

Storage Conditions

Figure 2 shows the storage set-up where the concrete beams were stored. The test cylinders and the test prisms have been stored in the same kind of set-up.

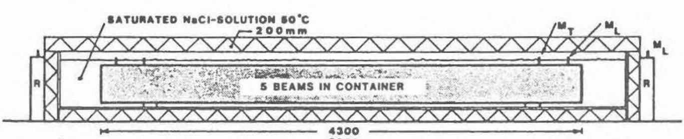

Figure 2. Storage tank for concrete beams with saturated NaCl solution at 50°C. M_L are measuring points for longitudinal expansion; M_T are measuring points for transverse expansion.

EXPANSIONS

Concrete Beams

The longitudinal and transverse expansions were measured with an external micrometer with 0.01 mm reading scale. Figure 3 shows the principle of measuring.

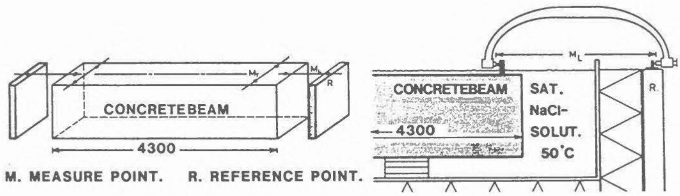

Figure 3. The R measuring points are placed on a steel profile, and each of them is fixed to the concrete floor with four 18 mm steel expansion bolts.

Concrete Prisms

The expansions in the (600x100x100 mm) concrete prisms were measured with the equipment shown in Figure 4.

Figure 4. Concrete prisms with measuring points for measuring longitudinal expansion. The dial gauge used has 0.01 mm as reading scale (Thorsen et al. 1986, Mogensen et al. 1984).

STRENGTH MEASUREMENTS

Shear Strength

In Figure 5 is shown the principle of the shear test set-up (AEC Report 1986).

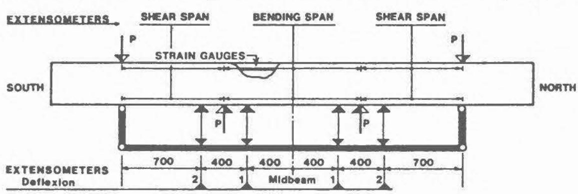

Figure 5. Principle of the shear test set-up.

PRELIMINARY RESULTS

Five of the beams are still stored in the NaCl solution, while 7 beams (A01, A1, A3, A4, A6, A8, and A11) have been evaluated with regard to ASR damage and tested with regard to shear strength. The results of the different tests and analyses can be summarized as follows.

Structural analysis of cores and cross-sectional slabs of the beams shows that a crack system parallel to the specimen surface is moving inwards with the penetration of saturated NaCl solution, Figure 6. It is possible to see the difference between a normally stored test cylinder and test cylinders stored in a saturated NaCl solution.

It seems to be essential to consider a mathematical model to evaluate the connection between the direction of compression and the orientation of the crack pattern.

Table 3. Measuring of expansions

Concrete specimen	Storage period weeks	Expansion [o/oo]				Visible cracks and popouts
		Longitudinal			Transverse	
		NaCl solution	100% RH	Out-doors	NaCl solution	
Temp. °C		50		-	50	
Prisms	~100	3-9	0.8-2.8	0-0.2	-	yes
Beams		0.5-1	-	-	7-17	yes

A survey of the results of the beam damage and the strength test is given in Figure 7. An evaluation of the damage on the surface shows degrees of deterioration of 2 and 3, while the evaluation of the interior damage from the structural analysis shows degrees of about 3 and 4.

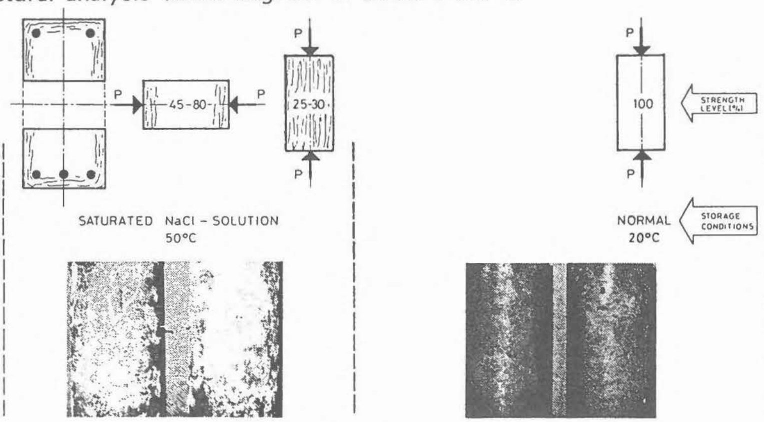

Figure 6. P is the direction of compression. The crack system in the beams is moving inwards with increasing storage time.

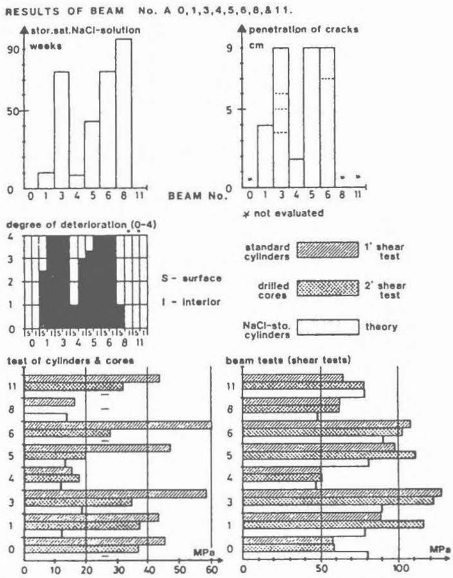

Figure 7.

COMMENTS

The aim of these investigations has been to isolate one single damage mechanism and accelerate this, for instance by using high concentration of alkalis or by increasing the temperature. On the other hand, it is necessary to consider how different side effects (for instance crystallization pressure) can influence the visual observation and the shear strength tests. It is obvious that this static test can give a result quite different from what would be obtained when making a test where the stress is a combination of static-dynamic stress.

Future investigations will determine whether faster development of damage can be achieved by creating thermal cracks in the beams before the NaCl storage. Compared to the visual, structural, and strength observations, perhaps a combination of thermal cracks, freezing-thawing cracks, and storage in an NaCl solution can produce damage which is more like that on the bridges we see in practice.

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