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ALKALI-AGGREGATE REACTION IN BELGIUM : CONCRETE HIGHWAY AND OFFICE BUILDING

Dionys Van Gemert

Dept. of Civil Engineering, Katholieke Universiteit Leuven
de Croylaan, 2, B-3030 Heverlee, Belgium

1. ABSTRACT

Two alkali-aggregate reaction damage cases are presented : one in a concrete road and one in the columns of an office building. The general appearance of the damage is described, and the causes of the reactions in the concrete and aggregate composition are investigated . In the case of column damage a simple repair method is presented, which is based on the use of epoxy bonded steel reinforcements. The design philosophy of such an epoxy bonded reinforcing steel casing is explained.

2. INTRODUCTION

Until 1980 Belgian concrete users were unaware of alkali-aggregate reaction in concrete. Concrete researchers knew about the problem, but in Belgium the phenomenon had never been observed. The Belgian aggregates and the Belgian cement seemed to be impeccable. However, damages due to alkali-aggregate reaction were first discovered in 1980 on a prestressed lightweight concrete bridge, built in 1976. Since then, the problem has been observed, and more and more alkali-aggregate damages have been discovered.

The paper deals with two cases. Firstly a plain concrete highway at Rotselaar, Belgium, which has been damaged by alkali-aggregate reaction over a length of 2500 m [1]. The highway was constructed in 1976. In 1987 an extensive chemical and petrographic study was executed on the concrete of the road, to determine the causes of the severe damages at the concrete surface. This study revealed the presence of alkali-aggregate reaction.

A second case-study concerns the supporting columns of a prefabricated concrete office building at Namur, Belgium [2]. The external appearance of the concrete damage showed all the characteristics of alkali-aggregate reaction, which was confirmed by laboratory tests.

The structural lay-out of the building made it impossible to remove and replace the columns. Therefore, the concrete of the columns was stabilised by means of epoxy-injection in the cracked concrete and by application of a water repellent; the columns were additionally strengthened by means of an external steel plate reinforcement, glued to the concrete surface with an epoxy glue. The work was executed in September 1988. The choice of this repair system is explained, and the design and practical execution of this strengthening procedure are presented.

3. ALKALI-SILICA REACTION IN ROAD CONCRETE

The plain concrete road, built in 1976, already showed some local damages three to four years after construction. No special attention was paid to these small damages, and they were repaired by the municipal technical services on the occasion of the regular maintenance inspections. The repairs were carried out with a bituminous mortar, as can be seen in Figure 1.

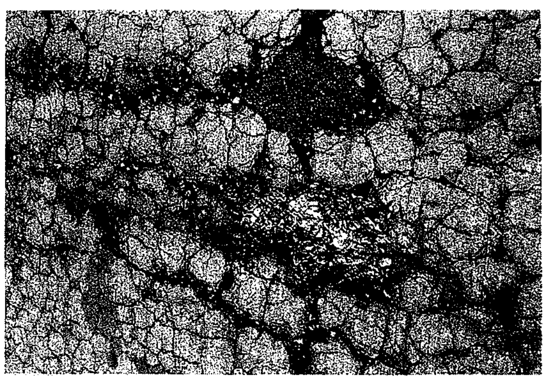

Fig. 1. : Typical damage and crack pattern, with local patchwork repairs.

In the course of time the deterioration gradually aggravated and, as the road section involved had a length of 2500 m, a profound study was ordered to determine the causes of decay, and to guide the decisions for the purpose of repairing or replacing the concrete road.

Four cores were bored out of the concrete. The cores K1 and K2 were taken out of deteriorated strips, whereas the cores K3 and K4 were taken out of visually non deteriorated strips. The cores are shown in Figure 2.

The sound cores were dry and had a grey outlook. The damaged cores were dark and still humid, because all the cracks had been filled up with water during the boring operation. Figure 3 gives a detailed view of core K1.

Fig. 2. : External appearance of test cores.

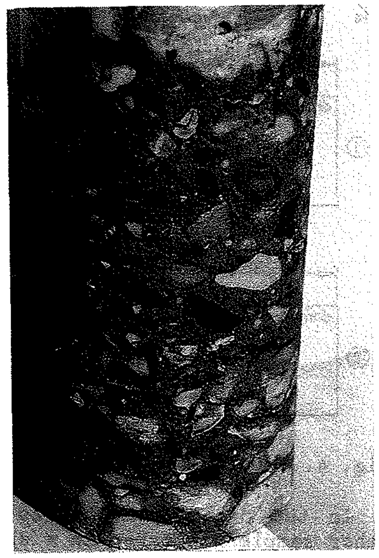

Fig. 3. : Core K1-detail.

From the aluminium and iron oxyde contents the tricalciumaluminate content is calculated through Bogue's formula

$$\% \ C_3A = 2.650 \ . \ \% \ Al_2O_3 - 1.692 \ \% \ Fe_2O_3 \qquad (1)$$

The results of C_3A content vary between 1.1 and 1.2 percent of concrete weight, or between 6.3 and 7.9 percent of cement content. Those results, combined with the low to normal content of sulphates, show clear that ettringite crystal growth can not be at the origin of swelling and degradation of the concrete. This was confirmed by petrographic analysis on thin section specimens. Ettringite needles were only present to a very small extent.

Figure 3 shows that the fracture surfaces run straight through the aggregate stones. A crevice originated around the stones, as a consequence of the chemical reaction between these stones and the cement lime. The crack openings amount to more than 5 mm. These local swellings generate very high stresses in the surrounding concrete, which the concrete is impossible to resist. As a result, the concrete becomes heavily cracked throughout the whole mass. In the cracks the concrete surface is covered with a white bloom, due to an amorphous salt deposit. This bloom was also present on a "freshly" cracked surface of the damaged as well as of the undamaged cores. Identification of the bloom salt material by means of RX diffractometry proved to be impossible, because of the non crystalline nature of the deposit. By chemical analysis we found that the bloom was mainly composed of K, Na, Ca and SiO_2. These elements also form the expansive silica gel. Six representative samples of the cores were chemically analysed, according to the procedures of the Belgian Standard NBN B15-250. The Al_2O_3 and Fe_2O_3 contents were measured by using the "Induction field coupled plasma"-technique. The Na_2O and K_2O contents were measured by means of the atomic absorption technique. The location of the test samples in the cores is indicated in Figure 4.

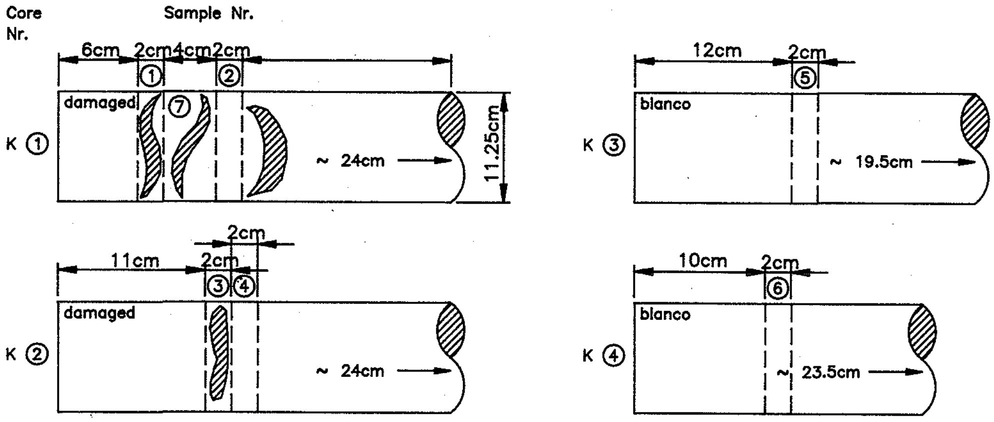

Fig. 4. : Location of chemically analysed samples.

In the deteriorated cores one sample was taken containing a crack, the other sample was taken in a still sound part of the core. The results of the analysis are summarized in Tabel 1.

Table I : Chemical composition of concrete samples.

Appearance	Damaged				Sound	
Core	1		2		3	4
Sample	1 g %	2 g %	3 g %	4 g %	5 g %	6 g %
Calcination loss	4,46	4,12	4,22	4,50	4,12	3,95
Insoluble	78,22	80,18	80,14	80,42	79,83	80,76
Soluble SiO_2	4,04	3,56	3,77	3,36	3,37	3,30
CaO	10,45	9,51	9,15	9,13	9,69	9,46
SO_3	0,49	0,45	0,49	0,45	0,40	0,38
Fe_2O_3 (ICP-method)	0,93	0,82	0,75	0,77	0,80	0,79
Al_2O_3 (ICP-method)	1,01	0,93	0,90	0,89	0,95	0,91
Cl (NBN T61-201)	0,0007	0,0007	0,0017	0,0128	0,0050	0,0098
Na_2O (atomic absorption)	0,100	0,064	0,096	0,062	0,093	0,044
K_2O (atomic absortion)	0,194	0,133	0,205	0,121	0,097	0,085
Σ	99,90	99,77	99,72	99,72	99,35	99,69
CO_2	0,43	0,36	0,46	0,39	0,37	0,31
Density	2,185		2,199		2,276	2,267
Cement type	Portland		Portland		Portland	Portland
Cement content %	17,67	15,90	15,99	15,20	15,92	15,36
kg/m3	401,3	361,1	363,1	345,2	361,5	348,8
Porosity (NBN B24-213)					3,68 %	3,7 %

The alcali content is calculated as a Na_2O-equivalent :

$$Na_2O\text{-equivalent} = g\ \%\ Na_2O + 0{,}658\ g\ \%\ K_2O \qquad (2)$$

The results are summarised in Tabel II.

Table II : Na_2O-equivalent

Sample	Na_2O-equivalent HCL*	H_2O*
1	1,455	0,456
2	0,970	0,342
3	1,474	0,506
4	0,906	0,380
5	1,002	0,266
6	0,632	0,247

*extraction in HCl/H_2O

It is found that all the alkali contents exceed the dangerous limit of 0,6 % of cement content. The fact that some samples show damage, whereas others do not, is accounted for by the higher content of water-soluble alkali in these samples (samples 1 to 4). Although we can explain the presence of alkali-aggregate reaction in the concrete, we cannot blame only the cement for it. It is the combination of reactive aggregates with highly alkali containing cements which is the cause of the damage. In this case of damaged road concrete the only solution is the complete renewal of the deteriorated section of the road.

4. ALKALI-SILICA REACTION IN CONCRETE COLUMNS

An interesting alkali-aggregate damage phenomenon was found in the supporting columns of an office building. The column type is shown in Figure 5. A detailed picture of the cracks and damage pattern is shown in Figure 6. A chemical and petrographic study of the concrete gave the same results as discussed above.

The only possible way to stop the swelling of the concrete is to avoid water penetration into the concrete. This means that any remedial treatment will only be effective if the whole exterior surface of the columns is coated with a damp permeable but waterproof coating. However, concrete will never be completely dry, because the hardened cement gel always contains some physically bonded water. This means that we can never be sure that the expansive reaction is completely stopped. The structure, used to strengthen the columns, must therefore be flexible enough to allow the additional deformations, accompanying the reactions. A rectangular steel casing allows important swellings without causing high strains, because the arc nearly remains equal to the cord. The remedial treatment consisted of two phases :

- injection of cracks
- placing of steel casing, welded in situ.

Fig. 5. : Column type.

Fig. 6. : Detail of crack pattern.

The design of the steel casing is shown in Figure 7.

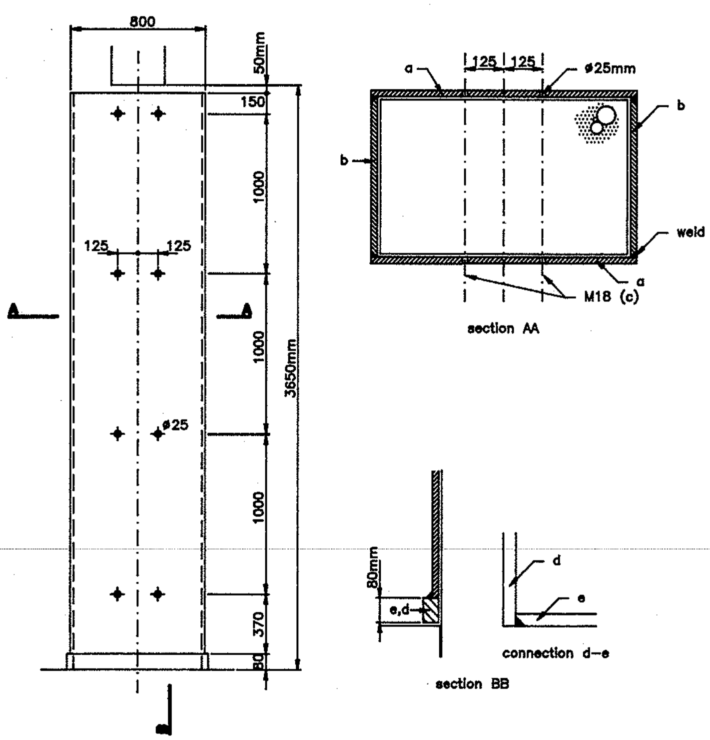

Fig. 7. : Plan of reinforcement.

The design and calculation of epoxy bonded steel strips are based on extensive research in the Reyntjens Laboratory of the Civil Engineering Department of K.U.Leuven [3,4]. The space between column and casing is injected with epoxy resin.

The reinforcement has a double action. If we suppose that the concrete is completely cracked, the casing holds the stones together and the structure keeps its load bearing capacity. If the concrete remains of better structural quality, it becomes possible that by reason of the adhesion between steel plates and concrete the plates have to carry all the vertical loads on their own. In that case the buckling of the plates must be avoided. This is achieved by means of the additional anchoring bolts, which diminish the buckling area of the plates.

5. CONCLUSIONS

Alkali-aggregate reaction becomes a concrete damage phenomenon of frequent occurrence. In many cases the only possible solution is the complete renewal of the concrete element or construction. Sometimes it is possible to slow down or even to stop the reaction, but in all these cases the remedial treatment is very costly. This leads to the conclusion that from a viewpoint of maintenance of constructions it becomes by all means necessary to avoid alkali-silica reaction from the very beginning, that is from the choice of the aggregates (the easiest way) and of the cement.

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