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ALKALI-AGGREGATE REACTIONS IN THE NETHERLANDS

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Up to one year ago the Dutch concrete world was convinced that ASR was no threat to their concrete structures. Recently, however, a few cases of deterioration as a result of ASR have been encountered. One of these is reported in this paper.
A shortage of local river-dredged gravel, the traditional coarse aggregate for concrete in The Netherlands, urges the Dutch building industry to import coarse aggregates. As these are imported from countries in which ASR is known to occur, a substantial research effort is directed towards test methods, specifications and guidance for avoidance of damage from ASR.

INTRODUCTION

At the department of traffic and transport of the Province of Zuid-Holland, there are approximately 700 structures (viaducts, fixed and lifting bridges, tunnels, locks and culverts) under management. These structures are predominantly composed of reinforced and/or prestressed concrete, and form an essential part of the infrastructure. Systematic inspections of these structures revealed an unusual case of concrete deterioration at a 30 year old viaduct in Schoonhoven.

A number of concrete cores extracted from this viaduct were sent for testing to TNO Building and Construction Research. Testing included tensile strength, cement content, chloride content, porosity and density. As a result of these limited investigations no conclusions could be made as to the origin of the crack pattern. In this preliminary investigation, cracking was noted associated with reaction rims around a number of aggregate fragments. Ettringite was also reported in and adjacent to these cracks. It was from these clues that TNO Building and Construction Research formed the hypothesis that the crack pattern could be a result of alkali-aggregate reaction in the concrete. To confirm this an additional inspection on site and a full laboratory investigation was undertaken, the results of which have been published in Dutch by Heijnen and van der Vliet (1).

OBSERVATIONS

General

From visual inspection, the road deck concrete surfaces and a number of the abutments showed some cracking. Most of the cracks run in the direction of the length of the viaduct and form a pattern of more or less parallel running cracks, these were also associated with transverse cracks (Figure 1).

A section of the cracked upper surface and the uppermost part of the side surfaces were accentuated by a brown discolouring. The majority of the cracks in the sides and isolated cracks in the soffit of the road deck were highlighted by stalactites, which indicate to the passage of fluid. The number of cracks on the westside was greater than on the eastside. There is possibly a relationship between the variation in cracking and the drainage of surface run off, since the viaduct is inclined in westerly direction with most of the wind and rain coming from the west.

None of the cracks on the concrete surface showed associated rust staining. Consequently, the cracking is probably not caused by corrosion of the reinforcement.

Concrete cover

The concrete cover was measured with a covermeter. On the sides of the deck the concrete cover varied between 25 and 80 mm; on the soffit values between 20 and 45 mm were found. During the measurement of the concrete cover it became clear that the cracks in the concrete generally did not coincide with the reinforcement present.

Carbonation depth

The carbonation depths were determined on the middle of the cores with Phenolphthalein as indicator and showed 1 to 2 mm. Such carbonation depths for a 30 year old concrete are exceptionally good. Perhaps these values have been influenced by the paint system on the concrete. The depth of the carbonation in relation to the thickness of concrete cover to reinforcing steel is very good, so that the risk of reinforcement corrosion by carbonation of the concrete can be regarded as zero.

Crack formation

Crack widths were measured on the side of the road deck, on the underside near the support point on the columns, and also on the top of the road deck. On the side of the road deck the largest crack widths were associated with horizontal cracks. On the eastside the crack widths varied from 0.4 mm to 3.5 mm for the horizontal cracks and from less than 0.1 mm to 0.2 mm for the vertical cracks. On the westside the crack widths varied from 0.5 mm to 3.5 mm for the horizontal cracks and from less than 0.1 mm to 0.4 mm for the vertical cracks. The largest crack widths measured on the top of the road deck were in the direction of the length of the viaduct. Dependent on the number of parallel running cracks, the crack widths varied from 0.2 to 1.0 mm for a small number of cracks.

The total sum of crack widths over a selected length was taken in five areas. The results were as follows:

topside road deck in the transverse direction of the viaduct:

1.7 mm over 0.60 m, is 2.8 mm/m;
1.8 mm over 1.60 m, is 1.1 mm/m;
3.0 mm over 1.25 m, is 2.4 mm/m.

side of road deck in a vertical direction at the support point on the columns:

7.8 mm over 1.0 m, is 7.8 mm/m (eastside);
12.0 mm over 1.0 m, is 12.0 mm/m (westside).

In view of these values it is apparent that the cracks have resulted from some cause other than shrinkage, for which they would be typically about 0.5 mm/m.

Cores were taken through cracks in the concrete. The cracks extended 50 to 60 mm deep from the concrete surface to the depth of the reinforcement. At that depth they changed over to cracks running parallel to the concrete surface and the rebars. In only one case the direction of a crack coincided with a rebar. The reinforcement, at this location, showed no signs of corrosion, nor was reinforcement corrosion noted elsewhere.

LABORATORY INVESTIGATION

A total 12 cores (diameter of approximately 100 mm) were extracted for the purpose of laboratory investigation. The core locations were chosen from various cracked and uncracked areas of concrete; from the side and the top of the road deck as well as the abutments.

The cores were visually inspected directly after been cored. Most showed a strange glassy lustre, contained a white substance on the crack surfaces and dried with unusual staining. A number of broken gravel fragments showed clear reation rims, existing of a sharp, dark outer rim, with a somewhat vague inner white zone.

Petrographic examination

The concrete petrography investigation was carried out by GEOS NV at Wellen, Belgium. The cores S-W 1 (bored into a wide crack in the side of the road deck on the westside of the viaduct out of a thicker section above the southernly row of columns), N-E 1 (bored into a small crack in the side of the road deck on the eastside of the viaduct out of a thicker section above the northernly row of columns) and N 1 (bored into a sound area from the northern abutment) were petrographically examined with the help of polarising and fluorescence microscopy. For a full report of these investigative methods see Soers and Meyskens (2). Out of each of the three cores two plates, 30 x 50 mm^2, thickness 30 μm, were made. Before the manufacture of the thin sections the specimens were first impregnated with a fluorescent dye, so that they could be examined under polarising as well as fluorescence microscope. One thin section was made from the concrete on the top of the core including the outer surface, the other from the middle concrete of the approximately 150 mm long core.

The coarse aggregate (gravel) in all three cores consisted of quartzite and fairly much chert. Some of the quartzite fragments showed laminations and contained mica and sericite.

The fine aggregate (sand) consisted of quartz and quartzite and in insignificant amounts of chert, pieces of limestone and pieces of slate. The sand, as was the gravel, was identical in the three cores.

From the petrographic investigation it is concluded that the concrete is made with relatively coarse grained Portland cement; there are no differences in composition. The degree of hydration is at a normal, but somewhat variable, level.

The capillary porosity is determined from the fluorescence microscopy examination. The intensity of the fluorescence from the examined concrete was thereby compared with the standards of similar composition. On this basis a conclusion can be made about the water/cement ratio of the examined concrete (1). The capillary porosity of the examined cores turned out to be very variable. The w/c ratio derived from the measured capillary porosity varied from 0.35 to 0.75.

Core S-W 1 contained a low amount of compaction pores (accidental air voids, which result from the incomplete expulsion of enclosed air during the compaction of the concrete mix), that sometimes were full with alkali-silica gel and ettringite.

Core N-E 1 contained a number of small round air voids, that contained some gel and ettringite.

Core N 1 contained numerous, mostly small air voids, similar to the air voids present in concrete to which an air entraining agent has been added. These pores were empty.

From the petrographic analysis it was concluded that the crack formation in the concrete of the cores S-W 1 and N-E 1 was caused by ASR. This reaction occurred in a number of porous chert particles in the gravel fraction.

Figure 2 illustrates this reaction clearly. In addition distinct types of quartzite (e.g. quartzites containing sericite and quartzites containing quartz grains showing undulatory extinction) present in the gravel fraction show some reaction. The reaction goes hand in hand with the formation of large amounts of expansive alkali-silica gel.

The cracks resulting from ASR are sometimes filled with secondary ettringite. The alkali-silica reaction was most intense in the interior of the concrete mass of core S-W 1 and to a lesser degree in core N-E 1. Core N 1 (from the northern abutment) showed no reaction.

SEM/EDS investigation

SEM investigation of a prominent reaction rim of a chert grain showed the presence of a gel-like substance (Figure 3). The gel showed obvious shrinkage cracks probably as a result of the extraction of water during the preparation. With help of EDS (Energy Dispersive X-Ray spectrometry) coupled with SEM the gel was found to comprise predominantly of SiO_2, but at the same time contained a considerable amount of potassium. The estimated Si/K ratio (in percentage atoms) was about 5:1.

Rosette-like conglomerations of potassium calcium silicate were found to be present in the reaction rim of another chert grain (Figure 4). Via EDS the estimated content (in percentage atoms) was about 1:1:4. Such rosette-like arranged crystals have been described in concrete affected by ASR by de Ceukelaire (3) and Davies and Oberholster (4).

Needle-like ettringite crystals were associated with various cracks and cavities in the concrete. Ettringite formation is often associated with concrete suffering from ASR ((3) and Soers and Meyskens (5)).

Chemical investigation

The acid soluble alkali content of the concrete was determined in the deepest part of three similarly cracked cores. The average alkali content was 3.3 kg Na_2O eqv. (this is defined as the percentage Na_2O + 0.658 x the percentage K_2O) per m^3 of concrete. This is marginally greater than the 3 kg Na_2O eqv. per m^3 of concrete, which is recommended e.g. in the UK as the maximum allowable alkali content for use with aggregates susceptible to ASR.

Assuming all alkalis were derived from the cement, suggests that the Portland cement used had an alkali content of about 1 % Na_2O eqv.. From the findings of various investigations, concrete remains free of damaging ASR as long as the alkali content of the cement remains under 0.6 % Na_2 eqv.. In the USA this value has already been included in the standards (ASTM C33-90). Apart from that, it should be realised that the alkali content can still become critical through the supply of sodium salts from external sources, especially originating from de-icing salts.

N.B. The Portland cement produced in The Netherlands has for years had an alkali content of about 0.6 % Na_2O eqv..

The chloride content of 3 cores (bored on the top of the road deck and the southern abutment on the west side of the viaduct) were determined as a function of the distance from the concrete surface. For this purpose 3 slices of 20 mm thick were cut from each core and analysed. A slight increase of chloride content was found towards the concrete surface. This probably has originated through the use of de-icing salts on the viaduct. The chloride content on the whole is insignificant (approximately 0.1 % (m/m) on cement). Apart from that, the alkali content can be concentrated in the cracks from the contact with alkali laden de-icing salts.

DISCUSSION AND CONCLUSIONS

The cracking in the reinforced concrete parts of the road deck and the abutments of this viaduct in Schoonhoven did not correspond with the reinforcement pattern. The carbonation did not exceed the concrete cover to the reinforcement and is confined to the outer 5 mm of the concrete surface. Numerous leakage spots present showed no staining from rusting reinforcement to point to it. The cracks are therefore not caused through corrosion of the rebars. The total (added) crack width is too great to be attributable to shrinkage cracking alone.

Microscopic investigation has shown that in the gravel significant amounts of chert grains are present and are attacked by ASR. Swelling as a result of this ASR is almost certainly the cause of the cracking in the concrete.

There are also a number of macroscopic indications of ASR in the concrete, such as the reaction rims in various gravel grains (Shayan (6)), the white substance on the concrete cores, the strange glassy lustre of a number of cores and the abnormal blotching of the surface on drying of most of the cores (BCA (7)).

On the basis of the high alkali content found in this investigations, it is plausible that the concrete in the Schoonhoven viaduct was made using a Portland cement with a relatively high alkali content.

Additionally, the w/c ratio of the hardened cement paste is somewhat variable (varying on a microscopic scale from 0.35 to 0.75) and hence may have resulted in increased localised porosity allowing migration and permeation of moisture (and dissolved species). The combination of relatively high porosity, high alkali content and the presence of reactive chert fragments in the coarse aggregate has resulted in damaging ASR in the concrete of the viaduct.

Damage to concrete structures due to ASR is truely new for The Netherlands. Up to five years ago, the general and convinced opinion was that ASR was no threat to Belgian concrete structures either. The Belgian aggregates were considered not to be susceptible to ASR. Since then in Belgium there have been about 25 reported cases of deterioration as a result of ASR (3,5).

Until today the Dutch concrete world was convinced that the Dutch aggregate was insensitive to ASR. One exception to this was Bosschaert (8), who in 1957 pleaded for thought to be given to ASR in The Netherlands. In Belgium most cases have occurred with sand and gravel combinations from the Maasdal (the valley of the river Meuse). Gravel and sand from the Maasdal is also often used as aggregate for concrete in The Netherlands. Since the origins of these deposits in Belgium and The Netherlands are closely related to one another, it would be useful to have a mineralogical summary of the Dutch sand and gravel deposits. This, unfortunately, is not readily available at the moment.

Yet it is still almost certain that ASR is much less of a problem in The Netherlands than in Belgium. This can be shown because firstly in The Netherlands many more slag concretes, with high slag contents, are used, which strongly reduces the risk of ASR occurring. This is principally the result of the more closed pore structure of slag concrete and possibly partly also the result of the reduced availability of alkalis in slag concrete. Another consideration is the possible variation of alkali contents between Dutch and Belgian Portland cements.

In addition to the case of damage due to ASR described in this paper, recently, indications have been found pointing to more deterioration of Dutch concrete structures caused by ASR.

WORKING PARTY

In 1991 CUR (Dutch centre for civil engineering research and codes) formed a working party "ASR in concrete" with the aim of studying the experience with respect to ASR in the surrounding countries and giving scientific and technical support in the process of drawing up regulations and specifications. This working party has to anticipate on the import of coarse aggregates from neighbouring countries. Some of these aggregates are known to be susceptible to harmful ASR.

Its current work consists of the following:

- To make an inventory of the coarse aggregates, which are most likely to be imported in The Netherlands.
- To gather information (by means of literature studies and interviews with experts in Western Europe) on the occurrence of ASR in concrete containing these aggregates in those countries, which supply these aggregates to The Netherlands.
- To draw up a Dutch procedure for testing the alkali-reactivity of (combinations) of aggregates.
- To draw up recommendations/specifications with respect to reducing the risk of harmful ASR occurring in concrete containing alkali-reactive aggregate combinations (e.g. by means of the application of low-alkali cements or cements with high slag contents).

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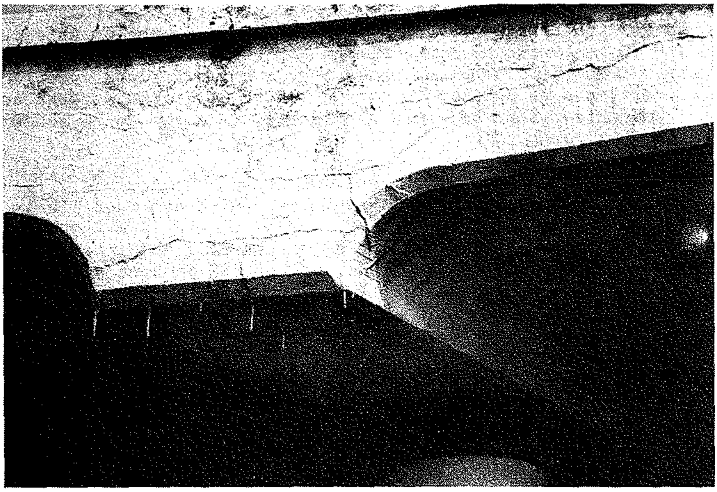

Figure 1 Cracks in the side of the road deck near a row of columns

Figure 2 Petrographic microscope picture of core S-W 1 (area shown=1.5x2 mm^2); **reaction of a porous chert grain with associated cracking and expulsion of gel**

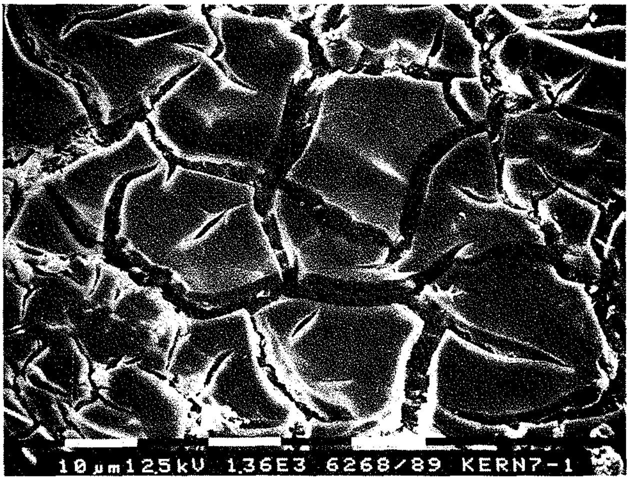

Figure 3 SEM picture of alkali-silica gel in a reaction rim of a chert grain

Figure 4 SEM picture of rosette-like conglomerations of crystalline ASR reaction products in a reaction rim of a chert grain