8th ICAAR 1989 KYOTO
8th Internationl Conference on Alkali-Aggregate Reaction

PETROGRAPHICAL RESEARCH ON ALKALI-AGGREGATE REACTIONS IN CONCRETE STRUCTURES IN BELGIUM

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ABSTRACT

The paper gives an overview of petrographical research on recently revealed cases of damage of concrete by ASR in Belgium. The reactive aggregates and their geological origin are reviewed. Based on petrographical observations, a description is given of crack development, crystallisation of ettringite and microstructure. Further research on reactivity of aggregates is briefly commented.

1. INTRODUCTION

Since a few years concrete petrography has been used in Belgium in damage analysis and quality control. This microscopical research revealed [1,2] that some of the concrete damages had to be attributed to alkali-aggregate reactions of the alkali-silica type (further referred to as ASR). Based on a number of petrographical observations, knowledge grew on the reactivity of the aggregates, their geological origin and their geographical distribution. Damages caused by ASR impelled to regular repairs and even to replacement of some concrete structures.

2. GEOLOGY

From a geological-geographical viewpoint, the Belgian territory can be divided in different areas where aggregates for the concrete industry are quarried (fig. 1).They range in age from paleozoic to recent deposits. Some proved to be reactive in an alkaline environment.

A. In the Northern part of Belgium, sands are quarried in marine and continental formations of cenozoic age.
B. In the Southern part of the country, a large number of quarries are producing crushed materials from paleozoic formations (Cambrium to Carboniferous): quartzites, sandstones, limestones, silicious limestones, dolomites.

C. In the North-Eastern part of Belgium, the River Meuse built up alluvial deposits during the Quarternary interglacial periods and recent times. This area is an important supplier of gravel and sand, mainly composed of silica-rich materials (quartz, quartzite, sandstone). They contain also a substantial amount of flintstone.

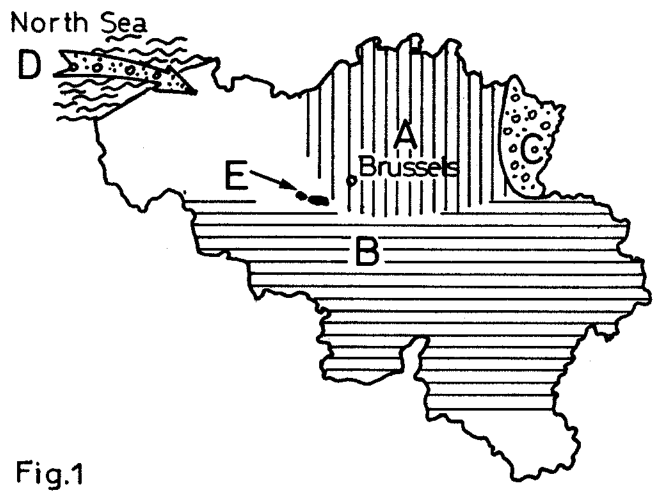


Fig.1

D. In the Western part of the country, the concrete industry makes extensive use of gravel and sand dredged from the North Sea. The larger part of these gravels consists of flintstone pebbles.

E. Centrally located, South of Brussels in the Quenast region, volcanic rocks with a quartz diorite composition are quarried in a few intrusive formations. Despite their relatively small size, large quantities of aggregate are produced.

The investigation of concrete structures affected by ASR indicates that reactive materials originate from areas B,C,D and E.

3. DAMAGED CONCRETE STRUCTURES

Eighteen structures, damaged by ASR and aged from 6 to 28 years, have been investigated. Different types of concrete have been used:

- Cast-in-place concrete for road pavements, marine constructions, buildings, lightweight concrete bridge construction.
- Prefabricated concrete for members, prestressed beams and masts.

The development of cracking that has been observed matches the characteristics of the typical ASR crack morphology. The cracks are multidirectional in an unstrained concrete, or directed according to the major stresses in reinforced or prestressed concrete. Cracking is more pronounced in those parts which have been better exposed to rain and moisture. Some of the ASR damages may also have been intensified by additional alkalis forthcoming from de-icing salts in roads or by seawater in marine environment.

4. PETROGRAPHY

The petrographical research has been carried out by polarisation and fluorescence microscopy on thin slides of samples that have been vacuum impregnated by a fluorescent epoxy. This microscopical research method [3] makes it possible to combine the traditional petrographic observations with a microstructural examination of the concrete. One gets an overview of:

- the type of the (reactive) aggregates and their porosity,
- the type of the cement that has been used,
- the structure of the macropores and voids, and the secondary products they contain,
- the capillar porosity of the cement, indicating the water/cement ratio of the fresh concrete,
- microstructural defects of the cement paste, such as microcracks and inhomogeneity of capillar porosity.

4.1 The reactive aggregates

The reactive aggregates which have been identified show a large variety in mineralogical and lithogical composition. They all take part in a reaction of the alkali-silica type. Alkali-silicate and alkali-carbonate reactions have not been observed. In order of importance, the following materials can be mentioned as being able to generate a deleterious reaction.

- Gravel and sand grains composed of chert, chalcedony, opal and micro- to cryptocrystalline quartz. They are present in the quaternary alluvial deposits and the dredged sea materials (areas C and D). The highest reactivity has been observed with the opal grains and the porous wheathered cherts.

- Crushed aggregates produced from the siliceous limestones of Carboniferous age (area B). These micritic limestones contain cryptocrystalline quartz and phyllitic minerals.

- Crushed aggregates of volcanic rocks with a quartz diorite composition and a porphyric texture (area E). The reactivity of this rock is caused by its microcrystalline quartz-groundmass.

- Sericitic fine grained sandstones occuring in paleozoic and recent formations (several areas).

- Strained quartz is an accessory mineral, mainly encountered in quaternary and recent alluvial deposits.

4.2 The cement

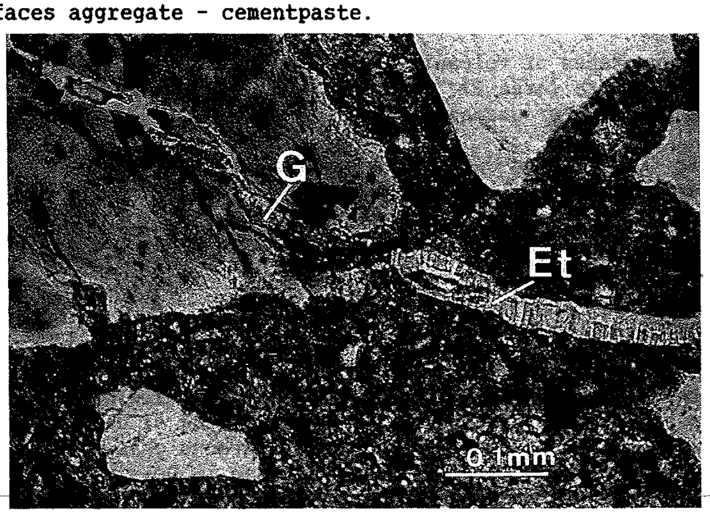
The concretes affected by ASR are mostly manufactured with a Portland cement. A couple of examples, however, have been found of damaged concretes manufactured with a blended cement (Portland + ground granulated blast furnace slag). This type of cement has already been in use in Belgium for several decades. Information on the chemical composition, and in particular on the acid soluble alkali content of the cements used in damaged concretes, is not available. A number of samples from investigated concretes have been analysed for their alkali content. Out of sixteen samples, fifteen contain more than 3.0 kg Na_2O_{eq}/m^3 ; fourteen range from 3.1 to 5.2 and one sample contains even 8.2 kg/m^3 Na_2O_{eq}. This last sample however, comes from a lightweight concrete. It is not clear whether the light aggregate (an expanded shale) may have influenced the alkali content. Anyhow, the results of chemical analyses indicate that the cements used in the concretes were of the high-alkali type.

4.3 <u>Crack formation and secondary crack filling</u>

Cracks produced by ASR can either be empty or partly filled with gel. Not seldom, however, they contain material formed by weathering or by secondary crystallisation (portlandite, calcite, ettringite). The gel development can be rather voluminous, showing typical flow structures, when larger flintstone pebbles are reacting. The reaction is mainly confined to the external zone consisting of a porous whitish opal-rich layer. If the reacting aggregates consist of siliceous limestones, volcanic rocks, or sericitic microquartzites, gel development is less important. When the cracks are caused by a reactive sand containing chert, chalcedony and opal, these grains often show a resolved internal structure with cracks radiating into the surrounding cement paste. The gel relicts observed outside of the reacting grains are often weathered due to absorption of $Ca(OH)2$ from the adjacent paste, and a subsequent carbonation nearer to the surface.

In six constructions affected by cracks clearly related to ASR, development of ettringite has been observed. This ettringite formation is characterized by its abundance and the secondary character of its crystallization. In some of the investigated samples, the volume of ettringite is far more important than the remaining gel deposits. The crystallization of this mineral obviously took place in already existing cracks that are related to expanding aggregates (fig. 2). In thin sections, ettringite appears in two different habits:

- as deposits of needle-like acicular crystals, filling uncompletely voids and cracks,
- as a massive crack-filling material composed of elongated or fibrous crystals, mainly developed in cracks related to ASR, but also at the interfaces aggregate - cementpaste.



<u>Fig. 2</u> Microscopic image in thin slide of a reacting chert with crack formation. Gel relicts (G) are visble inside the grain; secondary crystallisation of ettringite (Et) in the continuing crack outside. Normal light.

The former type did certainly not exert any deleterious effect, whereas the massive type may have contributed to the expansion of the concrete.

It seems that contamination by external sulphate bearing solutions can be excluded as a possible cause for the ettringite formation. Other interpretations based on recent research are possible. German researchers [4,5] have studied the relationship between heat treatment during concrete production and an expansive ettringite formation. They proved experimentally, that an inappropriate production process (too early heating or temperatures over 65°C) can cause a secondary ettringite formation due to the reaction of calciumsulphate, loosely bound to the calciumsilicate hydrates, with unhydrated tricalciumaluminate or monosulphate. This process gives a valid explanation for the presence of ettringite in steamed concrete members (lighting masts,beams), but seems less applicable to cast-in-place concrete, where the same phenomenon has been observed. In this respect, the mechanism proposed by Jones and Poole [6] seems to be more appropriate. They explain the formation of ettringite associated to ASR-cracking by the recrystallisation of a primary dispersed phase.

4.4 The influence of the microstructure on ASR development

It has been emphasized by various authors that the porosity and the microstructure of the cement paste play an important role in the development of harmful processes. Indeed, the rate of diffusion of aqeuous solutions will be slowed down or increased according to the quality (i.e. porosity) of the cement paste. The observations with fluorescence microscopy clearly illustrate this relationship.Most of the damaged concrete samples show a microstructure favouring the diffusion of pore solutions and therefore initiating or accelerating deleterious processes as ASR and ettringite formation:

- a high capillar porosity of the paste due to a high W/C ratio,
- an inhomogeneous paste showing a differentiation of zones with low and high capillar porosity, due to poor mixing,
- a network of microcracks, favouring permeability.

A striking example of the influence of the microstructure of the cement paste has been offered by a road damaged by ASR located in Rotselaar. Certain parts of this road show a dense map cracking pattern, whilst in others only a poor crack development is visible. Fluorescence microscopy revealed that in the heavily damaged zones a high capillar porosity (corresponding to a W/C-ratio of about 0.65) was present, while in the undamaged concrete a dense paste (with W/C=0.50) was observed. In the same way, the formation of ettringite may also have been favoured by the higher porosity, created by the ASR-cracking pattern.

5. FURTHER RESEARCH ON THE ALKALI-REACTIVITY OF THE AGGREGATES

Under the authority of the Belgian Ministry of Public Works, a research program is in progress on the alkali-reactivity of the aggregates used in concrete. A representative sampling has been carried out, based on the practical knowledge (see 4.1.) resulting from the petrographical examination of damaged concrete. The investigation on the aggregates (sand,gravel and crushed rocks) includes:

- a preliminary examination based on mineralogical and petrographical criteria to make an assessment of the amount of reactive material,
- a series of accelerated mortar bar and concrete prism tests according to the Danish [7] and South-African [8] methods,

- a subsequent petrographical examination of the mortar and concrete samples after the expansion test.

Insomuch available, the results of this research confirm the observations made on the damaged concrete structures.

6. CONCLUSIONS

The alkali-aggregate reaction in Belgium is of the alkali-silica type and brings about cracking damage in different types of concrete. The petrographical examination of damaged concretes proves that ASR is caused by rocks and minerals of varied nature, ranging from paleozoic formations to recent deposits, that are quarried all over the country.

The presence of secondary ettringite associated to cracking due to ASR is frequent. In some cases, its abundance and crystal morphology suggest a contribution to crack development.

The stimulating effect of a defective microstructure (high capillar porosity, microcracking) in the development of ASR is demonstrated by fluorescence microscopy. These observations confirm that deleterious processes as ASR are favoured by a declining quality of the concrete.

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