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CONSEQUENCES OF THE REACTION: ALKALIS – SILICA
FOR THE CONCRETE WITH AGGREGATE
OF QUATERNARY GRAVELS FROM NORTHERN POLAND

Abstract: Quaternary fluvioglacial gravels, used as aggregate to concrete production, were studied. The studies aimed to verify the thesis, that certain components of concrete are the cause of decrease of the concrete quality. The test concrete bars were prepared with use of the gravel as aggregate. The bars were investigated by optical microscope and electron microprobe, especially at the contacts of the potentially reactive mineral substances (chalcedony, opal, tridymite, fine-crystalline quartz), susceptible to alkalis present in the cement. The studies evidenced the formation of the substances typical of the reactions of alkalis with various forms of silica; these substances lowered the quality of the concrete.

Keywords: Quaternary, gravel, aggregate, alkali reactivity, fine crystalline silica

INTRODUCTION

Aggregate composes at least 75 percent of the concrete volume and its properties influence in a major degree the physical-resistance features and durability of the concrete in a construction. Due to their availability and mechanical properties, the Quaternary gravels are an important component commonly used to concrete (Jasiński 2000). It is supposed that the reactions between the reactive mineral substances (chalcedony, opal, tridymite, fine-crystalline quartz) and alkalis present in cement paste may be one of the reasons causing destruction of the concrete constructions. These reactions lead to an extensive swelling of the components and reaction products due to sorption of water from atmospheric precipitation and groundwaters. The sorption of water causes increase of volume yielding pressure sufficient to form fractures in concrete. This process resulting from alkaline reactivity in concrete is dangerous due to durable though slow destruction of the concrete buildings (Poole 1992).

To prove this supposition, the microscope petrographic studies of the selected Quaternary gravel, containing potentially reactive mineral substances, were performed. The pebbles included arkosic arenites, mudstones and rhyolites, which bore chalcedony in form of microcrystalline, colourless aggregates

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of fibrous microstructure. Lydite pebbles consisting of microcrystalline quartz (partly chalcedony), flints and cherts are other potentially reactive components. These gravels were used to prepare six concrete bars (according to the Polish Norm PN-91/B-06714/34) with cement containing $1.2 \pm 0.1\%$ Na_2O equivalent of active alkalis (Na_2O and K_2O) and 1 M NaOH solution. According to the “Procedura badawcza IBDiM (Investigation procedure in IBDiM)”, the samples were placed in water bath above the water level at temperature $38 \pm 2^\circ\text{C}$ and humidity $>85\%$. Measurements of the length of the concrete bars were made 14, 28, 60, 90, 180, 270 and 365 days after their formation. Quantitative determinations of the chemical composition of the reactive minerals and reaction products were made by means of a Cameca sx100 electron microprobe with the Noran Instruments EDS detector in the Microanalysis Laboratory of the Faculty of Geology, Warsaw University. Accelerating potential was 15 kV and beam spot size – $5 \mu\text{m}$.

RESULTS

After the 365-days-long experimental run, on the surface of the test bars there appeared light round spots 0.5 to 2.4 mm in dia. and fractures 0.15 mm wide and ca. 25 mm long (Fig. 1), typical of the products of the reaction of alkalis with silica. The increases of the concrete bar lengths equalled to 0.11% (Fig. 2).

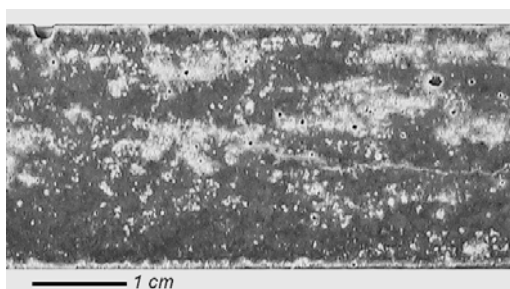


Fig. 1. Concrete bar surface after the whole run.

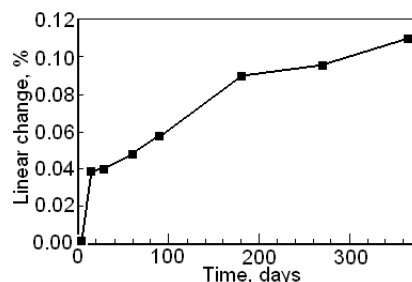


Fig. 2. Concrete bars length changes.

Polished thin sections were prepared from the altered places of the bars for the optical microscope and electron microprobe investigations. In most of such places there occurred the above-named potentially reactive components of the aggregate. In the contact with the cement paste one can observe in many places the occurrence of the substance being undoubtedly the product of reaction of the paste with silica from the aggregate grains. This substance is commonly called alkaline-calcic-siliceous “gel” (Regourd-Morainville 1989, Poole 1992, Owsiak 2000, 2001). The performed studies indicate that this substance not always is an amorphous true gel. It sometimes displays under polarizing microscope fractures typical of contracting dehydrated gel. However, it may be also partly crystallized, though its degree of crystallinity seems to be generally very low and extremely difficult to evaluate under polarizing microscope. However, the results of the analysis of chemical composition made by X-ray microanalyser (electron microprobe) suggested, that there are fragments of uniform composition, frequently differing in contents of

elements from the neighbouring parts. Thus, the physical state of the “gel” may have a very initial crystalline form and the fields or “domains” of this substance display great differences in chemical composition depending on the place of occurrence. Nevertheless calcium, sodium and silica are the main components.

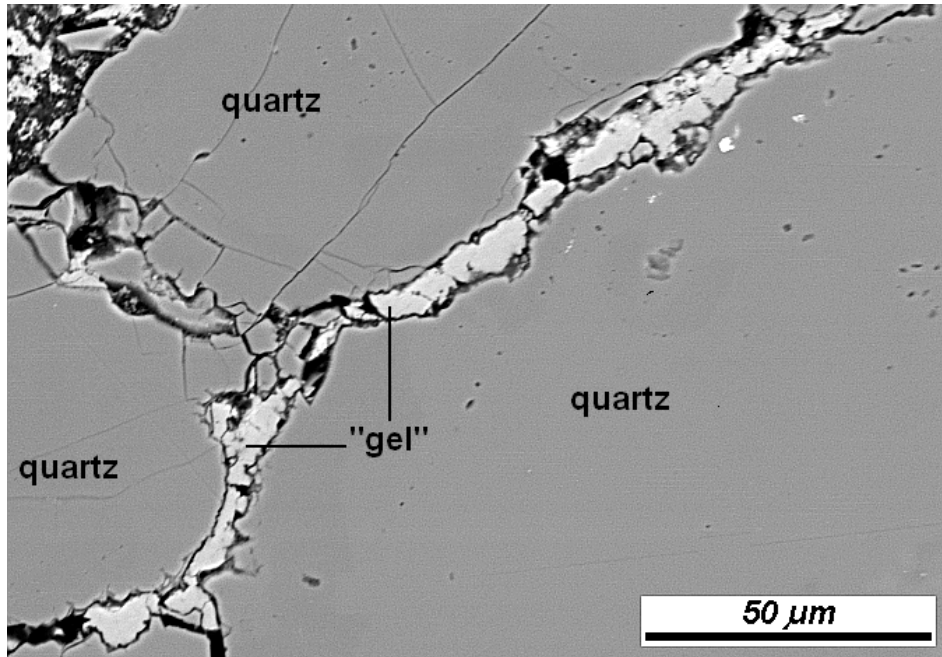


Fig. 3. Fractured quartz grain in concrete test bar, the fractures are partly filled by the product of the reaction of silica with alkalis from the cement paste. BSE image.

The fractured quartz grain (with inclusions of apatite) is a good example of silica mineral reacting with cement paste alkalis (Fig. 3). “Gel” occurring in the central part of the grain is lighter in the backscattered electron image, and has lower content of calcium and higher content of silicon than that in the marginal part of the quartz grain. Also “gel” surrounding the reacting quartz grain and in the contact zone with cement paste is darker than and has higher content of Ca^{2+} ions but lower of Si^{4+} than “gel” from the central part of the grain. Similar observations were made by Poole (1992). “Gel”, being initially a hydrated sodium-potassium silicate, migrates into micro- and mesofractures, filling them gradually. In the course of reaction “gel” accepts Ca^{2+} ions, transforming into a hydrated calcium-sodium-potassium silicate. In the initial stage around the reacting quartz grain a high concentration of Ca^{2+} occur, whereas Na^+ and K^+ penetrate into central parts of quartz via fractures. Later the ongoing reaction stimulates migration of Ca^{2+} ions into structure of gel, gradually replacing Na^+ and K^+ ions (Owsiak 2000).

CONCLUSIONS

1. Microscope analysis of the Quaternary gravel evidenced the presence of the potentially reactive mineral SiO_2 substances, consisting of chalcedony, opal, fine-grain quartz in pebbles of hornfels, chert, flint, lydite and massive quartz.

2. Concrete bars made from cement bearing active alkalis and Quaternary gravel aggregate, with 1 M NaOH added, after 365 days at $38\pm 2^\circ\text{C}$ and in humidity $>85\%$, revealed linear changes exceeding 0.1% and superficial alterations in form of round light spots and fractures up to 0.15 mm wide and up to 25 mm long.

3. The performed laboratory studies shown the presence of the product of the reaction of silica with alkalis – a hydrated calcium-sodium-potassium silicate called conventionally “gel”, which occurs in the fissures in quartz grains and at the margins of mineral or rock grains containing various forms of silica. This substance quickly loses a part of its water and maturates, probably entering the initial crystallization stage and the originating product has variable contents of Si^{4+} , Ca^{2+} , Na^+ and K^+ ions, depending on the distance from the contact of the reacting grains with cement paste.

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