Evolution of the Petrographic Textures of Concretes Suffering Alkali-Aggregate Reactions

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Abstract

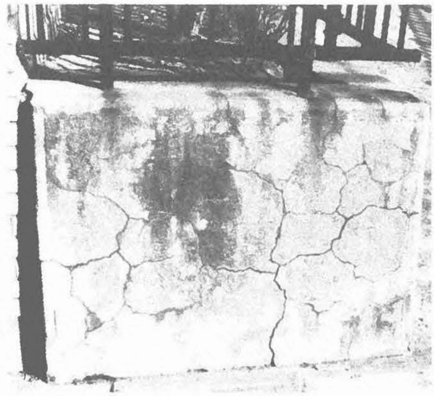
Petrographic examination of concrete specimens suffering damages caused by the alkali-aggregate reaction revealed the "histological" evolution of this disease as follows:1)The deterioration of concrete begins with the formation of fine reaction veins along the aggregate-cement matrix boundaries and in the matrix itself.2)The width of the veins increases with time.3)Carbon dioxide in the air diffuses deep in the structure and carbonates are formed in the matrix. 4)Finally the whole part of the matrix is carbonated and the concrete itself tends to disintegrate. The use of crushed andesite, chert, and granite cause most frequently this type of reaction. However, a possible reaction, caused by other kinds of rocks is also indicated in this study. The physical differences between crushed rocks and natural gravels are pointed out in this report together with the discussion about the causes of this disease of concrete occurring recently in Japan.

INTRODUCTION

Frequent occurrences of premature deterioration of concrete structures have awoken the attention not only of civil engineers but also the Japanese public. Fissures of several tenths of a mm width appear at first on the surface of structures such as pillars girders and retaining walls, aged 5 to 10 years. The same kind of anomalies are seen on the wall and floor paving of houses. The fissures increase in width with time and attain in the worst case, more than 6mm.

The 'cement matrix becomes loose and disintegrates. It is characteristic that the phenomena are limited to recent structures. Older structures, aged more than 50 years for example, are intact.

Figure 1: An example of the premature deterioration of a concrete wall of a house. The structure is aged less than 10 years.



The Japan Concrete Institute (JCI)* formed a commission to examine the extent of this "disease" in Japan and to determine its cause. As the first step of this workshop,they collected core samples taken from structures suffering this phenomenon. They performed both macroscopic, microscopic and X-ray examinations of these specimens.

EVOLUTION OF EXTERNAL ASPECTS OF THE CONCRETE

The deterioration begins with the appearence of fissures. The formation of these cracks are in conformity with the mechanical constraints prevailing in the concrete structure:they run in a vertical direction in the case of pillars and in a horizontal direction in the case of girders. A Fissure network with a polygonal pattern appears in the floor pavings or retaining walls (Figure 1).

The colour of the concrete is changed gradually from white-gray to pinkish brown. Transparent, slightly viscous liquid secretion is often observed along these cracks. Aggregates in the concrete are often sourrounded by thin (less than 0.1mm in width) white rims. Aggregates are often broken with flat fracture surface when a core sample is crushed by a hammer. This feature is not seen in the case of normal healthy concrete.

The surface of the concrete becomes more and more loose and sandy dust is easily scratched off by simple touch with a hard point.

*)Two (J.T.I and M.K) of the Present authors acted as members of the commission.

MICROSCOPIC OBSERVATIONS

The first sign of the deterioration is recognized under the microscope by fine reaction rim of 10-40 microns in width, between aggregates and cement matrix.

Detailed examination at this stage reveals the formation of very minute veins, few microns in width, in cement matrix. Veins are filled with amorphous transparent material which is supposed to be a kind of colloidal silica, with a small amount of sodium and other elements.

The reaction is most frequently seen in concretes using bronzite andesite which contains more than 40 % of glass in groundmass. **Aggregates in these concretes are** artificially crushed andesite prepared as a substitute for natural gravels.

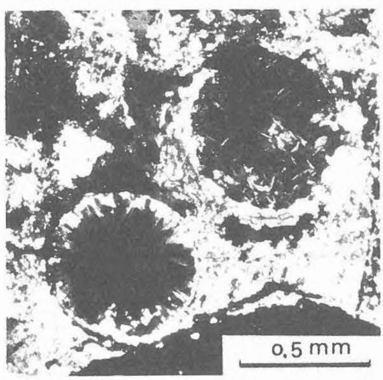


Figure 2: Microphotograph of a concrete suffering the fourth stage of deterioration. Crossed nicols Note the highly birefringent calcite aggregates and the presence of air voids and veins. Ascicular crystals formed in the interior of the voids are of unknown composition

The same kind of reaction occurs also in concretes using chert, granite, hornfels and natural sandstone pebbles.

The second stage of the reaction is the formation of very fine crystals of calcite disseminated in and around the reaction rim and veins. Carbon dioxide in the air diffuses in the reaction rim and veins, and reacts with calcium hydroxide of cement matrix. The width of veins and reaction rims around pebbles is widened and attains 50 to 100 microns. The presence of veins connecting the holes initially formed by air bubbles during concrete mixing should also be noted. The interior of these holes is filled with amorphous transparent materials;

calcite crystals are formed around them in the cement matrix. The concrete itself is still healthy except the presence of fine fissures.

Air bubbles were formed by the addition of an air entrain--ing agent and by the choice of high water/cement mixing ratio. These measures render the concrete slurry fluid and facilitate its placement. The texture of the resulting concrete becomes loose because of the excess water. The air bubbles may constitute a kind of reservoir of highly alkaline reactive solution.

The third stage of the deterioration is marked by the transformation of cement matrix to an aggregate of fine calcite crystals. The thickness of the transformed layer is limited 1 to 2 mm from the concrete surface.

Deposition of white material composed principally of calcite occurs on the concrete surface. Crystals of vaterite. cristobalite (formed metastably), quartz and anorthite (or larnite?) were found in some specimens. The deposit shows a layered structure marked by black dusty materials. Ettringite crystals were also found in some reaction veins. The deterioration of the surface of the concrete in this stage is still limited but its colour is changed to dark pinkish brown.

The fourth stage of the deterioration is marked by strong carbonation of the cement matrix. Under the microscope, the cement matrix seems to be entirely substituted by calcite crystals of 5 to 10 microns.

Because of the strong birefringence of calcite, its content in the concrete may be overestimated but it attains more than 50 %. The texture is loose showing no tight interlocking of calcite crystals. The bonding between aggregate and the cement matrix

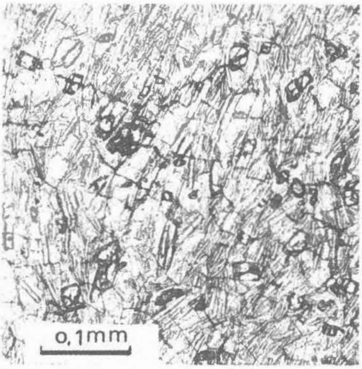


Figure 3: Microphotograph of an andesite aggregate found in one of the specimens of concrete examined.
Note the presence of a network of cracks.

is weakened. At this stage some pebbles are detached leaving smooth concave surfacesin cement matrix.

The fifth stage of the deterioration is the disintegration of calcite crystalline aggregate of the cement matrix.

POSSIBLE CAUSES OF THE ALKALI AGGREGATE REACTIONS OBSERVED IN JAPAN

The petrographic observation of concrete specimens shows that the use of artificial andesite aggregates for concrete preparation is one of the most remarkable causes of the alkali aggregate reaction (figure 4).

The andesite used in these structures is bronzite andesite containing a considerable amount of glass in the groudmass. Its weak resistance to alkali solution can be easily demonstrated.

It should be pointed out here that crushed natural rocks are, from physical viewpoint entirely different from natural river gravels and pebbles. Very fine cracks are formed in aggregates during crushing (figure 3). These cracks constitute potential passages for interstitial alkaline solution from the cement matrix. The chance of alkali aggregate reaction occurring is considerably increased with this kind of aggregate.

Natural gravels and pebbles are, on the contrary, exempt from these potential cracks. The transport by rivers or streams, of stones from mountain sites, disintegrates all parts of boulders containing fissures and joints.

The fact that the alkali aggregate reactions occur in concrete structures built after the first petroleum crisis may also indicate a change in the cement production process as one of the causes of deterioration. Energy conservation practiced in cement production can increase the content of reactive alkali oxide in final cement product.

The use of an air entraining agent and a high water-cement mixing ratio may also contribute to alkali aggregate reactions. The formation of reaction veins connecting air bubbles shown in figure 2, and other observed features such as the loose texture of the resulting concrete also contribute to the deterioration of concrete.

It is recognized that the carbonation of cement matrix is strongly accelerated by alkali-aggregate reaction and the final damage of concrete structures is caused by this reaction.

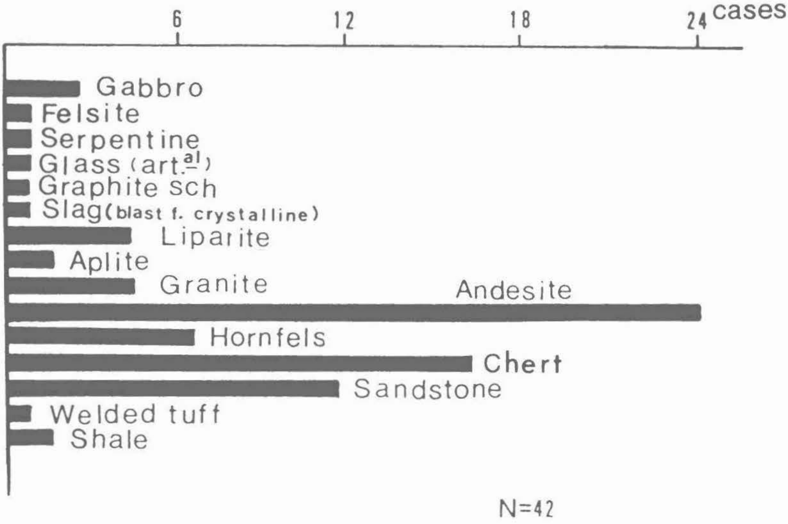


Figure 4:Histogram of rock species found in concrete specimens suffering the alkali Aggregate Reactions.

Number of specimen examined 42
Several species of rocks(1 or 2 rarely 3) were found in a same specimens.Each rock species was counted in the statistics.