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

ALKALI–SILICA REACTIONS BY OPAL PARTICLES IN JAPAN

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1. INTRODUCTION

Since 1983, the writer has surveyed about cracked concrete blocks whether alkali-silica gel occurred or not, by means of petrographic observation, and then researched what kind of rock in them reacted with alkali solution [1].

This observation method consisted of the following steps;

1) Sampling cores or blocks from the concrete constructions.
2) Cutting them by a diamond wheel cutter to make a flat surface.
3) Finding out alkali silica gel accumulation on it.
4) Making the spots comprizing the gel and the nearest aggregates into some thin sections.
5) Confirmation by a polarizing microscope what kind of rock the gel was derived from.

Among these observations it was found that opal particles in river sand reacted easily with alkaline solution in concrete, and the alkali-silica gel was formed to be in contact with them. The gel often acted on the surface of concrete as a pop-out eruption, and occasionally created expansional cracks in concrete constructions.

The alkali-silica reaction caused by opal was experimented, and reported by Hasaba, Kawamura, and Okada [2] but has not been clearly shown as case examples in Japan.

This report includes the petrographic descriptions on the alkali-silica reactions, the occurrences of opal particles in river sands, a method of detecting them and measuring their content, and examining mortar-bar tests about an example of the real river sand.

2. THE PETROGRAPHIC OBSERVATION

Pop-out phenomena occurred sometimes on concrete surfaces in different localities. Some of them were proved to be caused by alkali-aggregate reaction. Because the pop-out chips had opal small aggregates at their bottoms (fig.1) and the parts of alkali-silica gel were found in contact with the aggregates (fig.2).

The photographs of a thin section on the perpendicular plane to the surface exhibited to have an opalized volcanic aggregate at its bottom. A plagioclase phenocryst became to be opalized and the pseudomorphic texture were preserved (fig.3, 4). Adding the texture, the aggregate included alunite $[KAl_3(SO_4)_2(OH)_6]$ and sulfur which were characteristic of those hydrothermally opalized volcanic rocks.

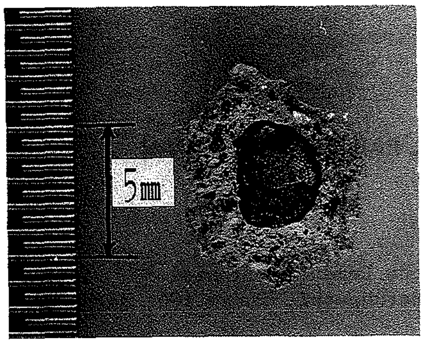

fig.1 A pop-out chip of concrete by AAR. A black particle is an opal fragment.

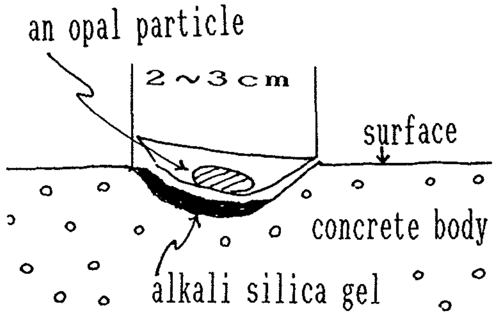

fig.2 An illustration of pop-out concrete by AAR.

fig.3 Microscopic photograph of pop-out chip (vertical section).
Op: an opalized fragment including plagioclase pseudomorph.

fig.4 The same part of fig.2 on crossed nicols. A plagioclase relict is also isotropic.

fig.5 SEM photograph shows siliceous fossils in porcelanite.

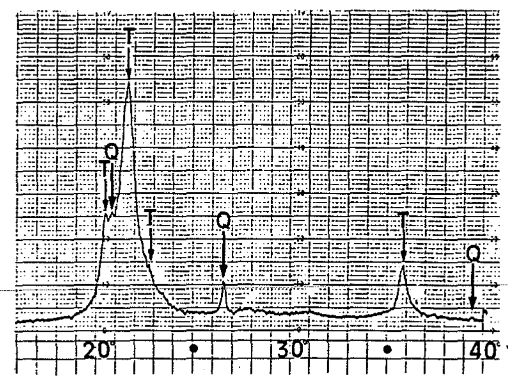

fig.6 XRD of porcelanite, T:tridymite Q:quartz

The opaline particles were occasionally derived from another kind of origin. It was a sedimentary rock to be called porcellanite, as it may be called siliceous shale, hard shale, or Opal CT. It was a marine sedimentary rock to be made of biogenic opal. The SEM photograph (fig.5) showed siliceous fossils in the particles which were etched by dilute hydro-fluoric acid.

The peaks of XRD showed the mixture of tridymite and quartz, but they were dull. On the hand, microscopically they were isotropic, and then any tridymite and quartz crystal could not be found.

In Japan this sedimentary formations are distributed from Niigata pref. to West Hokkaido, and are called Onnagawa formation, and etc., and the geological age was middle Miocene. These formations were compared with the Montrey formation in West coast of U.S., the age of which was also middle Miocene and which was the typical locality of porcellanite [3].

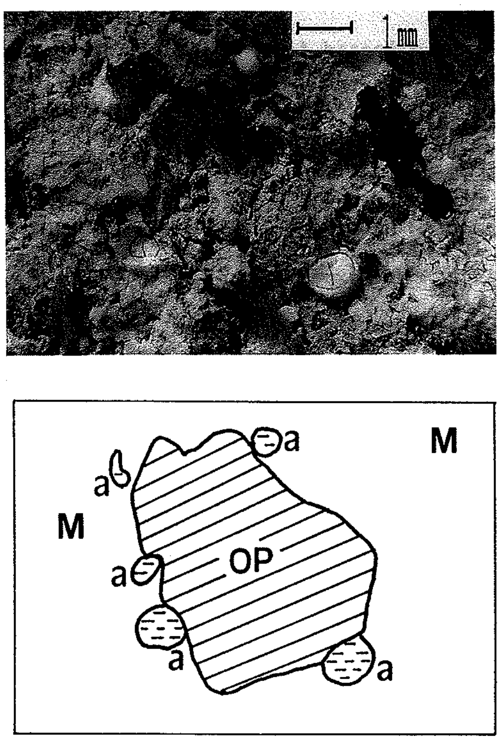

fig.7 The macrophotograph of a cracked concrete block. Many globules of alkali silica gel were formed around an opal particle.
Op:opal particles, a:alkali silica gel, M;mortar part, B:air bubbles

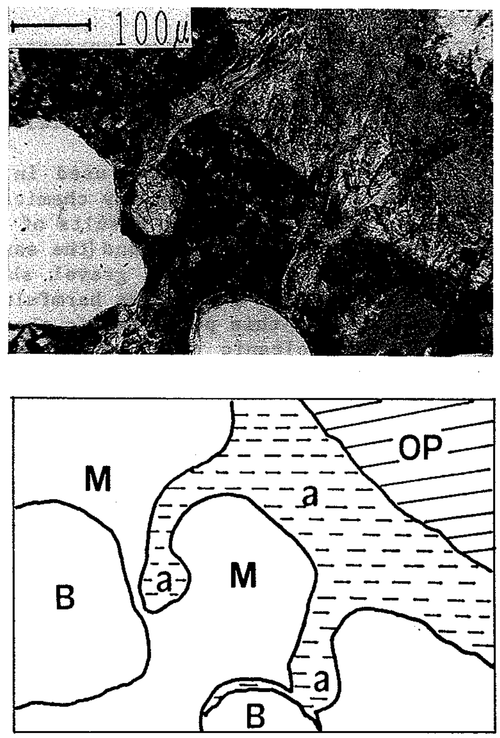

fig.8 This microphotograph showed the alkali silica gel was derived from the opal particle in the sand.

On the reports of AAR some destructions of concrete were found to be derived from opal rocks. The fine river sand along the West coast of U.S. brought about the popular AAR which was made clear by Stanton [4]. The sand included these porcelanite particles. The AAR reported at first in Japan [5] was assumed that the destructed concrete included the same type of rocks as the West coast.

On the petrographic observation of a destracted concrete the writer found that the AAR were originated from the particles of hydrothermally opalized volcanic rocks. The macrophotograph of fig.7 showed that a opal particle was surrounded with five alkali-silica gel globules on the cracked surface of concrete. Microscopically the opal particle changed to alkali-silica gel on its surface, and the gel flowed out towards the openings.

Both opal and the gel were istropic, and had lower refractive indicies than Canada balsam (n=1.55). However the opal had inclusions of alunite and sulfur minerals, and the gel (n=1.48) had higher refractive index than the opal (n=1.46).

In this concrete coarse aggregates were collected from the same river, and their rock types were granite and volcanic rocks. The volumetric ratio of them was nearly 1:1. The volcanic rocks were andestic lava and welded tuff which were originated from a same Tertially volcano. Each volcanic rock included volcanic glass.

The gravel and the sand used in the concrete were digged from the same river-bed. They were tested by chemical test and mortar-bar test (JIS A5308).

About both of them the results of chemical tests were in deleterious region [the gravel]: Sc=181, Rc=81, and [the sand]: Sc=194, Rc=95 (millimoles per liter). The mortar-bar test of the gravel showed 0.230% expansion at storing time-6 months and then the gravel was harmfulness.

However, on this petrographic observation any evidence of AAR could not be found on the volcanic rocks but the opal particles in the sand were the only reactive aggregates in this concrete. No opal rock was in the gravel. The precise contents in the sand could not be defined, but the floating particles in ZnCl heavy liquids (ρ=2.05) were measured as 0.23 wt% and all the particles were verified to be opal by polarizing microscope.

If the contents were nearly this order they might be too little to bring about AAR from the studies [2]. It might be guessed that the contents of opal in the river sand were heterogenious in each part, and opal particles had a tendency to accumulate to some parts by their smaller density, and then the destruction by AAR occured when the contents reached from one to several percent by weight.

3. THE MORTAR-BAR TESTS

Preparations and Testing Method

The active river-sand included opal particles; The opal was a porcelanite; The sand was sieved, and each part was mixed to have the particle size distribution according to JSCE-specification; The prepared sand included about 5 wt% opal particles which were measured by floating them on the solution saturated to ZnCl (ρ=2.04); Non reactive sand was prepared from Ottawa and Sakata quartz sands (particle sizes 1.2-0.15 mm); The used cement was a low alkali type of normal Portland cement offered by the Cement Association of Japan, Laboratory; The cement was 0.47% alkali content (equivalent percent Na_2O); these mortar-bar tests were examined at three alkaline levels (0.47, 0.80 and 1.20% Na_2O equivalent percent to the cement) by adding Na(OH) solution; The reactive river-sand was mixed with non-reactive sand and these mixtures were used for mortar-bar tests at each alkaline level; The mortar-bar tests were according to JIS A5308.

The Results

All the results of mortar-bar tests at 6 months were displayed on fig.9, and summarized as follows:

1) There was no harmful condition at lower alkaline levels (Na_2O equivalent 0.75, and 0.47%) on any mixtures of reactive river sand.

2) On these tests any obvious pessimistic condition could not be found at Na_2O equivalent 1.2% level. On 20% and 50% mixtures of reactive river sand the tests showed harmful expansion but the tests between them and about the others showed no harmfulness. Some other elements about these tests might be influenced on the expansions.

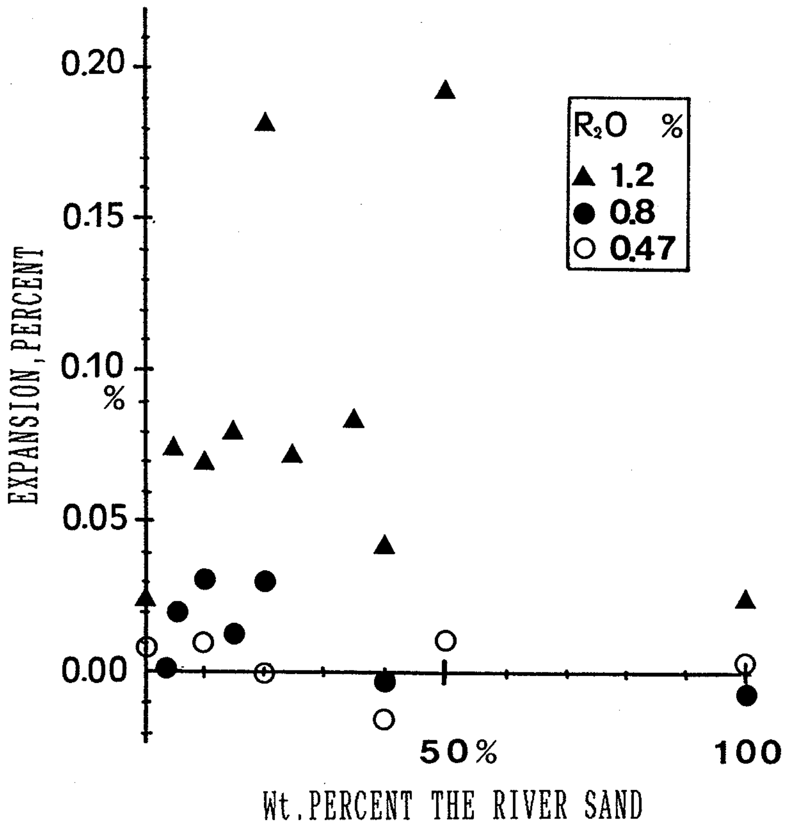

fig.9 Relationships between content of reactive aggregate and expansion of mortar-bar at 6 months

4. SUMMARY

By petrographic observations the writer researched that some alkali aggregate reactions resulted from opal particles included in the river-sand.

The opal particles originated from two kind of rocks. One was a porcelanite (a sedimentary rock), and the other was a hydrothermally opalized volcanic rock.

By expansion tests the harmful expansion might be occured by lwt.% opal content in the river-sand at 1.2% Na_2O equivalent.

The use of the low-alkali Portland cement will be effective to prevent this type of AAR.

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