Characteristics of Aggregates in Concrete and Alkali-Silica Reactions in Japan

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ABSTRACT. Visual examination of and sampling of test pieces were carried out on 21 concrete structures in Japan in which map-like cracks had occurred. Measurements of length changes were performed on these test pieces. In addition, measurements of the alkali reactivities of the coarse aggregates separated from the test pieces and analysis of their mineral assemblages by means of X-ray diffraction were undertaken. The results showed that in 20 structures the cracks were due or possibly due to alkali silica reactions. The rocks which were the cause of these reactions were aphyric bronzite andesite (so-called sanukitoids) and other andesites and cherts.

INTRODUCTION

Until recently no aggregates in Japan were known to show alkali silica reactions (ASR). But in 1983, it was made clear that the map-like cracks in concrete structures in the Osaka and Kobe region were due to ASR. The coarse aggregates used in these structures were bronzite andesites (sanukitoids), and these rocks were the cause of the ASR.

A 1984 questionnaire showed that map-like cracks were found in many concrete structures in Japan. To confirm whether these map-like cracks were induced by ASR or not, and to determine which kinds of aggregates are the cause of the ASR, various experiments were made.

EXPERIMENTAL

Object concrete structures

Most of the concrete structures which have map-like cracks are highway bridges. 21 structures were selected from among these with due regard to the state of deterioration and geographycal distribution. These structures had been constructed 6 to 22 years ago. 6 test pieces (10cm in dia., approx. 60cm in length) were cored from each of the structures.

Experimental procedures for the test pieces

Description: Naked eye and microscopic observations were performed in order to understand the distribution of the cracks, the reaction state of the test pieces and the rock assemblage of coarse aggregates.

Measurement of length changes: 2 stainless steel gauges were fixed in each test piece. The initial length of the test pieces is the length between the gauges after steeping in water (20°C, 24 hours). Test pieces were then cured at 38°C in wet conditions, and length changes were measured at curing ages of 4 weeks, 3 and 6 months.

Experimental procedures for the coarse aggregates

Measurement of alkali reactivities: The coarse aggregates were separated from the test pieces with a rock hammer and 6N-HCl (steeping 1 hour), then petrographycal classification of the aggregates was performed. ASTM C 289 was applied to the aggregates.

X-ray powder diffraction: X-ray powder diffractions (Cu target, 40kV, 20mA) were made on powder samples (less than 149μm) of the aggregates. The scanning range was 40° to 2.5° two theta.

RESULTS AND DISCUSSION

Length changes of the test pieces

Fig.1 shows the expansion of each test piece at curing ages of 4 weeks, 3 and 6 months. In the figure, the NA series indicate the results of the test pieces containing only non-reactive aggregates. Expansions of the test pieces taken from structures Nos. 7 to 12 and 20 are remarkably greater than those of the NA series. The above structures are considered not to be affected by causes other than the ASR. Sanukitoids are contained in Nos.7,8, 9,12 and cherts occur in Nos.10 and 20 in large amounts.

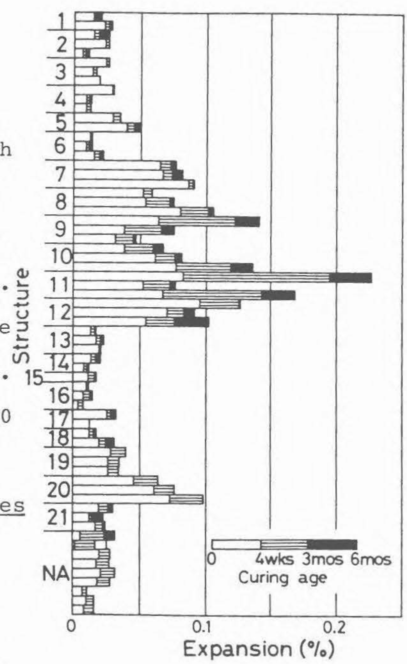

Fig.1 Length changes of the test pieces.

Characteristics and alkali reactivities of the coarse aggregates

Mode of occurrence and rock types of the coarse aggregates: The coarse aggregates consist of crushed stones, gravels and mixtures of both, in approximately the same proportion. The total number of classified coarse aggregates is 196. These consist of granites (7%), diabases (3%), porphyrites (3%), granite porphyries (3%),

Table 1 Relationships between ratios of appearance of sol-like products and alkali reactivities of the each rock types.

Rocks \ Reactivity	Ratios of appearance of sol-like products		
	Deleterious	Potentially del.	Innocuous
Granites	- (%)	- (%)	0 (%)
Diabases	-	-	0
Porphyrites	-	-	0
Granite por.	-	-	0
Andesites	50	28	0
Sanukitoids	100	100	-
Dacites	0	-	-
Rhyolites	67	100	0
Tuffs	0	-	0
Sandstones	0	-	0
Shales	14	-	0
Siliceous sh.	0	-	-
Chert	0	-	-
Others	-	-	0

andesites(21%), sanukitoids(11%), dacites(2%), rhyolites(4%), tuffs (8%), sandstones(5%), shales(9%), siliceous shales(5%), cherts(8%) and others(12%).

Reaction states of the coarse aggregates:Various phenomena caused by the ASR, such as reaction products around the aggregates and cracks in the aggregates themselves were observed in the test pieces just after sampling. In particular, we can identify deleterious aggregates by the appearance of sol-like products which occur on cut surfaces of the test pieces. Table 1 shows the relationships between ratios of appearance of sol-like products and the alkali reactivities of the each rock type. Volcanic rocks belonging to the deleterious and potentially deleterious categories as determined by the alkali reactivity test have high ratios, whereas sedimentary rocks have a low ratios. The Sc of the aggregates which develop the sol-like products are all more than 250 m mol/l.

Mineral assemblages of the coarse aggregates:In this section, only the coarse aggregates which are concerned with the ASR are described. Some of the andesites and rhyolites, and all of sanukitoids include cristobalite or volcanic glass which is a deleterious mineral. In addition, the andesites are composed of quartz, plagioclase, pyroxenes, chlorite, muscovite and illite. The sanukitoids consist of plagioclase and bronzite. The rhyolites contain quartz, orthoclase and plagioclase. The cherts are composed of large amounts of crystalline quartz and small amounts of chlorite and illite. The siliceous shales and shales contain more clay minerals than the cherts.

Rock types of the coarse aggregates and alkali reactivities: Fig.2 shows the results of the alkali reactivity tests of each of the rock types. Because 6N-HCl was used for aggregate separation, the chemical nature is changed from the original state, and the values of Sc and Rc are rather higher than those of aggregates separated from the test pieces without 6N-HCl. Therefore, the "deleterious?" category in the figure may be considered essentially "innocuous". As the figure shows, the alkali reactivities differ greately according to rock type.

This is more clear in Sc and Rc distributions of each rock type (Fig.3). All of granites have low Rc and belong to the innocuous category. Andesites and rhyolites have very wide range of Sc values. Sanukitoids constitute a high Sc group. Sandstones are distributed on the boundaries between the deleterious and innocuous groups. Shales, siliceous shales and cherts are under 100 m mol/l

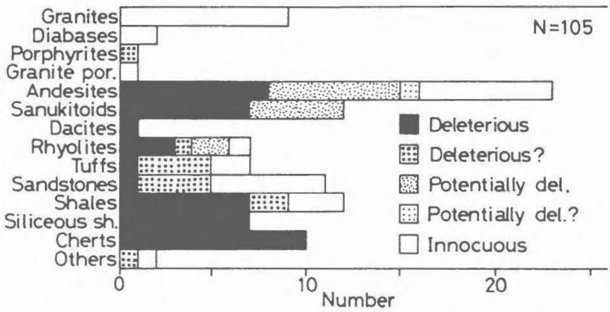

Fig.2 Results of the alkali reactivity tests of the each rock types.

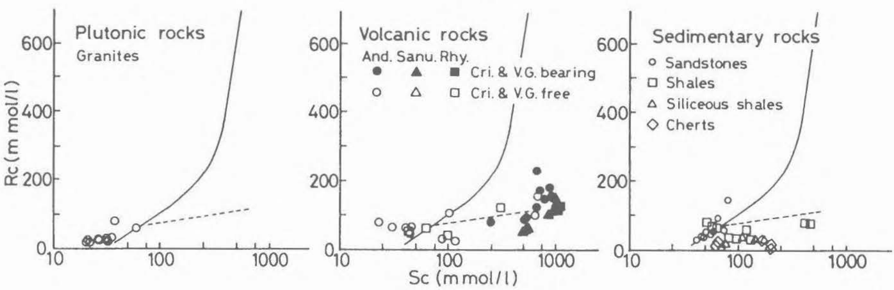

Fig.3 Sc and Rc distributions and rock types of the coarse aggregates.

Rc, and the almost deleterious category. Thus, the mineral assemblage, grain size and texture of rock are concerned along with the Sc and Rc distributions of each rock type. Volcanic rocks which include cristobalite and/or volcanic glass belong wholly to the deleterious category. The Rc values for the cristobalite-bearing rocks are higher than those for rocks containing volcanic glass. In sedimentary rocks, the Rc of shales containing clay minerals are higher than those of cherts, which are mainly composed of quartz.

Judging from the results of the alkali reactivity test for each structure, all the structures except No.13 contain deleterious aggregates.

Geological settings of the deleterious aggregates

Among the deleterious aggregates, the only rock types with known geological distributions are the sanukitoids, some andesites and cherts. They are all crushed stones. The so-called sanukitoids consist of aphyric bronzite andesite, erupted in the Miocene epoch. The andesites were also erupted in the Miocene epoch, and consist of porphyritic pyroxene andesites with large amounts of volcanic glass. The cherts are of the Triassic period. Except for the sanukitoids, these rocks are relatively widely distributed in Japan.

Distribution of the deteriorated concrete structures

The judgment on whether the map-like cracks of the 21 structures were produced by ASR or not was made by the reaction states, the expansion ratios of the test pieces and the alkali reactivities of the coarse aggregates. Only structure No.13 is considered to be unaffected by the ASR, because it does not contain reaction products and deleterious aggregates, and the expansions are small as in the NA series (Fig.1). The cracks in the other structures are caused by the ASR or possibly other factors. The distribution of them is shown in Fig.4.

CONCLUSIONS

The test pieces were cored from the 21 concrete structures which have map-like cracks. Various experiments were made on them. The conclusions are as follows:

1. All of structures except for No.13 are affected or possibly affected by the ASR.
2. The rock types in the aggregates which are the cause of the ASR are andesites, sanukitoids, rhyolites, shales, siliceous shales and cherts.
3. In the above aggregates, the only rocks with known geological settings are: (i) sanukitoids-Miocene, (ii) andesites-Miocene, (iii) cherts-Triassic.

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Fig.4 Distribution of the concrete structures studied and judgment of the ASR influence.