

Reaction Products of Alkali-Silica Reaction— A Microstructural Study

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ABSTRACT

Microstructural features of ASR as studied with the help of SEM with EDAX, chemical, petrography and XRD are described. The reaction products with metastable silica minerals in aggregates seem to be of separate formation and those with strained quartz alter the aggregates. Though occasional crystalline features are observed the ASR products are mainly amorphous gel-type.

INTRODUCTION

This paper presents the details of microstructural studies, characterising the products of alkali-silica reaction (ASR) in concrete dams after 25 to 30 years of service. In particular, the microstructural characteristics of ASR in case of reactive aggregates containing metastable silica minerals are compared with those caused by aggregates containing strained quartz.

DESCRIPTION AND METHODOLOGY

In the case of a concrete spillway to an earthen dam, the reactive aggregates were quartzite river pebbles containing chert and chalcedony. The second case was of a concrete gravity dam where the crushed rock aggregates were biotite-granite, muscovite-granite or mica-granite; in which 50-80 percent quartz grains exhibited strain effect with UE angle varying from 25 to 30°. No alkali reactive metastable silica minerals were present.

External manifestations of ASR in both the cases were typical map-cracking, long horizontal cracks in the gallery structures, mal-functioning of crest gates and sluice gates, misalignment of power generating machinery, cranes etc. Concrete core samples from such locations were fragmented for chemical, petrographical and instrumental analyses.

In case of quartzite, the primary evidence of ASR on visual observation was substantial presence of white, amorphous gel deposits on the aggregates, in the cracks and voids in the concrete, and on the smooth mortar-aggregate interface (Fig 1).

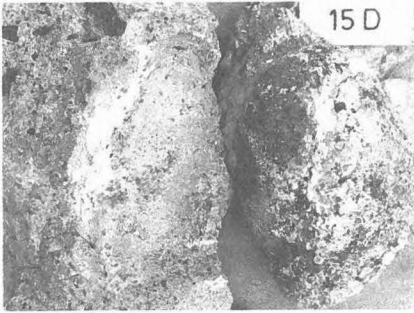


Fig 1 ASR in Quartzite



Fig 2 ASR in Granitic rocks

In the case of granitic aggregates, the presence of dark reaction rims was conspicuous but typical white alkali-silica gel was not so frequent (Fig 2).

RESULTS AND DISCUSSION

SEM Studies

Under the scanning electron microscope, quartzite aggregates in the first case were found to be surrounded by a reaction zone consisting mainly of an amorphous gel (Fig 3); sometimes with micro-cracks in the aggregate pieces. In many instances, such micro-cracks were apparently caused by the formation of the reaction products inside the aggregates. Gel also formed in micro-cracks in the mortar phase. An EDAX point analysis of these reaction products indicated considerable amount of K in addition to Si and Ca (Fig 4). Due to instrumental limitations Na could not be detected. In addition to the predominant amorphous nature of the reaction products, occasionally crystalline structures were also observed (Fig 5).

In the second case, the granitic aggregates contained reaction rims altering their borders. Sometimes micro-cracks were observed either in the aggregate or in the mortar phase or in both, similar to what was observed in quartzite aggregates. The products of reaction were either of fluffy, gel-type formation or of crystalline nature (Figs 6,7). EDAX point analyses in both showed the presence of K in much greater proportions than in the previous case (Fig 8). No ettringite could be detected in either case.

Chemical Analysis

A composite gel sample was made in both cases by carefully scooping out the gel from various locations; this was used for the chemical analyses, XRD and optical microscopy. The chemical analyses of the gels are presented in Table 1. The alkali contents were determined by flame photometry. The compositions were similar to the ranges indicated by others as representative of alkali-silica gel (Mather, 1952).

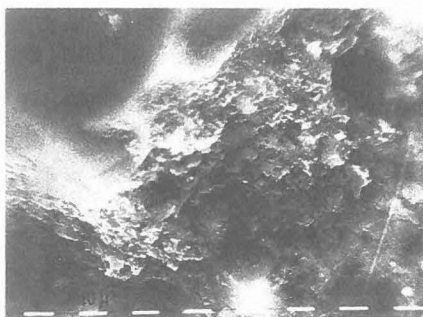


Fig 3

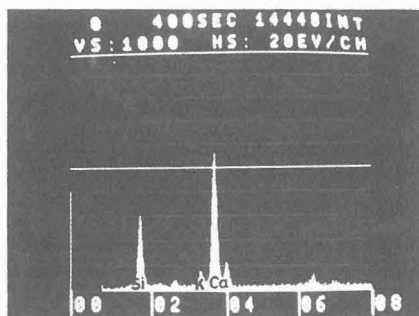


Fig 4

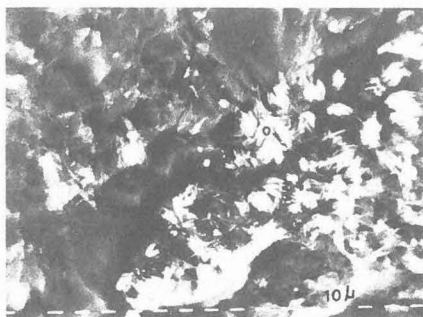


Fig 5

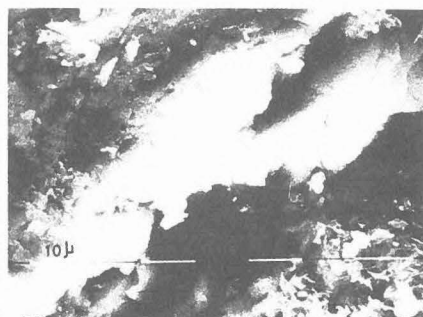


Fig 6



Fig 7

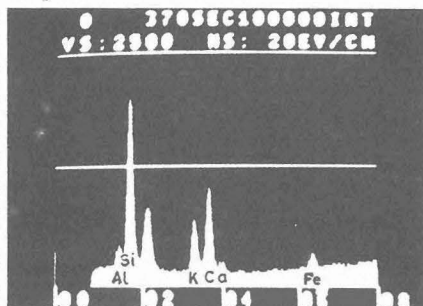


Fig 8

Figs 3-8; (3) Gel formation around aggregate (4) EDAX of gel (5) Crystalline structure and gel formation around aggregate (6) Gel formation (7) Crystalline structure (8) EDAX of gel and crystals. (Fig 3 to 5 refer to quartzite; 6 to 8 relate to granitic aggregates)

Petrography

The composite gel was petrographically examined under polarising microscope in immersion liquids. In case of quartzite the material showed the following distinct composition; (i)

TABLE 1
COMPOSITION OF GEL

Sl No	Constituents	Quantity, %	
		From Quartzite	From Granite
1	LOI	14.04	16.70
2	SiO ₂	43.31	49.36
3	CaO	21.76	15.94
4	Al ₂ O ₃	2.78	1.77
5	Fe ₂ O ₃	0.66	0.49
6	MgO	0.83	0.49
7	Alkalies		
	(a) Na ₂ O	3.74	3.88
	(b) K ₂ O	12.88	11.71

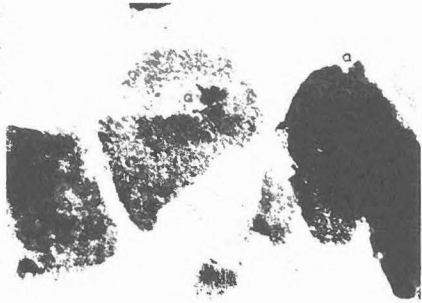


Fig 9 Grains of amorphous gel material (a) X25

amorphous gel-type matter of irregular shape (Fig 9), with refractive index 1.48 to 1.50 which compared favourably with 1.455 to 1.502 reported by Mather (1952); (ii) distinct small grains of chert or chalcedony with refractive index 1.50 to 1.52; (iii) crystalline material with patches of opaque mineral; (iv) crystals with slight anisotropism and no birefringence, presumably of the crystalline white deposits with refractive index of 1.42 to 1.48. The white material also showed occasional grains of aragonite and calcite with a refractive index of 1.65 to 1.66. In case of granite, similar features were noted except presence of chert or chalcedony.

XRD Analysis

Typical X-ray diffractograms of the alkali-silica gel obtained in both the cases are given in Fig 10. In the background of predominant amorphous nature of the gel and in addition to the typical cement hydration products, some new crystalline products, believed to be due to ASR, have been identified. In the case of quartzite pebbles, the peaks at 5.5, 16.7, 25.7 etc., degrees 2 θ (Cu-K α) were assigned to a crystalline alkali-silicate-hydrate of composition - Na Si₁₇O₁₃(OH)₃·3H₂O and other prominent peaks at 31, 29.8, 29.4 etc., 2 θ degrees to a composition - K₂Ca(SO₄)₂·H₂O. Contrasted to that, in the case of granitic aggregates, the prominent peaks at 6.9, 13.6, 30.5, 53.3 etc., 2 θ degrees are ascribed to a composition of crystalline potassium-sodium-calcium-silicate hydrate - (K₂Na₂Ca)₁₆Si₃₂O₈₀·2H₂O. These compositions are different from those reported earlier (Cole et al 1981).

CONCLUSIONS

The microstructure of alkali-silica reaction products are predominantly amorphous gel-type, with occasional crystalline habit. In case of metastable silica minerals, the products seem to be of separate formation, whereas, in case of strained quartz, it is more in the nature of alteration in and of the aggregates.

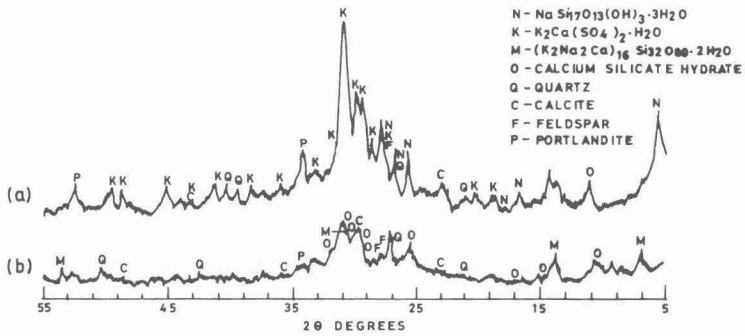


Fig 10 XRD of gel formed with (a) Quartzite (b) Granite

ACKNOWLEDGEMENTS

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