INTERACTION BETWEEN SELF-HEALING PHENOMENA IN 'OLD' CONCRETE STRUCTURES (DAM STRUCTURE) AND PRECIPITATED CALCIUM CARBONATE

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1. Introduction

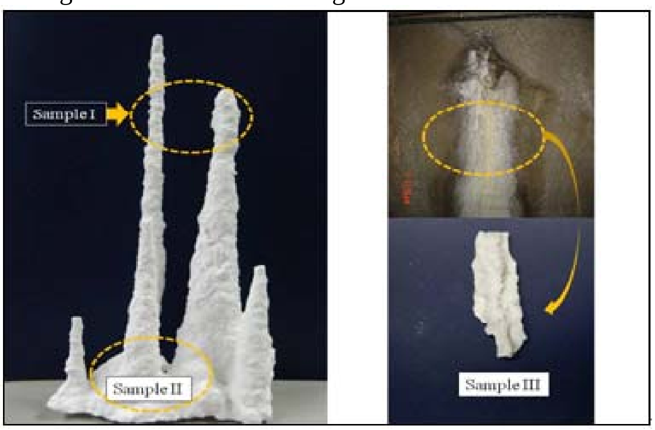
In this research, the self-healing phenomenon and secondary phases of newly-formed products based on concrete structures were investigated in a dam structure. Moreover, in order to understand the precipitation conditions of calcium salts in the cracks, morphology, and the shape and size of re-hydration products in the old concrete, microscopy and SEM(EDS)analyses were conducted. Kurobe Dam is one of the many large dams in Japan, and is located in the Tateyama Kurobe Alpine route on the Nagano side. It is situated in a deep canyon at an altitude of 1500 meters and dams the Kurobe river. Construction lasted seven years and the labor force amounted more than 10 million people. The total construction cost was 51,300 million yen at that time. There are tunnels inside the structure, as shown in Fig.1, and some areas of these tunnels showed many secondary phases on the ceiling and wall surfaces. These secondary phases were selected for sample investigation in this research. [1]

Fig. 1 Formation areas of secondary phases in the inner tunnel of Kurobe dam (Japan)

2. Experimental method

2.1 Materials

Fig. 2 shows a sample of secondary products on the surface and in the cracks of old concrete in the Kurobe dam. Three samples were selected for chemical analysis from a ceiling and wall as shown in Fig. 2.



(a) Ceiling side (b) Wall side

Fig. 2 Secondary phases on the surface and crack of old concrete in the Kurobe dam

2.2 Analysis of samples

Microscopy and SEM with EDS-detector were carried out to investigate morphology and the shape and size of re-hydration products. A JEOL JSM-5600LV SEM (Scanning Electron Microscopy) and a Keyence VE-7800 for microscopy were used. A JEOL JFC-1200 fine coater was used to gold-coat specimens. X-ray elemental microanalysis with Energy Dispersive X-ray Spectroscopy (EDS) was used in conjunction with the JEOL SEM. Moreover, the carbonation of re-hydration products was measured using a Fourier-transform infrared spectroscope (FT-IR). Each sample was scanned from 400 to 4000cm^{-1}. Observations were performed at each stop by moving around and following paste/aggregate bond zones and cracks.

3. Results and discussion

3.1 Relationship between $CaCO_3$ crystal and the presence of organic substrate in secondary phases

The XRD patterns of three samples showed that the samples are mainly composed of $CaCO_3$. Furthermore, in order to understand the precipitation conditions of calcium salts in this old concrete, FT-IR was conducted as shown in Fig. 3.

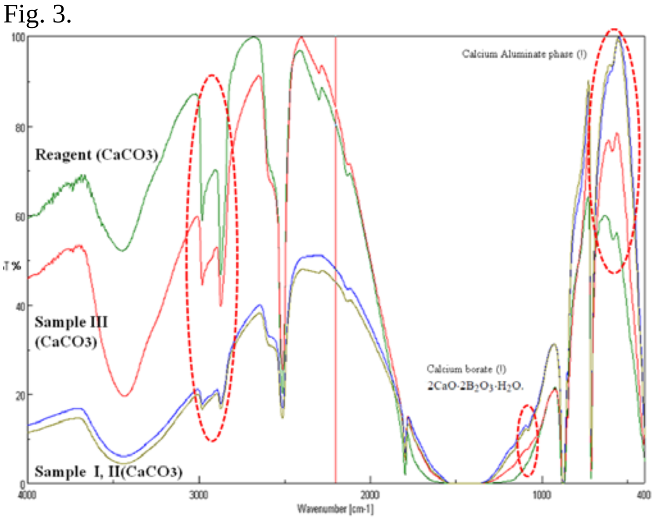


Fig. 3 FT-IR spectra of $CaCO_3$ precipitated in the presence of various organic substrates

The peak area of the particles nucleated in the absence of organic substrate was chosen as the reagent for comparison. The absorption that occurred around 3000-3500 cm^{-1} was characteristic of O-H stretching. IR absorption bands at 2510, 1423, 878 and 712 cm^{-1} are characteristic of $CaCO_3$, and at these regions [2], sample I, II and III are completely the same as the curve of the reagent. However, samples I, II and III also show the presence of various organic substrates compared to the reagent. These organic substrates only induce the nucleation and growth of $CaCO_3$ and they don't change the surface property of $CaCO_3$. The destruction resistance of $CaCO_3$ changed according to the type of

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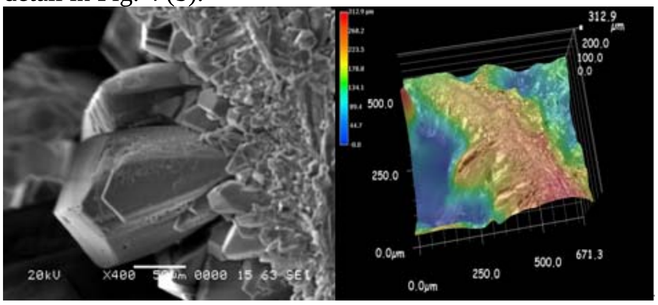
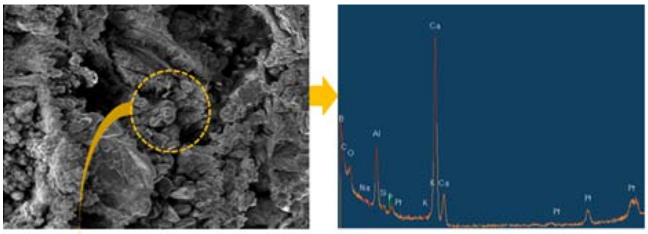
organic substrates. Sample III, from the wall, which had absorption band of organic substrate at 618, 591 and 405 cm^{-1} (calcium aluminate), showed high strength compared to samples I and II. Therefore, these substrates also seem to play an important role in the formation of $CaCO_3$. Furthermore, it is considered that utilization of appropriate organic substrates for the precipitation and the increment of strength of $CaCO_3$ is desirable. Fig. 4 shows the cross section area of sample I. It was found that many pores existed in sample I. It was primarily composed of several layers over time and showed nucleation and growth of $CaCO_3$ crystal between various layers, which are shown in detail in Fig. 4 (b).

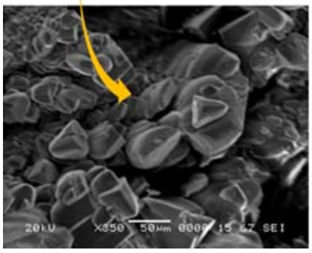


(a) (b)

Fig. 4 Nucleation and growth of $CaCO_3$ crystal on the layers

In addition, differences were found in the formation of precipitated $CaCO_3$ between organic substrates. In particular, the morphologies of $CaCO_3$ were different compared to rectangle $CaCO_3$. It was supposed that organic substrates affected the formation of $CaCO_3$. Fig. 5 clearly shows the differential formation behavior of $CaCO_3$. X-ray spectra obtained from these $CaCO_3$ revealed differential trends in their chemical composition as the formation of $CaCO_3$ including B and Al ions such as organic substrates as shown in FT-IR results. This means that various organic substrates affected the formation of precipitated $CaCO_3$ in the natural status.





Chemical Compositions	Wt%
B	49.84
C	22.86
O	4.62
Al	2.69
Mg	0.01
Si	0.12
P	0.02
K	0.11
Ca	19.72

Fig. 5 Morphologies of precipitated $CaCO_3$ in the presence of various organic substrates

3.2 Relationship between natural self-healing phenomena and precipitated $CaCO_3$

Fig. 6 shows natural self-healing area of a crack for sample III. The average crack width was 0.13mm, and most of the crack was fully filled by precipitated $CaCO_3$.

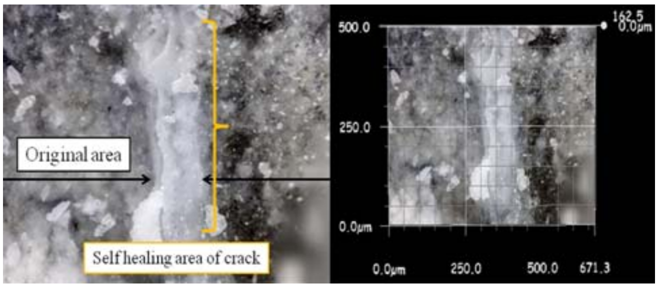


Fig. 6 Microscopy image of natural self-healing area based on precipitated $CaCO_3$ (crack width 0.13mm)

It seems that $CaCO_3$ precipitated through water passing through the crack, and the crack could be blocked by these precipitated $CaCO_3$ as water passed over time. Secondary phases include calcium aluminate phases which also showed high strength compared to samples I and II. In other words, the chemical properties of the secondary phases depended on the various organic substrate conditions. Therefore, the selection of appropriate organic substrates for precipitated calcium carbonates might be considered as one methodology for self-healing.

4. Conclusions

In this study, the self-healing phenomenon of old concrete structures from a dam structure in Japan was investigated. Various special factors from these results were suggested for the design of a cementitious composite with self-healing capability.

1) Precipitated $CaCO_3$ from old concrete structures showed the presence of various organic substrate compare to reagent.

2) This means that various organic substrates affected the formation of precipitated $CaCO_3$ in the natural status. Therefore, the selection of appropriate organic substrates for precipitated calcium carbonates might be considered as one methodology for self-healing.

Acknowledgments

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