Evaluation of Calcium Leaching in Concrete using High-intensity X-ray CT

Concrete is a widely used construction material that is normally very durable. However, it has been found that in some environments it deteriorates and breaks down. It is now understood that this deterioration results from ion elusion and invasion both internally and externally. Civil structures are normally expected to have long lifetime, sometimes more than one hundred years.

Deterioration due to leaching occurs gradually in structures in long-term contact with water. This results in the elusion of calcium, which is a major component of concrete, and is called leaching.

Leaching is described as follows. Concrete is a solidified mixture of cement and rock. The main components of cement are calcium and silicon. Cement solidification occurs with hydration, which generates calcium compounds. The resulting solidified cement structure is a porous material. Pores in the structure are connected and form a network. The calcium compounds are gradually dissolved in water that invades the pores. Dissolved and ionized calcium migrates into the concrete medium. As a result, in environments where the concrete is in contact with water, the solidified cement component of the concrete is gradually dissolved. This cement dissolution increases the porosity of the concrete structure. It is understood that concrete strength is correlated with its porosity.

This phenomenon of concrete leaching is currently considered to be the key to the long-term safety of structures. Due to the long-term nature of this process of at least a few decades, it is difficult to experimentally simulate it. Thus, an attempt has been made to predict the leaching rate by computer simulation. A leaching predictive simulator is constructed on the basis of diffusion equations.

There are complicated boundary conditions for concrete, which take into account various factors such as aggregate and cracks. The calcium diffusion rate with these conditions is determined in the simulation. Some of the aggregate and cracks are only a few tens of microns. To determine their distribution, observation by X-ray CT with a large visual field and high resolution in SPring-8, using beamline **BL20B2**, was necessary.

Calcium ion migration is described as a diffusion phenomenon. Thus, a diffusion coefficient for the concrete medium that fits the leaching conditions is indispensable. Understanding of the fine concrete structure is essential to understand the deterioration mechanism, including the diffusion coefficient. However, no observation method has been available, and fine structure study has relied on assumptions from macroscopic experiments. Thus, until now, a simulation-based fine concrete structure has been limited to a simple model.

Electron microscopy, the mercury injection method and X-ray CT, among others are now available for observing the fine concrete structure. Electron microscopy can allow us to only observe the surface, so it not suitable for structure observation. The mercury injection method can be used to measure the distribution of pore radius, but not to obtain the three-dimensional structure of the pores. The size of the picture element of the conventional X-ray CT is as large as over 10 microns. Furthermore, radiated X-ray energy is too large for concrete whose main components are light elements. Thus, conventional X-ray CT cannot be used to observe pore structure.

High parallelism and high brightness of the beam enable us to realize high resolution and high visibility for X-ray CT at beamline **BL47XU**. This accuracy cannot be obtained by other methods.

A cross-sectional image of the internal concrete obtained by X-ray CT is shown in Fig. 1. The

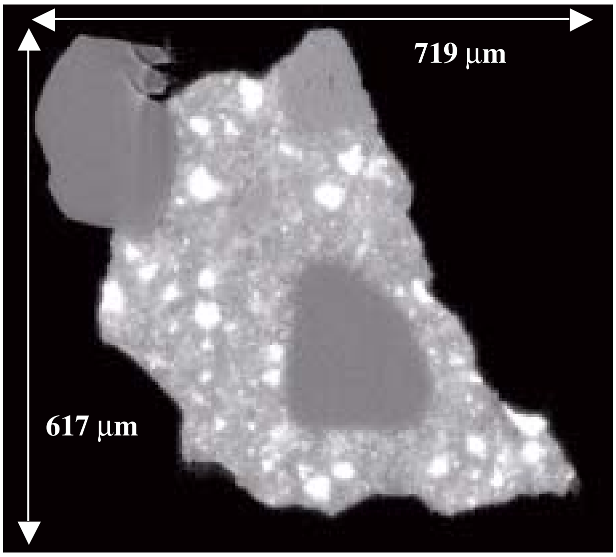

Fig. 1. Cross-sectional image of healthy mortar W/C 0.4.

specimen is made of concrete whose aggregate was removed under healthy conditions where no leaching occurred. The pores are shown as a dark color. The granular uniform structure shown in the figure is sand. The rock part and porous cement part can also be observed. A cross-sectional image of the concrete structure in which leaching occurred is shown in Fig. 2. It is found that the cement structure has many pores.

Digitization of these pictures enables us to capture the pores in the concrete cross section. Stacking of the pores in the cross section enables three-dimensional reconstruction. A three-dimensional image of the pores is shown in Fig. 3. The central part of Fig. 2 was three-dimensionally extracted and only the continuity of the cement structure was examined. The colored part in the region shows the pores that are vertically continuous in the scanned range.

Understanding of the three-dimensional structure of the pores enables us to determine the diffusion path of the ions that cause the concrete to deteriorate. Base data for estimating the diffusion coefficient of calcium and other ions are obtained from the diffusion path.

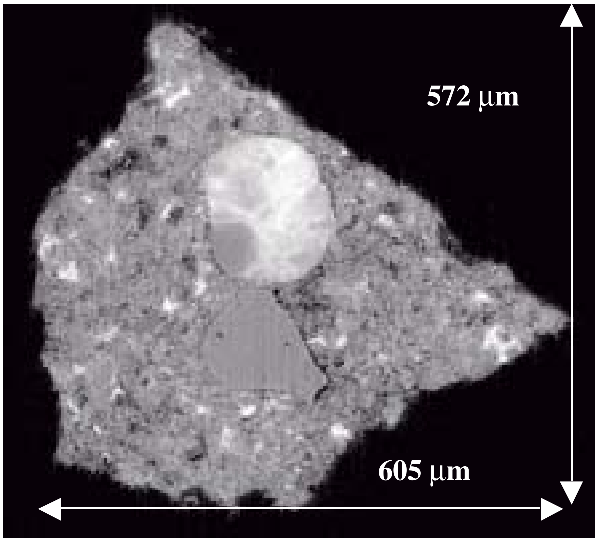

Fig. 2. Cross-sectional image of mortar W/C 0.4 with leaching.

It is impossible to capture independent air bubbles by the mercury injection method. Understanding of the independent air bubbles is essential in constructing a theoretical model that can predict changes in structures after deterioration occurs. Furthermore, the correlation between material strength and porosity would be clarified. Thus, the material strength at an arbitrary material age can be estimated from the degree of deterioration. Fine sampling is difficult because cement is a highly brittle material.

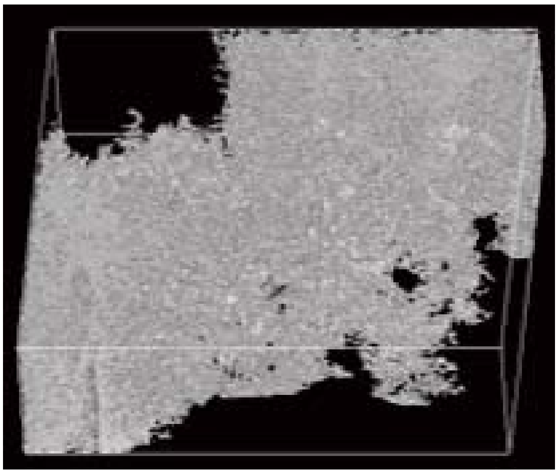

Fig. 3. Continuous pores of mortar W/C 0.4 with leaching.

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