OBSERVATION OF MICROSTRUCTURE OF COMPACTED BENTONITE BY X-RAY MICRO CT METHOD OPTIMIZED WITH COMPUTER SIMULATION

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INTRODUCTION

Compacted bentonite is a candidate buffer material for high-level radioactive waste disposal in Japan. Microstructure of compacted bentonite is considered to influence radionuclide migration in the buffer. To clarify the migration behavior of the radionuclide, nondestructive observation inside a bentonite sample is needed. An X-ray micro CT method is one of the most powerful techniques for microstructural study because of its high spatial resolution [1]. However, in order to acquire fine cross-sectional images, experimental conditions, such as voltage applied to an X-ray tube and filtering to attenuate the low energy X-rays, are needed to be optimized with taking into account size and elemental composition of sample. In this study, the optimum conditions in the X-ray micro CT observation for the compacted bentonite were estimated from the results of the computer simulation of X-ray transmission using a three-dimensional Monte Carlo Code (EGS5 [2]). The conditions evaluated were examined in the observation, and fine cross-sectional images were obtained from the observation under the condition.

SIMULATION OF X-RAY TRANSMISSION

Transmission of X-ray in the compacted bentonite was simulated in regard to the X-ray micro CT experiment. The simulation was performed by a Monte Carlo code, EGS5 (Electron Gamma Shower 5), which enables us to calculate electromagnetic cascade and interaction of charged particles in materials such as simples, compounds, and mixtures. The virtual system in the simulation corresponds to the experimental setup of the X-ray micro CT apparatus under atmospheric condition; an X-ray beam of 1 x 1 mm² in section from a source reaches a detector through a filter (Al or Ta) and a sample holder with bentonite sample under dry or water-saturated states. The dry density of the bentonite was 1.0 Mg m⁻³ and the sizes of the sample holder and the bentonite sample were the same as those in the experiment described below. The effect of the cavity on the X-ray transmission was evaluated for the bentonite samples with and without a cavity cube of 1 mm³ at the center of bentonite sample. Moreover, effect of the filter (Al or Ta) on the transmission and its dependence on the X-ray energy were examined.

X-RAY CT OBSERVATION

The microstructures of compacted dry and water-saturated bentonites were observed with an X-ray micro CT system, SkyScan-1172 (SKYSCAN), having about 1 μm resolution under the best condition. It consists of a sealed microfocus X-ray tube, 10M pixel cooled CCD fiber-optically coupled to scintillator, a rotatable stage to place a sample, and a data-processing system.

The bentonite samples used in this study was Kunipia F, Kunimine Industries Co., Ltd., Japan. The Na-bentonite power of 75-150 μm in grains size was prepared by homoionization followed by sieving. The Na-bentonite powder was compacted into a sample holder (glassy carbon tube with 7-mm outer and 5-mm-inner diameters, and with 10-mm high). A small amount of glass beads was introduced into the bentonite...
sample as reference. The water-saturation of the compacted sample was carried out by contacting the sample with de-ionized water through a sintered stainless filter.

RESULTS AND DISCUSSION

From the computer simulation with EGS5, it turned out that X-ray transmission in the lower energy region under 50 keV was sensitive to the presence of the cavity in the bentonite sample. In addition, the simulation indicated that the use of Al filter with thickness of 0.5-1.0 mm could effectively attenuate X-rays under 30 keV. It is said that artifact rings, which often appear in CT images, can be removed by using a monochromatic X-ray. Accordingly, it was concluded that the applying voltage of 50 kV and Al filter of 0.5 mm in thickness were an appropriate condition in the X-ray micro CT observation for the bentonite sample prepared in this study. Figure 1a shows the cross-sectional image of the dry bentonite sample observed under the condition. Well-defined cross-sectional images of the bentonite can be seen in the figure; both flake-like montmorillonite particles (Montmorillonite particles of elliptic shape) and circular glass beads are clearly observed. Especially the long axis of the elliptic montmorillonite particles in the figure is around 100 μm, which is in good agreement with that determined with SEM. In addition, the shape of glass beads is not distorted at any position inside the circle of the sample holder. Therefore, it is considered that the image reflects the information of the microstructure of the bentonite sample. Figure 1b shows the image of the water-saturated sample. Although glass beads are observed as clearly as in the dry sample, the montmorillonite particles are not seen, suggesting grain size of bentonite becomes less than spatial resolution of X-ray micro CT due to the water-saturation.

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References:

Figure 1: Cross-sectional images of (a) dry and (b) water-saturated bentonite samples observed with X-ray micro CT.