Thermal Conductivity of Compacted Ca-Bentonite for the Buffer Material in a High-level Radioactive Waste Repository

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1. Introduction

A repository for high-level radioactive waste would be constructed in the bedrock at the depth of several hundred meters below the ground surface. The repository would be expected to be room-and-pillar design, and the waste containers would be deposited into the boreholes drilled on the floors of the emplacement rooms. After the emplacement of the container, the gap between the container and the wall of the borehole would be filled with a buffer material [1,2]. The compacted bentonite has been considered as a potential buffer material. The engineered barrier system (EBS) of a high-level waste repository consists of the waste form, the container, and the bentonite buffer.

The major role of the EBS is to control the intrusion of groundwater, and then to minimize the release of radionuclide to the surrounding host rock. The coupled processes occurring in the EBS such as the heat generation from the waste, the intrusion of groundwater from the surrounding rock, and the stress changes due to the swelling of buffer material are the important issues in the performance assessment of the repository. The thermal conductivity of bentonite buffer material is a key parameter for the analysis of the coupled thermal-hydraulic-mechanical process occurred in the EBS. This study intended to measure the thermal conductivities of the compacted domestic bentonite with various dry densities and water contents, and also to investigate the quantitative relationship between the thermal conductivity and the dry density of bentonite.

2. Experimental

2.1 Materials

In Korea, bentonites are mainly produced from tertiary sediments in eastern Kyungsangbuk-do, and the bentonite used in this study is the product of Volclay Korea Co. in Kyungju. The bentonite was air-dried and passed through a 200 mesh of ASTM standard sieve. It contains approximately 53.2 % SiO_2, 22.1 % Al_2O_3, 8.4 % F_2O_3, and some minor elements and Ca^{++} is the predominant exchangeable cation. The results of X-ray diffraction analysis shows that the bentonite contains montmorillonite(70%), feldspar(29%) and small amounts of quartz(~1%). It has a cation-exchange capacity of 71 meq/100 g [3].

2.2 Measurement

The thermal conductivities in compacted bentonites with the dry densities of 1.2 Mg/m^3, 1.4 Mg/m^3, 1.5 Mg/m^3, 1.6 Mg/m^3 and 1.8 Mg/m^3 were measured within the water content range of 11.9 to 25.0 %. To measure the thermal conductivities, the bentonite blocks with the dimension of 150 × 60 × 20 mm were prepared. The bentonite was uniaxially compacted to the desired density in a stainless steel mould using a hydraulic press.

A quick thermal conductivity meter (Kyoto Electronics, QTM-500) was used to measure the thermal conductivities of bentonite blocks. In case of high water content, the bentonite blocks were wrapped with thin polyethylene film to prevent wetting of the probe. All measurements were done at 25 ℃.

3. Results and Discussion

When the water content is constant, the thermal conductivity of bentonite block increases with increasing dry density of bentonite. The thermal conductivity versus bentonite dry density has been plotted when the water content is 11.9 % and the results are shown in Fig. 1. The thermal conductivity increases from 0.36 to 0.82 W/mK with increasing dry density of 1.2 to 1.8 Mg/m^3. This phenomenon can be explained by the decrease of void fraction among the bentonite particles with increasing dry density. The relation between the thermal conductivity and the bentonite dry density can be fitted to a straight line. When the water content is 11.9%, the expression of this line is

$$k = 0.767\ \rho_d - 0.554 \qquad (r^2 = 0.988)$$

where k is a thermal conductivity(W/mK), ρ_d is a dry density of bentonite (Mg/m^3).

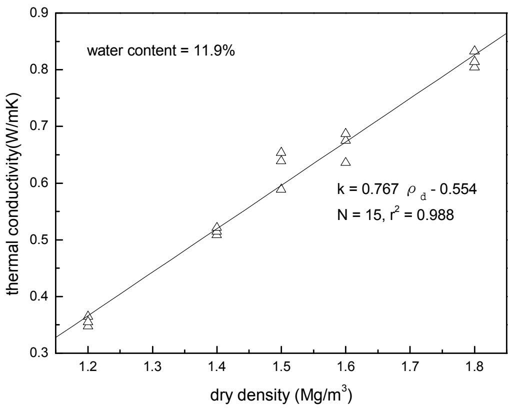

Fig. 1. Thermal Conductivity versus Dry Density of Bentonite (water content = 11.9%)

At constant dry density, the thermal conductivity of bentonite increases with increasing water content. As the water content increases, air with low thermal conductivity in the void among the bentonite particles is replaced by water with relatively high thermal conductivity. This results in the increase of thermal conductivity of bentonite. At the dry density of 1.6 Mg/m^3, the relation between the thermal conductivity and water content can be fitted to a straight line.

$$k = 0.046\ \omega + 0.124 \qquad (r^2 = 0.974)$$

where k is a thermal conductivity(W/mK), ω is a water content of bentonite (%).

4. Conclusion

The thermal conductivities of the compacted domestic bentonite with various dry densities and water contents were measured, and the experimental correlations were obtained. When the water content is constant, the thermal conductivity of bentonite increases with increasing dry density of bentonite. At constant dry density, the thermal conductivity of bentonite increases with increasing water content.

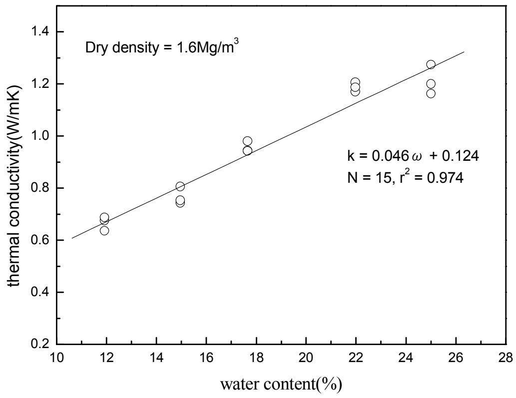

Fig. 2. Thermal Conductivity versus Water Content of Bentonite (dry density= 1.6 Mg/m^3)

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