Recent Suction and Temperature-Controlled Tests for Measuring the Mechanical Properties of Unsaturated Bentonite Buffer

Jaw Owan Lee and Geon Young Kim
Korea Atomic Energy Research Institute, Daedeok-daero989ben-gil 111,Yuseong-gu, Daejeon, Republic of Korea
jolee@kaeri.re.kr

1. Introduction

The mechanical properties of bentonite buffer are essential for the performance assessment and design of engineered barrier system (EBS). The mechanical properties have been measured mostly for saturated bentonite buffers, whereas measurements for unsaturated bentonite buffers have been performed recently and, for that reason, generalized measurement method and device are not established. Especially for unsaturated bentonite buffer, they are complicated and different depending on different investigators. Those difficulties are attributed to the problem of considering the swelling and high suction of unsaturated compacted bentonite and the elevated temperature due to decay heat of radioactive waste. The purpose of this study is to review the measurement methods (mainly for oedometer test and triaxial cell test) of the mechanical properties of unsaturated porous medium (soil, bentonite, etc.) reported in literature and, based on the review results, to suggest measuring systems which are suitable for the mechanical properties of unsaturated bentonite buffer for a Korean HLW repository.

2. Oedometer and Triaxial Cell Tests

2.1 Basic test concept

Consolidation is the removal of water and air from the pores of porous medium. An oedometer test is a geotechnical test to measure the consolidation properties of the porous medium during one-dimensional loading. The loading condition results in vertical strain without lateral strain in response to a change in effective stress during drying/wetting. A triaxial cell test is to measure the consolidation properties of the porous medium allowing independent control of the loading (stress) in three perpendicular directions. The three dimensional loading produces a total volume change (strain) of the porous sample during drying/wetting. Both the oedometer test and tri-axial cell test have several variations: Consolidated Drained (CD), Consolidated Undrained (CU), Unconsolidated Undrained (UU).

2.2 Suction Control

For the unsaturated porous medium, the void ratio and specific volume are different depending on the suction when a loading acts on the sample. Because of this, suction-controlled apparatus for the oedoemter test and triaxial cell test is needed to measure the consolidation properties of the unsaturated porous medium. There are two types of suction control method: axial translation (AT) method and vapor equilibrium (VE) method. The AT method is the most widely used suction control method. It is based on the fact that the liquid phase in a porous medium undergoes an increase in pressure equal to that of the gaseous phase. The AT method, which controls the matric suction $(\mathrm{s} = u_a - u_w)$of the porous medium, is applicable in the suction range of less than 1.5 Mpa, because water cavitation may occur in a higher value of matric suction. The VE method overcomes the limitation of the AT method which can not be applied to the higher suction >1.5 MPa. The VE method controls the relative humidity and thus total suction (including the effect of capillary action, osmotic force, and sorptive forces)

in the porous medium. It assumes vapor transfer and equilibrium with pore water in the porous medium. The thermodynamic relationship between total suction and relative humidity is based on Kelvin's law:

$$s = -10^{-6}\,(RT/V_w)\ln(RH/100) \qquad (1)$$

where s is total suction [MPa], R is universal gas constant [8.3143 J/K mol], T is absolute temperature, V_w is molar volume of water [1.8 x 10^{-5} m^3/mol]. This suction control method is applied especially to unsaturated bentonite with higher suction value >1.5 MPa.

2.3 Temperature Control

The consolidation properties of unsaturated bentonite buffer are affected not only by suction but also by temperature change due to radioactive decay heat. In most studies, the temperature-control has been performed by installing a water bath and heating coil in the suction-control test apparatus.

3. Discussion and Conclusions

The oedometer and triaxial cell tests are used for measuring the mechanical (i.e., consolidation) properties of unsaturated porous medium including bentonite buffer. They require suction control because the unsaturated medium has different consolidation properties depending on the moisture content. If temperature control is required, the oedometer and triaxial cell test apparatuses should be installed in a water bath or with heating coil to keep a constant temperature. The suction and temperature-controlled oedometer and triaxial cell test apparatuses are suitable for measuring the mechanical properties of unsaturated bentonite buffer for an HLW repository. As the unsaturated bentonite buffer has total suction and the suction value is high, it is reasonable to use VE method instead of AT method for the suction control of unsaturated bentonite buffer [Fig. 1 and 2].

The results of this study can be utilized to build a measuring system for the mechanical properties of unsaturated bentonite buffer which are affected under thermal-hydro-mechanical(THM) condition, and the mechnical properties determined using this system will improve the reliability of EBS performance assessment and design.

References

[1] Alonso, E.E., Hoffmann, C., Romero, E., "Pellet mixtures in isolation barriers," J. of Rock Mech. and Geotech. Eng. 2(1), 12-31(2010).

[2] Cai, G., Zhao, C., Li, J., Liu, Y., "A new triaxial apparatus for testing soil water retention curves of unsaturated soils under different temperatures," J. of Zhejiang Uni.-Sci. A (Applied Phy. & Eng.) 15(5), 364-373 (2014).

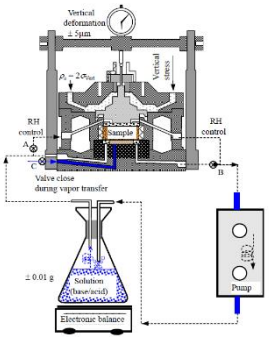

Fig. 1. Schematic diagram of oedometer test apparatus based on VE suction control [1].

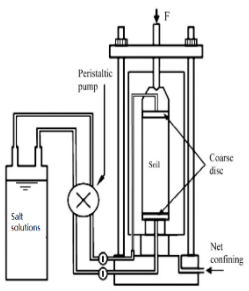

Fig. 2. Schematic diagram of triaxial cell test apparatus based on VE suction control [2].