Thermo-hydro-mechanical behaviour of compacted MX80 bentonite at 150°C

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Abstract

This paper presents the behaviour of compacted MX80 bentonite specimens when they are subjected at thermal and thermohydraulic gradients. The purpose of this work is to develop an improved understanding of heat and moisture movement in unsaturated clay barriers at temperatures above 100°C. Each specimen was statically compacted at 1.65 Mg/m³ and has dimensions of 300mm height and 100mm diameter. With the aid of a thermohydraulic column cell it was possible to apply boundary conditions that imitate the conditions in an underground repository. For the two ongoing tests undertaken in this study the applied temperatures were 25°C and 150°C at the top and bottom of each specimen. For applying the hydraulic gradient, water injected from the top of the specimen at a pressure of 600kPa. The test results show that, the temperature along the depth of the specimen stabilized in about 3-10 days whereas the relative humidity did not equilibrate. The exposure of the specimen at thermohydraulic gradient manifested a greater axial stress than that of the thermal gradient.

Introduction

The current concepts for engineered barriers in high-level radioactive waste (HLW) repositories suggest the usage of unsaturated compacted bentonite blocks as a buffer material. Main functions of the buffer are to protect the waste containers from rock movements by being ductile and retard the migration of ground water and radionuclides in a repository [1]. Bentonite has been widely considered as an engineered buffer material for deep geological disposal of radioactive wastes because of its low permeability, good swelling capacity, chemical buffering capability, etc. The hydrothermal conditions in the repository can trigger physical/chemical processes that affect the favourable properties of the buffer and can decrease its effectiveness to isolate the waste canisters from the biosphere [2].

In order to investigate the behaviour of compacted bentonite when it is subjected at high temperatures and hydraulic pressures a multidisciplinary research programme commenced called SAFE Barriers project (a Systems Approach For Engineered Barriers). The experimental investigation of the thermal, hydraulic, mechanical and chemical behaviour of the bentonite when it is exposed at high thermal and hydraulic gradients and the improvement of existing numerical models for temperatures above the 100°C have been studied at Cardiff University.

Properties of the MX80 bentonite

Laboratory tests were performed on an industrial MX80 bentonite from Wyoming, US acquired by the TOLSA group. MX80 bentonite has a montmorillonite content around 85%. The initial water content of the bentonite was found to be 15.2% at ambient laboratory conditions. The liquid and plastic limits are 439% and 62% respectively.

Experimental device

The thermal and thermohydraulic tests were conducted in a column thermos/hydro/mechanical (THM) test device. The tests were carried out on compacted bentonite specimens. The experimental device used (Fig.1) is able to facilitate both thermal and hydraulic gradients. Three types of measurements can be taken during the testing period. Five relative humidity and temperature probes bored along the depth of the cell made possible to measure the humidity and the temperature along the depth of the bentonite specimen. The generated axial pressure can be measured at the top of the column device with the aid of a load cell and a plunger attached to it.
Application of the cell
At first the raw bentonite powder was statically compacted to form specimens with 300mm height and 100 mm diameter. The compaction process took place in the same cell body which was used for the thermal and thermohydraulic tests. The possible extraction and reinsertion of the specimen in a different apparatus could cause rebound effects that would alter the desirable dry density. For the first ten days only thermal gradient applied at both tests. A constant temperatures of 150°C at the bottom end of the specimen applied with the aid of a steel heater. At the top end a constant temperature of 25°C sustained with the aid of a circulating copper coil connected to a heated circulating bath. For the tests subjected to hydraulic gradient, deionized water injected at the top of the specimen with a pressure of 600kPa.

Results and Discussion
Figures. 3, 4 and 5 show the effects of thermal and thermohydraulic gradients on the compacted bentonite specimens. Two tests are described in this section, a thermal and a thermohydraulic test. Both tests subjected on thermal gradient (25 °C at the top end and 150 °C at the bottom end of the specimens) for the first 10 days. The temperature equilibrated along the depth of the specimen within 96 hours. The achieved temperatures were 112, 90, 72, 59 and 49°C at 40, 60, 120, 180 and 240mm from heater respectively. The increased temperature led to an immediate increase of the specimens' relative humidity along their full length. Additionally at the areas closer to the heater (40, 60, and 120 mm from the heater) the relative humidity decreased after 4 days. With the application of thermal gradient the axial pressure at the top end of the specimens increased to a value of 1943 kPa for the thermal test within 21 days and further decreased to non-equilibrate values yet. After 10 days of thermal loading deionized water injected at the top of one of the specimens with a pressure of 600 kPa. The water supply decreased the temperatures within the specimen. The final temperatures were 110, 88, 70, 56 and 45°C at 40, 60, 120, 180 and 240mm from the heater. After a testing period of 80 days the relative humidity hasn’t equilibrate yet except of the area at 240mm from heater were due to the water intrusion the relative humidity reached the 100%. The hydraulic gradient increases the axial pressure to a value of 2,386 kPa. The axial pressure equilibrate after 60 days at a value of 2,267 kPa.
The behaviour of compacted bentonite when subjected to thermal and thermohydraulic gradients were studied. Compacted MX80 bentonite specimens with dry density 1.65 Mg/m³ were used. The tests’ thermal boundary conditions were 25°C at the top end and 150°C at the bottom end of the specimen. The hydraulic gradient achieved with the injection of deionized water was at the top of the specimen with a pressure of 600 kPa. The conclusion drawn from this study are: 1) The temperature in the specimen equilibrates much faster than the relative humidity. 2) Axial pressures were exhibited by both thermal and therohydraulic gradient tests. The axial pressure occurred at the latter test exceeded significantly the pressure recorded during the thermal gradient.

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**References**
