EFFECT OF HEATING-WETTING CYCLES ON ROCK PERMEABILITY

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EFFECT OF HEATING-WETTING CYCLES ON ROCK PERMEABILITY

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ABSTRACT

High temperatures that exist in rock mass can affect the properties of rocks, resulting in the formation of new discontinuities or expansion of the existing cracks. Such changes in the rock structure would likely influence the water flow in rock mass, which may undermine the rock storage capacity. This study seeks to investigate the effect of high temperatures on rock permeability. Fresh and weathered rock samples of argillite were subjected to heating and wetting cycles under the laboratory conditions to simulate the impact of high temperatures on rock mass. After each cycle the rock permeability was determined and compared with its initial value. It was found that as the number of heating-wetting cycles increased the coefficient of permeability of rock specimens also increased. However, this change depended on the initial rock properties and the number of heating-wetting cycles. The observed increase in permeability was attributed to the changes in the rock structure caused by the heating-wetting process.

Keywords: Rock permeability, Heating-wetting procedure, Laboratory testing, Argillite

INTRODUCTION

Variations in temperature and moisture content tend to affect the mechanical properties of rocks through the initiation of new or developing already existing cracks [1]. It is already known that 1) heating and cooling of rock can generate fractures through the thermal expansion and contraction [2], and 2) this process can close or open the existing fractures [3]. A better understanding of the effect of temperature on rock material is extremely important for underground waste repositories including nuclear waste. It is vital to contain the waste by preventing any leakage of hazardous material that can contaminate the surrounding environment. Although rocks are generally considered hard material with very low permeability, it can increase or decrease depending on the behavior of fractures under high temperatures. For example, recent studies [4] indicate that extremely high temperatures of 800-900°C resulted in lower values of permeability (by nearly four orders of magnitude) as the thermal stresses closed the existing fractures.

It is clear that temperature-induced changes in the rock structure would likely influence the fluid flow in rock mass, which may affect the rock storage capacity. This study seeks to better understand the effect of high temperatures on rock permeability.

TESTING PROCEDURE

Rock specimens used

Four borehole core specimens of argillite (diameter 50 mm) (Fig. 1) from the Neranleigh–Fernvale Beds formation [5-6], Gold Coast, Australia were used in this research. Two fresh specimens (F1 and F2) and two slightly weathered specimens (W1 and W2) were subjected to the same testing procedure that consisted of 3 heating and wetting cycles.

Fig. 1 A view of the fresh and slightly weathered rock used in this study.

Before testing, each specimen was enclosed in a concrete mould (diameter 150 mm) with fiber reinforcement as shown in Fig. 2. Silicone sealant was used to separate the rock from the concrete mould to ensure that the specimen permeability is not affected by the concrete.

Rock permeability tests

To conduct a permeability test, the permeability apparatus with a 50-mm diameter O-ring was positioned on top of the specimen and clamped down to the specimen as shown in Fig. 3. To begin the test, a pressure of 500 mBar was applied and the volume of water permeated through the rock specimen was measured every minute. The test continued for 15 min when only limited variation in pressure (less than 1%) was observed.

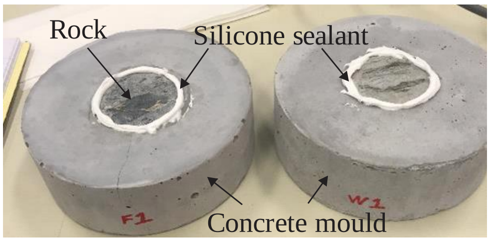

Fig. 2 Specimen preparation for the permeability tests.

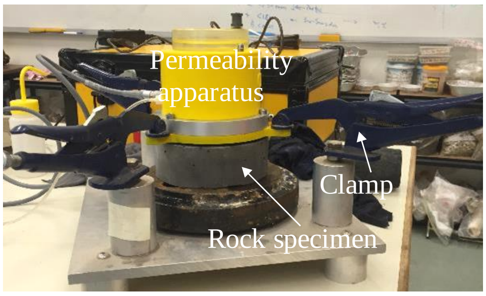

Fig. 3 Experimental setup used for a series of permeability tests.

Heating-wetting cycles

After the initial permeability test was conducted, the specimen was left to dry before starting the first heating cycle. The specimen was placed in an oven for 24 h at a temperature of 105°C. The specimen was then taken out of the oven and left in a controlled environment to cool before being submerged in distilled water (at a room temperature) for 24 h. The final stage of the heating cycle was to remove the specimen from the distilled water and let it dry for 24 h under controlled temperature (20°C) conditions. After each heating-wetting cycle, a permeability test was conducted to investigate the effect of the heating-wetting process on rock permeability. In addition, visual observations of the rock surface were performed after each cycle to study the influence of high temperatures on the crack formation and development.

RESULTS AND DISCUSSIONS

Permeability test results

Three heating-wetting cycles were performed and the obtained results for the fresh specimens of F1 and F2 are given in Fig. 4 as the variation of coefficient of permeability with time. This figure also presents the data recorded after each heating-wetting cycle. As can be seen in Fig. 4, the initial permeability of the rock was relatively low; that is, about 1x10^{-6} m/s for F1 and 5x10^{-7} m/s for F2. It is also clear from Fig. 4 that the heating-wetting process resulted in higher values of permeability for each specimen. It is interesting to note that for F1, a change in the permeability was much greater compared to F2. It is also evident from this figure that the coefficient of permeability of both specimens (F1 and F2) tends to increase with an increasing number of heating-wetting cycles.

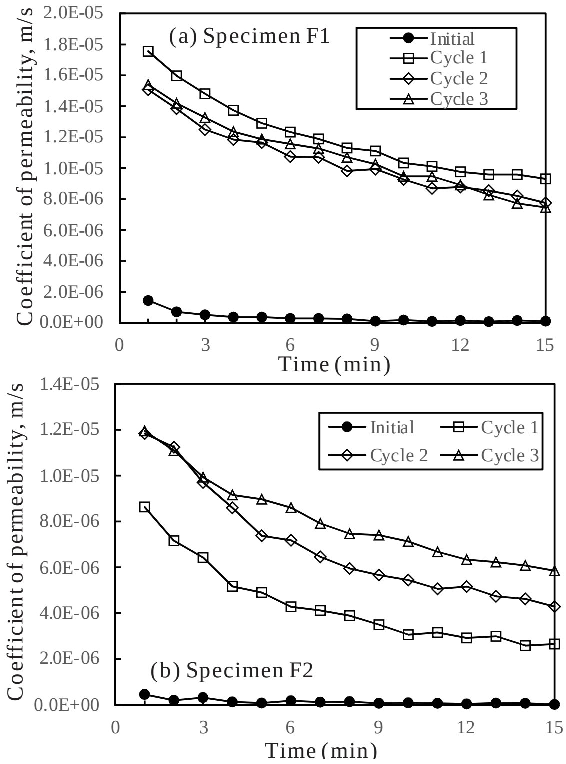

Fig. 4 Results from a series of permeability tests on the fresh specimens of argillite: (a) specimen F1, and (b) specimen F2.

A similar tendency was observed for the slightly weathered rock specimens (W1 and W2). The initial permeability was as low as the one observed for the fresh specimens: W1 – 1.4x10^{-7} m/s, and W2 – 3.5x10^{-7} m/s. In addition, the coefficient of permeability of both specimens increased as the heating-wetting procedure continued. It is noted that for W1, a significant increase in the permeability occurred after the third heating-wetting cycle while for W2, the increase appeared to be more gradual.

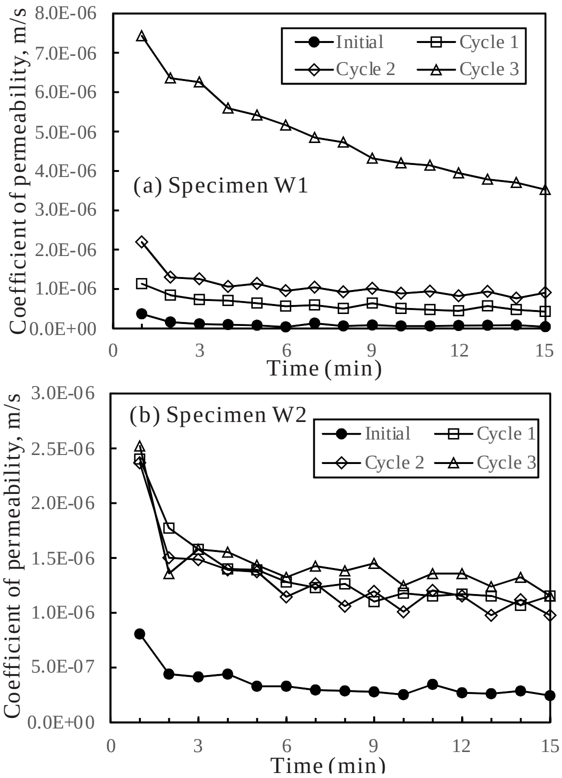

Fig. 5 Results from a series of permeability tests on the slightly weathered specimens of argillite: (a) specimen W1, and (b) specimen W2.

The summary of all permeability tests is given in Fig. 6 as changes in the coefficient of permeability with increasing heating-wetting cycles. It can be inferred from this figure that the initial coefficient of permeability of all specimens (both fresh and slightly weathered) was similar (about 1-3x10^{-7} m/s), and it increased after each heating-wetting cycle.

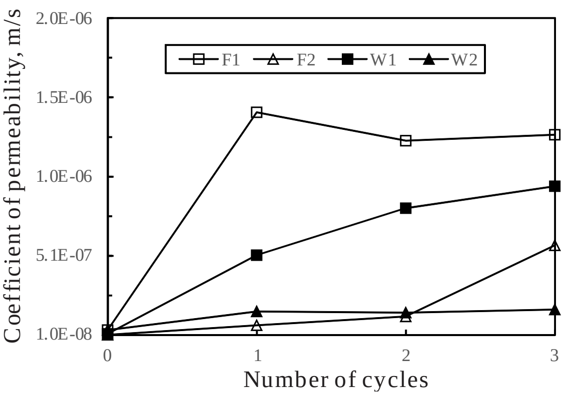

Fig. 6 Summary of permeability tests for the fresh and slightly weathered specimens of argillite.

Visual observations of rock surface

To better understand the effect of the heating-wetting process on the permeability of the tested rocks, the surface of each specimen was visually examined after each cycle. The surface of F1 (the specimen that exhibited the largest increase in the coefficient of permeability) is shown in Fig. 7a (before the heating procedure) and Fig. 7b (after the third heating-wetting cycle). The change in the rock surface was quite pronounced and can be described as follows: a) a central part of the surface was chipped due to the heating process, b) some minor cracks appeared on the surface as well. Such changes were believed to lead to a higher coefficient of permeability which was observed for F1. For the slightly weathered rock W2 (Fig. 7c), discoloration and some increase in the crack length were observed as a result of heating-wetting (Fig. 7d).

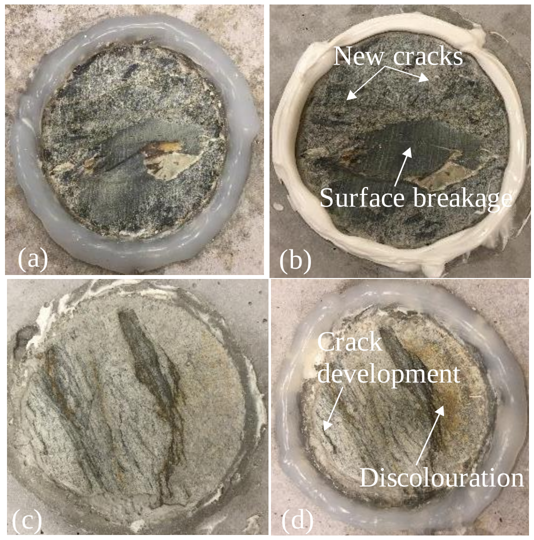

Fig. 7 A view of the specimen surface. F1: a) before the heating-wetting cycles, and b) after the third heating-wetting cycle. W2: c) before the heating-wetting cycles, and d) after the third heating-wetting cycle.

CONCLUSION

A series of permeability tests were performed on core specimens of argillite which were subjected to three cycles of heating and wetting. The following conclusions can be drawn:

- The permeability of the tested rocks, regardless of their weathering degree (fresh or slightly weathered), was found to be low, in the range of 1 to 3x10^{-7} m/s.
- The heating-wetting process caused some increase in rock permeability (approximately by one order of magnitude). This increase was observed for all tested rocks.
- The increase in the coefficient of permeability was mainly attributed to the formation of new cracks or extension of the

existing ones. These cracks were observed on the surface of each tested specimen.

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