Study on short-term permeability of fractured rocks under different confining pressures and temperatures

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1. INTRODUCTION

Fractured rocks are the main storage and transport place for groundwater in the underground environment, so the permeability of fractured rocks is important for underground engineering projects, such as geothermal energy extraction and underground radioactive waste disposal. **Yasuhara et al.** (2015) proved the influence of confining pressure, duration, and temperature; and **Kishida et al.** (2015) indicated the evaluation of permeability of fractured rock is dependent on fracture surface. Therefore, in this research, based on a permeability system which can be scanned by X-ray CT equipment during the flow through, the permeability changes and section behaviors will be studied. In this report, the short-term experiment results in loading-unloading processes under different temperature are indicated.

2. OUTLINE OF THE EXPERIMENT

Fig.1 exhibits a cylindrical granite sample with a diameter of 15mm and a height of 30mm.Tensile fracture was intentionally introduced at the center of the specimen.

Fig.2 illustrates a schematic diagram of the steady-state permeability test system. An internal heater is installed to maintain a constant temperature of the sample, while a bottom heater can heat the water flowing through in the tube. The syringe pump applies a constant water pressure to the sample. The cell pressure ranges from 0 to 3 MPa. Pressure sensors monitor the real-time water pressure at both ends of the sample and confining pressure around the sample. The discharge is periodically collected and weighed by the electric balance.

The cylindrical sample was placed in the cell and subjected to isotropic consolidation at an effective confinement pressure of 1.0 MPa. Subsequently, the confining pressure was loaded and unloaded for three cycles between 1.0 MPa and 3.0 MPa to improve contact between discontinuous surfaces.

After the completion of the three loading-unloading cycles, the test was started. The confining pressure was increased to 1.0 MPa at room temperature (25°C), and the input water pressure in the syringe pump set 200 kPa to initiate the permeability test. The confining pressure was then gradually increased to 2 MPa and 3 MPa to continue the permeability test, followed by a gradual decrease in confining pressure from 3MPa to 1 MPa for a separate permeability test. This loading-unloading process was repeated for three cycles. Subsequently, the temperature was raised to 60 degrees and kept the same water pressure, the loading-unloading process was repeated for three cycles.

Regarding of the steady-state permeability test at constant pressure, considering that the liquid is an incompressible solution, Darcy's law is used to calculate the permeability, as follows:

$$k = \frac{\mu q L}{\Delta P A}$$

where k is permeability of sample; q is volume rate of flow; L is the length of the rock specimen; μ is viscosity of the fluid; A is the cross section the rock specimen; ΔP is pressure differential across the rock specimen.

Considering the assumption that water only passes through the fracture, the hydraulic aperture is calculated as follows:

$$k = \frac{b^2}{12}$$

where k is permeability of sample and b is hydraulic aperture.

In order to ensure Darcy's law, laminar flow states need to be evaluated by Reynolds number. **Kishida et al.** (2013) indicated that the flow between fractured rocks can be regarded as a parallel plate model, and when the Reynolds number is less than 1, laminar flow states can be considered.

3. EXPERIMENTS RESULTS AND DISCUSSION

3.1 The influence of confining pressure

Fig.3 exhibits the hydraulic aperture changes of the sample under different conditions, which indicates that the hydraulic aperture continuously decreases in the loading processes with the increase of confining pressure. In the process of unloading, the hydraulic aperture tends to recover with the reduction of confining pressure, but this trend is not obvious in the initial three cycles of loading-unloading. This phenomenon indicates that before the first cycle at 25°C, the fractures may not be well-mated, the permeability is very large, but their matedness improved during the previous three cycles. In the next cycles, the permeability greatly decreases and reversible tendences can be observed. With the repeated loading and unloading cycles at 25°C, the hydraulic aperture continuously decreases from the initial value of 4.03E-7 to the final value of 3.80E-7 under a confining pressure of 1 MPa. This indicates that the matedness of the section continuously increases during the loading processes.

Fig.4 illustrates the relationship between permeability and confining pressure during the loading and unloading processes at 25 °C, demonstrating the reversible tendencies. Although the permeability cannot fully return to its initial state after the loading process, a clear reversible recovery curve can be observed.

3.2 The influence of temperature

Fig.5 illustrates the comparison of permeability at different temperatures. Similar changes in permeability are observed during the loading-unloading process at 60°C, and the permeability also shows reversible behavior, decreasing with the increase of confining pressure. However, the recovery of

Keywords: Permeability test, Short-term, Loading-unloading, Heating
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permeability appears to be reduced at 60°C, with a decrease of 2E-8 below the initial state after each loading-unloading process, compared to a decrease of about 1E-8 at 25°C.

The measured permeability and hydraulic aperture show clear temperature dependence, with permeability being lower at 60°C than at 25°C. This is due to thermal expansion, which results in a decrease in aperture and an increase in the contact area between fractures.

4. CONCLUSION

This paper reported the changes of permeability and hydraulic aperture of a granite fracture during loading-unloading processes at 25°C and 60°C. According to the results, the fracture permeability decreased with the increase of confining pressure and recovered in the process of unloading. It also showed that matedness of the fracture surface will greatly affect the hydraulic aperture. Therefore, before starting the permeability tests, it is necessary to improve the matedness. At the same time, the thermal expansion of the rock leads to decreasing in the permeability and hydraulic aperture.

Based on this study, X-ray CT equipment will be used later to observe the mechanical aperture of fractured rock sample, and at the same time, it is considered to continue to increase the temperature and a long-term water permeability test, so as to further study the water permeability properties of fractured rock.

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ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant Number 21H01869 and 22H01589.

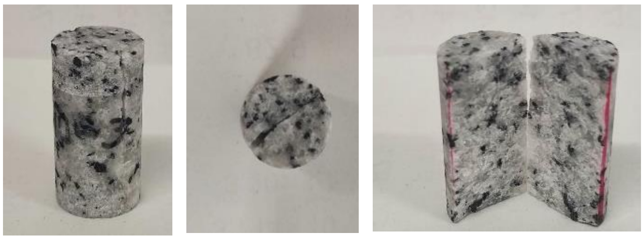

Fig.1 Granite specimen including tensile single fracture

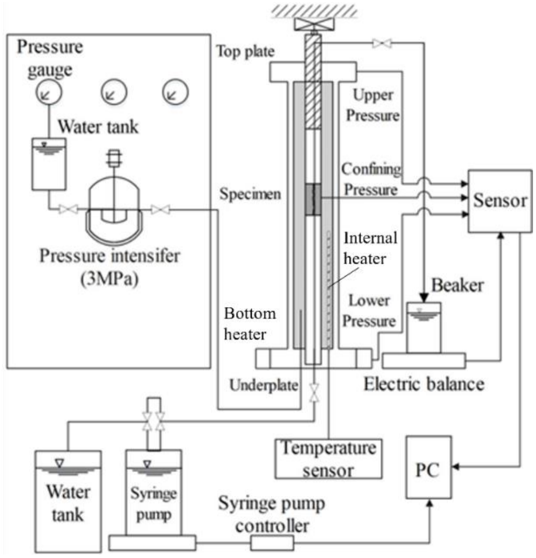

Fig.2 Schematic diagram of steady-state permeability test

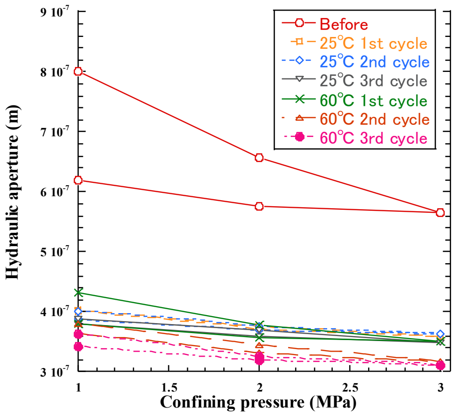

Fig.3 The hydraulic aperture and confining stress relation on the loading and unloading processes

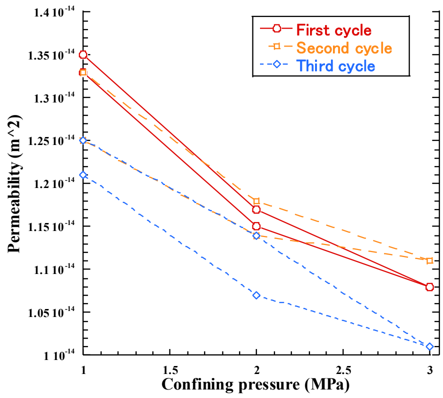

Fig.4 The permeability and confining stress relation on the loading and unloading processes at 25°C

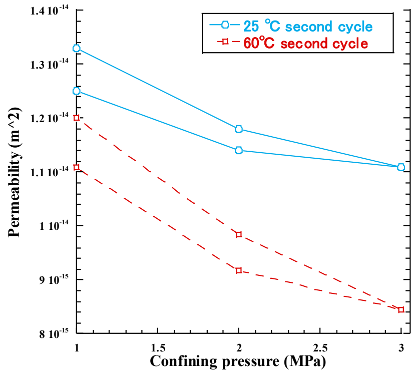

Fig.5 The comparison of permeability at different temperature