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Temperature-Confining Pressure Coupling Effects on the Permeability of Three Rocks under Compression

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The temperature-confining pressure coupling effects on the permeability of Shikotsu welded tuff, Kimachi sandstone and Inada granite under compression were experimentally investigated. Details of the experiments were described in Alam et al. (2014a, b).

In case of Shikotsu welded tuff, the permeability after 24 hour consolidation at 295 K was higher than the permeability at 353 K (Fig. 1a) and permeability under 15 MPa confining pressure (P_c) was the lowest. Permeability decreased monotonously during compression (Fig. 1c). The post-failure permeability at 295 K decreased with confining pressure (Fig. 1b). On the other hand, it was almost independent of confining pressure at 353 K and lower than that under 15 MPa P_c at 295 K. The flow speed was lower at 353 K (Fig. 2a).

The permeability decreased by failure (Fig. 2b) and the decreased ratio increased with confining pressure from 2% to 92% at 295 K. On the other hand, the ratio was almost independent of confining pressure at 353 K.

The post-failure porosity at 353 K under 1 MPa was as low as that under 15 MPa P_c (Fig. 3). This implies much stronger influence to porosity by temperature than by confining pressure.

In case of Kimachi sandstone, the permeability after 24 hour consolidation at 353 K under > 5 MPa P_c was slightly lower than that at 295 K (Fig. 4a). During compression,

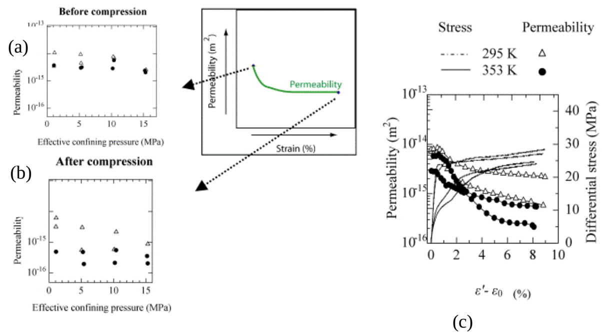
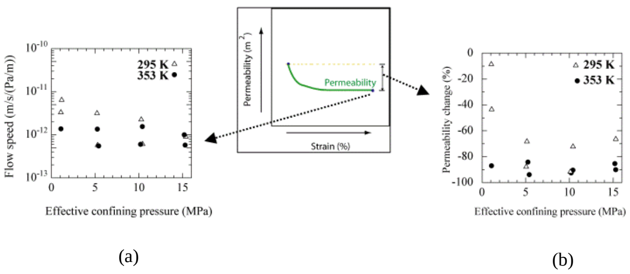


Fig. 1 Permeability of Shikotsu welded tuff.



Sig. 2 Flow speed and permeability change by failure of Shikotsu welded tuff.

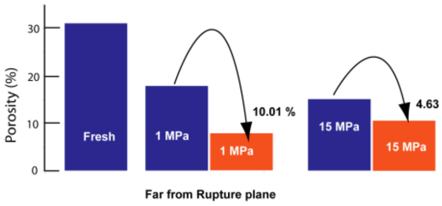


Fig. 3 Porosity of Shikotsu welded tuff after compression.

permeability decreased first, began to increase before peak load and showed almost stable value during the residual strength state (Fig. 4d). The minimum permeability decreased with confining pressure and no significant difference was observed between 295 K and 353 K (Fig. 4b). The post-failure permeability decreased with confining pressure and the permeability at 353 K was slightly lower than that at 295 K (Fig. 4c). The flow speed at 353 K was slightly higher (Fig. 5a).

The permeability at 295 K increased by as high as 180% by failure under low confining pressures (Fig. 5b). It however decreased by as low as 47% under high confining pressures. The permeability at 353 K decreased by almost the same amount as that under 15 MPa P_c at 295 K except for 1 MPa P_c.

In the post-failure specimens, main and subrupture planes with several fractures were observed under 1 MPa P_c at 295 K in CT images. Only one main rupture plane with a sub rupture plane was observed at 353 K. There were two rupture planes under 3 MPa P_c at 295 K but only one in the case of 353 K. The rupture planes were absent in the cases of 15 MPa P_c. The average thickness of cementing material was more strongly affected by confining pressure than by temperature (Fig. 6).

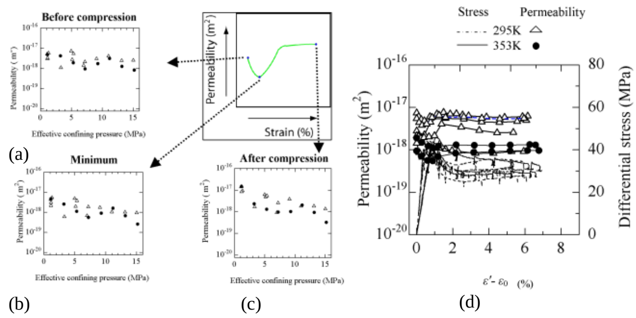


Fig. 4 Permeability of Kimachi sandstone.

In case of Inada granite, the permeability after 24 hour consolidation at 353 K was lower than that at 295 K (Fig. 7a). Permeability decreased, began to increase before peak load and showed almost stable value under residual strength state during axial compression (Fig. 7d). The minimum permeability at 353

K was slightly lower than that at 295 K and the difference was larger in low confining pressures (Fig. 7b). The post-failure permeability decreased with confining pressure up to 9 MPa P_c at 295K or 7 MPa P_c at 353 K, and increased afterward (Fig. 7c). The permeability and the flow speed at 353 K were obviously lower than those at 295 K (Fig. 7c, 8a).

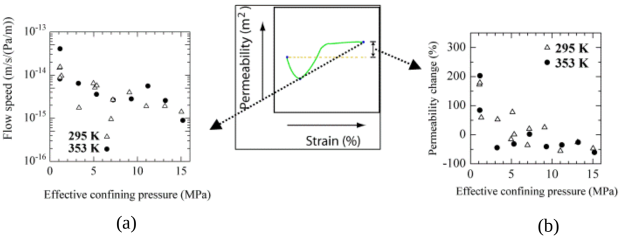


Fig. 5 Sealability and permeability change by failure of Kimachi sandstone.

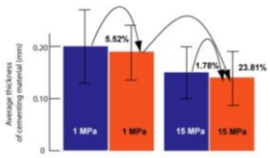


Fig. 6 Thickness of cementing materials of Kimachi sandstone after compression.

The permeability increased as high as 4780% by failure under 1 MPa P_c (Fig. 8b). The increase amount decreased until 9 MPa P_c to 394% and increased again up to 6640% at 15 MPa P_c. At 353 K, the permeability increase was as low as that under 9 MPa P_c at 295 K and did not show confining pressure dependency except for the result under 15 MPa P_c.

In the post-failure specimen, under 1 MPa P_c at 295 K, there occurred one distinct thick main rupture plane with a lot of subrupture planes and fractures in CT image. The rupture plane was a network of microcracks, and axial cracks from biotite were observed. Under 7 MPa P_c at 295 K, one main thin rupture plane was observed. Two main rupture planes formed at 295 K under 15 MPa P_c. One main thin rupture plane with a subrupture plane as well as elongation of biotite along the rupture plane was observed for 1 MPa and 7 MPa P_c at 353 K. Many subrupture planes and fractures formed under 15 MPa at 353 K.

The change in sealability of a deep underground opening due to EdZs and EDZs is discussed below, assuming that post-failure permeability can be used for rock mass fractures.

For Shikotsu welded tuff, groundwater flow along fractures does not have to dominate. Permeability decreases and sealability improves with progress of EdZs and EDZs. The sealability of EDZ under low support pressure may higher at 353 K than at 295 K.

For Kimachi sandstone, groundwater flow along fractures does not have to dominate. Permeability may increase in EDZs under low support pressure around the opening, but may decrease in either EDZs or EdZs under relatively high confining pressure. Permeability in EDZs may even decrease at 353 K, namely the total sealability improves.

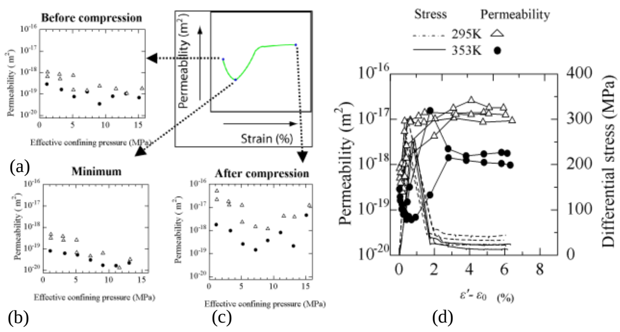


Fig. 7 Permeability of Inada granite.

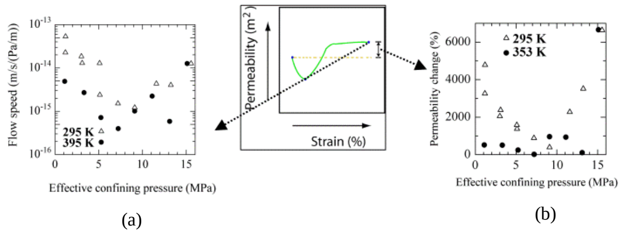


Fig. 8 Flow speed and permeability change by failure of Inada granite.

For Inada granite, the groundwater flow along fractures dominates. Sealability is poor regardless of EdZ and EDZ progress. The sealability becomes better at 353 K because of the lower flow rate.

Thermal stress, chemical processes, differences in the size and the origin (shear or tensile) between the rupture planes and rock mass fractures should be further investigated.

Acknowledgement

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