Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-P19 Room:Convention Hall Time:May 24 15:30-17:00

X-ray CT imaging and hydrologic characterization of fractured core samples under stress

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Analyzing fluid flow within naturally fractured samples under in-situ stress conditions is desirable. The present study first focuses on the feasibility of a precise 3D numerical modeling coupled with X-ray computed tomography (CT), which enables simple analysis of heterogeneous fracture flows within core samples, as well as the measurement of porosity and permeability. A numerical modeling was developed and applied to two fractured granite core samples having either an artificial single fracture or natural multiple fractures. With a linear relationship between the CT value and the fracture aperture, 3D distributions of the CT value for the samples were converted into fracture-aperture distributions in order to obtain fracture models for these samples. The numerical porosities reproduced the experimental porosities within factors of approximately 1.3 and 1.1 for the single fracture and the multiple fractures, respectively. Using the fracture models, a single-phase flow simulation was also performed. The numerically obtained permeabilities reproduced the experimental permeabilities within factors of 1.3 and 1.6 at for the single fracture and the multiple fractures, respectively. Consequently, a precise numerical modeling coupled with X-ray CT is essentially feasible. Furthermore, the development of preferential flow paths (i.e., channeling flow) was clearly demonstrated for multiple fractures, which is much more challenging to achieve by most other methods.

The method was then applied to two granite core samples having either a mated artificial or a mated natural fracture at confining pressures of 5 to 50 MPa. Numerical results were evaluated by a fracture porosity measurement and a solution displacement experiment using NaCl and NaI aqueous solutions. The numerical results coincided only qualitatively with the experimental results, primarily due to image noise from the aluminium liner of the core holder. Nevertheless, the numerical results revealed flow paths within the fractures and their changes with confining pressure, whereas the experimental results did not provide such results. Different stress-dependencies in the flow paths were observed between the two samples despite the similar stress-dependency in fracture porosity and permeability. The changes in total area of the flow paths with confining pressure coincided qualitatively with changes in breakthrough points in the solution displacement experiment. Although the data is limited, the results of the present study suggest the importance of analyzing fluid flows within naturally fractured core samples under in situ conditions in order to better understand the fracture flow characteristics in a specific field. X-ray CT-based numerical analysis is effective for addressing this concern.

Finally, a novel core holder with a carbon fiber reinforced polyetheretherketone (CFR PEEK) body has been proposed and developed. Medical CT scans for granite and sandstone samples containing a saw-cut fracture revealed that the core holder had no adverse influence on image quality due to the small X-ray attenuation. Moreover, with medical CT scans using the new core holder, a numerical analysis of single-phase flow was successfully completed on a fractured granite sample at confining pressures of 3-10 MPa, where real fracture porosities and permeabilities could be predicted within factors of 1.2-1.3 and 1.4-1.5, respectively. Although the maximum available confining pressure and sample size are currently limited due to the design, the novel core holder with the CFR PEEK body enables CT scans on fractured samples under confining pressure without image noise problem. Consequently, with the new core holder or a core holder having similar X-ray attenuation, the X-ray CT based numerical analysis can be successfully conducted on naturally fractured samples under confining pressure, which should contribute to better understanding of fluid flow characteristics in the crust.

Keywords: X-ray CT, hydrological characteristics, fracture, core sample, stress