地球開発環境学分野　Earth Exploitation Environmental Studies (Takahashi & Sakaguchi Lab.)

地殻環境・エネルギー技術の新展開

Toward Advanced Environmental Geomechanics and Energy Technology

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2022年に当研究室で行った主な研究は以下のとおりである。
1）軟岩体の水没鉛直井に適用可能な高精度地圧計測法の開発
2）鉱物の粒内と粒界の破壊靭性の実測に基づくき裂進展シミュレーション
3）超臨界 CO_2 による地熱貯留層岩石き裂のすべり挙動
4）花崗岩のマクロ破壊靭性とマイクロ破壊靭性
5）岩石の直交異方弾性と非線形弾性を考慮できる地殻応力評価法に関する研究

In 2022, our research activities were as follow:
1) Development of a high-precision rock stress measurement method applicable to submerged vertical borehole in soft rock mass
2) Simulation of crack propagation based on actual measurement of intragranular and intergranular fracture toughness of minerals
3) Slip behavior of a crack in geothermal reservoir rock by supercritical CO_2
4) Macro- and micro-fracture toughness of granite
5) Study on a rock stress evaluation method considering orthotropic and nonlinear elasticity of rock

軟岩体の水没鉛直井に適用可能な高精度地圧計測法の開発

軟岩体に対して、地表から削孔された水没している鉛直井で地圧測定が可能な新たな高精度地圧測定法として円錐孔壁ひずみ法を開発した。今年度は主に、実用化を目指した室内実験および原位置試験を行い、以下の成果を得た。
(1) 開発した掘削ビットによって所定の形状のボアホールを掘削・加工できることを確認した。
(2) 開発したボアホールカメラで十分な解像度で円錐孔壁の観察ができることを確認した。
(3) どぶ漬け接着法の実用性を確認した（Fig.3）。
(4) ストレインセルを含む測定部と貼り付け装置を分離する機構（新たに開発）が想定通りの機能を果たすことを確認した（Fig.4）。
(5) 開発した掘削ビット、センタリングガイド等で想定通りのオーバーコアリングができることを確認した。
(6) ストレインセルが接着されている回収コアによる二軸感度試験の有用性・有効性が確認できた。

Development of a high-precision rock stress measurement method applicable to soft rock submerged vertical borehole

The conical borehole wall strain method has been developed as a new high-precision rock stress measurement method for soft rock mass that is submerged in vertical borehole drilled from the ground surface. In this fiscal year, we mainly conducted laboratory experiments and in situ tests aimed at practical application, and we obtained the following results. (1) We confirmed that the developed drilling bit can drill and process a borehole with a predetermined shape. (2) We confirmed that the developed borehole camera can observe the conical borehole wall with sufficient resolution. (3) The practicality of the dipping adhesion method for the strain-cell adhesion was confirmed (Fig.3). (4) We confirmed that the mechanism (newly developed) that separates the measurement unit, including the strain cell, from the attachment device functions as expected (Fig.4). (5) We confirmed that the developed drilling bit, centering guide, etc. could perform overcoring as expected. (6) We confirmed the usefulness and effectiveness of the biaxial sensitivity test using the recovery core to which the strain cell is adhered.

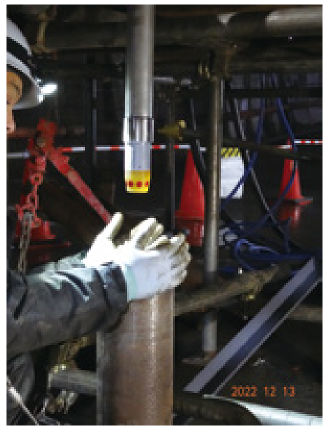

Fig.1 In-situ test for (3)

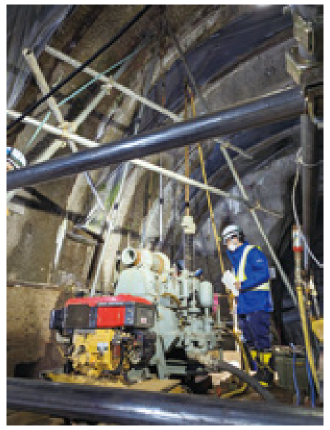

Fig.2 In-situ test for (4)

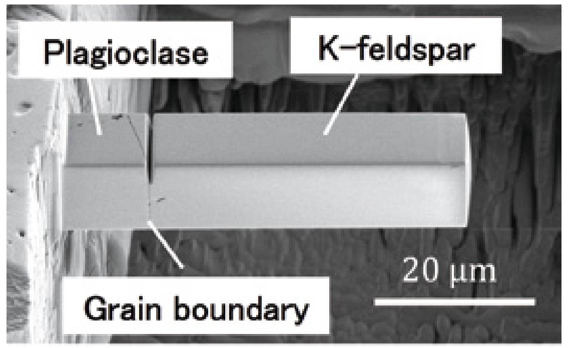

Fig.3 Specimen for grain boundary fracture toughness test

鉱物の粒内と粒界の破壊靭性の実測に基づくき裂進展シミュレーション

岩石の破壊メカニズムの解明を目的として、岩石の構成鉱物（石英、カリ長石、斜長石、黒雲母）の個々の破壊靭性試験および２つの鉱物の粒界の破壊靭性試験（Fig.3）を行い、得られたマイクロパラメータ（引張強度、粘着力、ヤング率）を用いてき裂進展の数値シミュレーションを実現した。破壊靭性試験はカンチレバー型の供試体を用いて、３種類の寸法の供試体（10μm×10μm×50μm、20μm×20μm×50μm、20μm×20μm×100μm）で行った。数値シミュレーションには個別要素法(DEM)コード PFC2Dを用い、SCB試験を対象としたシミュレーションモデルを、鉱物および鉱物粒界を模擬したGBM（Grain Based Model）で作成した。SCB試験のき裂発生、進展には、粒界や黒雲母といった弱い構成要素が影響を与えている可能性を明らかにした（Fig.4）。

超臨界 CO_2 による地熱貯留層岩石き裂のすべり挙動

超臨界 CO_2 地熱発電の実現のために、超臨界 CO_2 による岩石の間隙水圧誘起すべり実験を行い、すべり挙動の特徴の検討、圧入媒体による挙動の比較を行った（Fig.5, 6）。き裂面の性状や圧入媒体の違い（水と CO_2）による、すべり挙動（せん断膨張→初期すべり→定常すべり）には違いが見られないことが示唆された。初期すべりと定常すべりの速度比を超臨界水と超臨界 CO_2 で比較した結果、後者の方が小さいことが明らかになった。したがって、超臨界 CO_2 地熱発電は、誘発地震が抑制できる可能性を有している。

Simulation of crack propagation based on actual measurement of intragranular and intergranular fracture toughness of minerals

Individual fracture toughness tests on the minerals (quartz, K-feldspar, plagioclase, and biotite) that compose rock and the grain boundary fracture toughness tests of two minerals (Fig.3) were conducted to elucidate the fracture mechanism of rocks. A numerical simulation of crack propagation was realized using the obtained microparameters (tensile strength, cohesion, and Young's modulus). The fracture toughness tests were conducted with specimens of three types of cantilever shape (10 µm × 10µm × 50µm, 20µm × 20µm × 50µm, and 20µm × 20µm × 100µm). The discrete element method (DEM) code PFC2D was used for numerical simulation. A simulation model for the SCB test was created using a grain-based model that simulates minerals and mineral grain boundaries. We clarified the possibility that weak constituents such as grain boundaries and biotite affect crack initiation and propagation in SCB tests (Fig.4).

Slip behavior of a crack in geothermal reservoir rock by supercritical CO_2

Pore-pressure-induced slip experiments of rock by supercritical CO_2 were conducted to investigate the characteristics of slip behavior and to compare the behavior with injected media for the purpose of realization of supercritical CO_2 geothermal power generation (Fig.5, 6). It was suggested that no difference exists in the slip behavior (shear expansion → initial slip → steady slip) due to the difference in the properties of the crack surface and the injection medium (water and CO_2). As a result of comparing the velocity ratio between the initial slip and the steady slip for supercritical water and supercritical CO_2, it was found that the latter is smaller. Therefore, supercritical CO_2 geothermal power generation has the potential to suppress induced earthquakes.

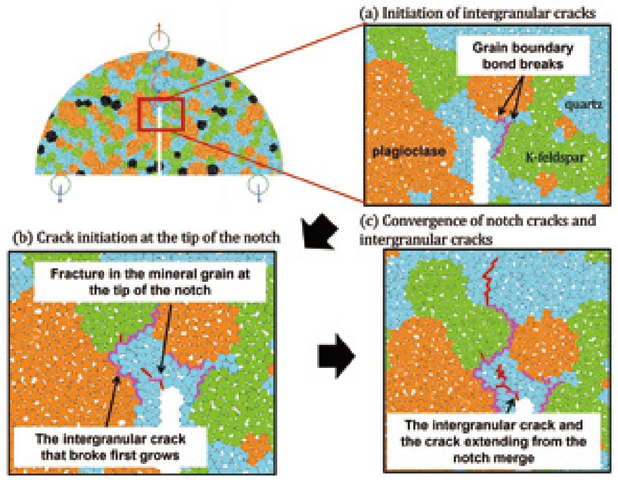

Fig.4 An example of numerical simulation results

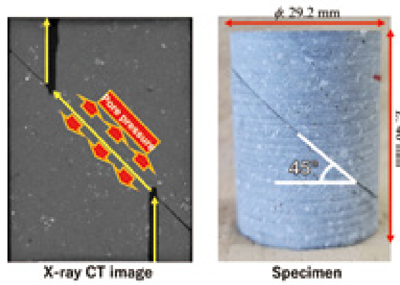

Fig.5 Specimen and image of pore pressure induced slip experiment

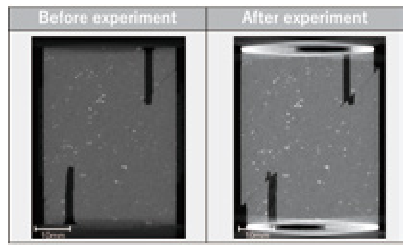

Fig.6 X-ray CT image of specimen of before and after experiment