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Mechanical properties of shale following saturation with CO2 and CO2-based fluids: experimental and modeling study

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Impacts of saturation with CO_2 and CO_2-based liquids are vital for understanding shale's mechanical properties associated with supercritical-CO_2 optimized shale gas extraction and geological capture and storage of CO_2 in shale reservoirs. A sequence of triaxial compression tests is performed to examine the impact of subcritical CO_2, supercritical CO_2, subcritical CO_2-water, supercritical CO_2-water, subcritical CO_2-NaCl, and supercritical CO_2-NaCl saturation on shale strength. A statistical damage constitutive model of shale after CO_2, CO_2-water, and CO_2-NaCl saturation is established to describe shale's stress-strain relationships under various immersion conditions.

The laboratory findings indicate that the change of the axial stress, Young's modulus, and axial strain of shale after immersion verifies the physical and chemical reactions that occur between shale and the soaking fluids. Mechanical properties of shale show the greatest variations after CO_2-water saturation. The variation in mechanical properties of shale after CO_2-NaCl saturation is smaller than those of shale under CO_2-water saturation owing to the precipitation of NaCl crystals. Pure CO_2 saturation has the smallest influence on shale's mechanical properties among the three types of liquids assessed. CO_2 in a supercritical state shows a stronger impact on shale than the subcritical state for the same sort of fluids. Also, following saturation, all the shales display a mixed tensile-shear failure mode. The cohesion force of shale increments following pure CO_2 saturation, whereas it diminishes following CO_2-water and CO_2-NaCl saturation. Decreases in the internal friction angles are observed for all the soaked shales. The anisotropy of shale leads to a slight difference between the actual failure angle and the failure angle measured by the Mohr-Coulomb criterion.

The stress-strain relationship of shale under different confining pressures is effectively described by the Weibull probability distribution and the principle of strain equivalence. This establishes statistical damage constitutive equations of shale under different soaking conditions. The values of key modeling parameters, including F_0 and m, are highly dependent on the brittleness and strength of shale associated with various soaking conditions.