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CO_2 Storage Duration Effects on Mechanical Properties of Different Lithological Caprocks

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ABSTRACT

The caprock selection is challenging due to the potential impact of CO_2-caprock reactions on the geological trap stability. In this study, various caprock environments (dolostones, sandstones, shales) with different CO_2 storage durations are investigated. Laboratory experiments are conducted to evaluate the deterioration degree of mechanical properties of the damaged caprocks, including tensile and compressive strength, Young's modulus, and Poisson's ratio. These analyses enable to assess the caprock stability and further provide the theoretical guidance for CO_2 secure storage.

Keywords: CO_2 storage, Caprock damage, CO_2 leakage, Caprock selection, Mineralized storage

1. INTRODUCTION

CO_2 emissions into the atmosphere, is closely related to global warming [1, 2]. The Paris Agreement suggest that the global average temperature increment within 1.5 -2 ℃ before 2100 years should be controlled [3-5]. CCUS is determined that it can reduce the amount of CO_2 emissions, in which the CO_2 storage is an important part [6]. Pumping device injects CO_2 into the reservoir for storage, and the rock formation above the reservoir is a caprock for sealing CO_2 [7-9]. The working performance of caprock directly determines the safety and stability of CO_2 storage. The mechanical damage of caprock is prone to induce CO_2 leakage. For example, the CO_2 leakage is visually observed by the Plymouth Marine in UK. The results from the chemical sensors indicate that approximately 15% of the gas flowing on the seabed is due to CO_2 leakage at the 500 m^2 experimental site from 2010 to 2013 [10]. During this period, the CO_2 dissolves in the seawater, which changes the pH value [11]. A similar situation is observed in Block H-59 of the Jilin oil field in China, where there is an annual increase in CO_2 concentration of around 4% detected in both the soil and the atmosphere within the storage area [12]. It is important to note that a large-scale CO_2 leakage could pose a threat to terrestrial animals. It is widely recognized that rock damage is primarily caused by the mechanical-chemical coupling response.

In summary, this study investigates different lithological caprocks using dolostones, sandstones, and shales. Both experiments and simulations are conducted to evaluate the physical and mechanical properties of the damaged caprocks, including porosity, permeability, compressive strength, and Young's modulus. These analyses aid in assessing caprock stability and further provide theoretical guidance for CO_2 secure storage.

2. EXPERIMENTAL METHODOLOGY

In the CCUS reservoir, exceeding a burial depth of 750 m can be considered as CO_2 reaching the supercritical phase [13]. The critical point of CO_2 phase transition is 7.38 MPa and 31.1 ℃, if beyond the threshold, the state is supercritical CO_2 (SCO_2) [14], which viscosity is similar to that of CO_2 gas, with a surface tension of almost 0. Therefore, the experimental process

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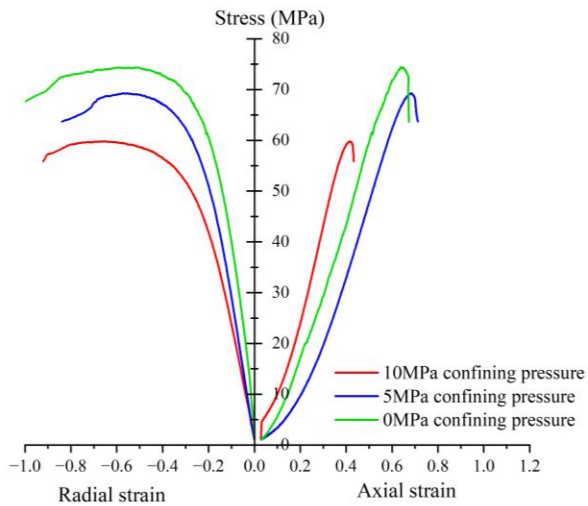
Fig. 1. Experimental samples and apparatus.

uses SCO_2 to simulate the state of deep reservoirs. The CO_2 soak is conducted in a high-temperature and high-pressure chamber, with a temperature set at 40 ℃ and a pressure set at 9 MPa to ensure that CO_2 is in a supercritical state. The sandstone, shale, and dolostone are employed as caprocks, and the soak time sets 15 days. Uniaxial compression and triaxial compression experiments, Brazilian splitting experiments, are conducted. The rock mechanics experimental press adopts the GCTS rock three-axis digital servo testing system (Fig. 1), which can accurately complete uniaxial and triaxial compression experiments of rocks, and accurately obtain rock mechanics parameters such as compressive strength, elastic modulus, bulk modulus, stress-strain, etc.

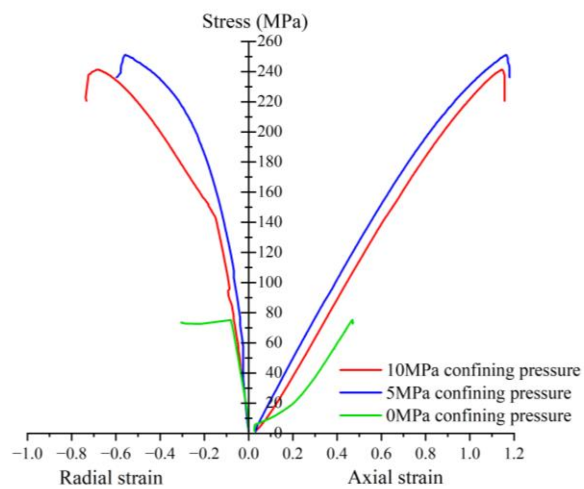
3. RESULT AND DISCUSSION

3.1 Compressive strength

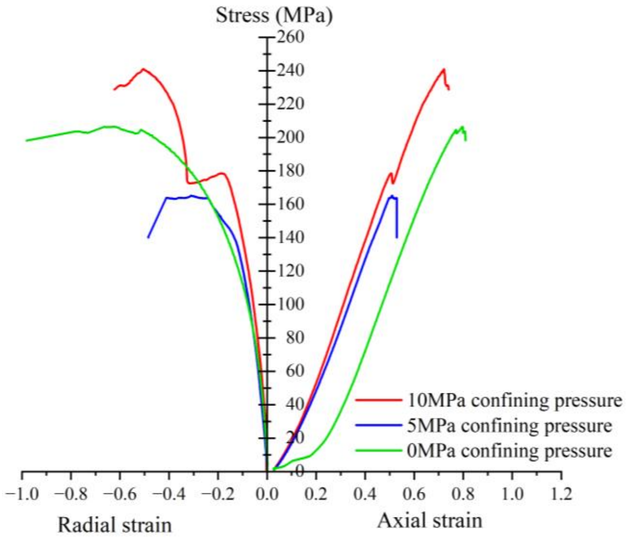
As shown in Fig 2, after being soaked in CO_2, sandstone exhibits significantly lower ultimate bearing ability compared to shale and dolostone. In terms of compressive strength, sandstone performs best with no confining pressure (0 MPa) and worst at a confining pressure of 10 MPa. In contrast, shale shows the highest compressive strength at a confining pressure of 5 MPa and the lowest with no confining pressure (0 MPa). Similarly, dolostone demonstrates its strongest compressive strength at a confining pressure of 10 MPa and its weakest at a confining pressure of 5 MPa. These findings indicate that the mechanical properties of caprocks vary under different in-situ stress environments following CO_2 treatment.



(a) Stress-strain curve of sandstone



(b) Stress-strain curve of shale



(c) Stress-strain curve of dolostone

Fig. 2. Stress-strain curves of different lithological caprocks under various confining pressures after CO_2 soak.

3.2 Young's modulus and Poisson's ratio

Under low confining pressure, the Young's modulus and Poisson's ratio of sandstone, shale, and dolostone increase to a certain extent after CO_2 soaking. This increase may be attributed to mineralized storage, and the stability of the trap structure may be slightly enhanced in the short term, though long-term storage needs further discussion. After soaking, the Young's modulus of the three types of caprocks shows an increasing trend with the increase in confining pressure, while the Poisson's ratio of dolostone does not change significantly. It is possible that CO_2 increases the rock's ability to resist deformation, but this effect is not significant for extremely hard dolostone.

4. CONCLUSIONS

This paper attempts to indicate the deterioration degree of mechanical properties of three types of caprocks under CO_2 mineralized storage. Laboratory experiments are conducted to reach the following conclusions:

(1) After soaking in CO_2, the sandstone exhibits a significantly lower ultimate compressive strength compared to shale and dolostone. Caprocks demonstrate unique mechanical properties when subjected to different geostress environments during CO_2 mineralized storage.

(2) Under low confining pressure conditions, the Young's modulus and the Poisson's ratio of sandstone, shale, and dolostone increase to a certain extent after being exposed to CO_2. Additionally, the mechanical properties of dolostone are more susceptible due to the distribution of natural fractures.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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