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Effect of Confining Pressure on Mode I and Mode II Fracture Toughness of Lushan Sandstone

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ABSTRACT: Rock is a brittle naturally material that is subjected to a variety of environment impacts, such as temperature, confining pressure, humidity and water erosion. Moreover, the effect of confining pressure on rock fracture in most engineering fields has been considered. These include the stability analysis of rock to accumulate atomic waste in underground reservoirs, the hydraulic fracture process for extraction of oil and gas from different layers of the earth and analysis of the stability of underground mines. In this paper, Effect of confining pressure on Mode I and Mode II fracture toughness of Lushan sandstone were investigated. To investigate the effect of confining pressure on mode I and II fracture toughness, was used a Cracked Chevron Notched Brazilian Disc. In this study, the specimens were subjected to a confining pressure of 3, 5, 7and 10 MPa. In this experiments, specimens of Lushan sandstone is studied specimens. The results show that, with increasing confining pressure, mode I and II fracture toughness of sandstone increases linearly and nonlinearly respectively.

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INTRODUCTION

Fracture mechanics is used in the stability analysis of surface and underground mines, determining the strength of rock structures in underground reservoirs for long-term maintenance of radioactive waste and hydraulic fracturing process to extract oil and gas from different earth layers that are subject to triaxial pressure and heat. Since the rocks are cracked and parted and are under triaxial pressure under the ground, the effect of the confining pressure on the fracture toughness must be investigated. In fracture mechanics, the critical condition of a cracked block is estimated using the stress intensity factor on the crack tip. As a result, one of the most important steps in fracture analysis and crack propagation behavior is on the basis of fracture mechanics, is studying this factor. The critical value of this factor is called fracture toughness.

Many researchers have investigated the effect of confining pressure on the mode I and mode II fracture toughness in rocks.

Schmidt and Huddle [1] determined the fracture toughness of Indiana limestone using SENB specimens under confining pressure. They observed that the mode I fracture toughness increase substantially with the increase in confining pressure. Abou-Sayed [2] and Müller, [3] who researched Indiana limestone, obtained similar results. Al-Shayea et al. [4] have studied the influence of confining pressure on the mode I fracture toughness of limestone using SNBD specimens. According to the study, the fracture toughness of the limestone increased from an average of 0.42 MPa under atmospheric pressure to 1.57 MPa (psi4000) under confining pressure. Backers et al. [5] used the PTS test to investigate the effect of confining pressure on the fracture toughness of granite, marble, and limestone. The study of the effect of pressure on the mode II fracture toughness represents the same behavior for all of the three types of stones. This effect can be divided into two parts. In the first part (confining pressure < 30 MPa), the fracture toughness increases linearly with the increase in confining pressure. In the second part (Confining pressure> 30 MPa), the mode II fracture toughness almost remains constant and independent of the confining pressure. In fact, the micro-cracks are closed with the increase in the confining pressure. Funatsu et al. [6] studied the effect of confining pressure on the mode I fracture toughness of Tage tuff and Kimachi sandstone and observed that the mode I fracture toughness of tuff and sandstone increased significantly by

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increasing the confining pressure. Wu et al. [7] used the PFC simulator program to investigate the effect of confining pressure on the mode II fracture toughness. Experimental results by Backers and the simulation results by Wu shows the similar effect of confining pressure on the mode II fracture toughness of granite in terms of quality and quantity. In fact, they have noticed, when the confining pressure increases to 30 MPa, the relationship between the confining pressure and the fracture toughness is linear, and with a confining pressure higher than 50 MPa, the fracture toughness is almost constant with very slight fluctuations.

This study has been conducted on the Lushan sandstone. The reason for the selection of sandstone is its availability in Iran and the reason for the selection of Lushan sandstone is its low variation of physical, mechanical, and mineralogical properties in its various blocks, which therefore make it suitable for research work. Library research shows that no experimental study on the effect of confining pressure on the mode I and II fracture toughness have been conducted in Iran and the majority of previous researches in the world on the impact of confining pressure have not been conducted on the Brazilian disc specimens.

TESTS CONDUCTED ON THE SPECIMENS AND THE ANALYSIS OF THE RESULTS

To investigate the effect of confining pressure on the mode I and II fracture toughness, the experiments were performed at 4 pressure levels (3, 5, 7 and 10 MPa) and to ensure the reliability of the results in each pressure level, the experiments were conducted on two specimens of sandstone. Then the fracture toughness at each pressure level was obtained through the calculation of the mean of the two numbers. The fracture toughness of the first mode in atmospheric pressure is 0.57 MPa√m. by increasing the confining pressure to 10 MPa, the Mode I fracture toughness increases up to 453 %. The mode II fracture toughness in atmospheric pressure is 1.37 MPa√m. The change in the mode I and II fracture toughness by confining pressure is calculated through Eq. (1) and (2).

$$k_{IC} = 0.26\sigma_3 + 0.57 \quad R^2 = 0.98 \tag{1}$$

$$k_{IIC} = -0.05\sigma_3^2 + 1.0052\sigma_3 + 1.37 \quad R^2 = 0.97 \tag{2}$$

In these equations K_{IC} and K_{IIC} represent the mode I and mode II fracture toughness respectively and σ_3 represents the confining pressure.

Comparing the results of this experiment with that of the aforementioned researchers show that, similar to the results of the experiment by Al-Shayea et al[4], the relationship between mode I fracture toughness is linear with the confining pressure and the fracture toughness increases by increasing the confining pressure. The results of the mode II fracture toughness shows that the relationship between the mode II fracture toughness and the confining pressure is nonlinear and by increasing the confining pressure the fracture toughness increases which is identical to the results of Backers et al [5].

CONCLUSION

The study of the effect of confining pressure on the fracture toughness of rock is highly applicable especially in the process of hydraulic fracture to extract oil and gas from underground reservoirs. The study, therefore, is essential. In this paper, the effect of the confining pressure on the mode I and mode II fracture toughness is investigated. In order to investigate the effect of confining pressure on the mode I and II fracture toughness, the Brazilian disc is used with Chevron notch. In this study, the specimens were tested under confining pressure of 3, 5, 7 and 10 MPa. In this experiment, Lushan sandstone was used as the sample.

Based on the experiments, the following conclusions are obtained:

The mode I fracture toughness has a linear relationship with the confining pressure and a nonlinear relationship with the mode II fracture toughness.

The mode I fracture toughness of the sandstone with Chevron notch increased with increasing the confining pressure ranging from the atmospheric pressure to 10 MPa, in a way that the amount of this increase for mode I is 453 %.

The mode II fracture toughness of the sandstone with chevron notch increased with increasing the confining pressure from atmospheric pressure up to 10 MPa, in a way that the amount of increase in mode II is 439.5 %.

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