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Technical Note

The influence of cyclic wetting and drying on the fracture toughness of sandstone

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1. Introduction

It is well known that there are some micro-cracks, pores or faults in a rock mass because of the complexity of rock structure, and the essence of the rock material failure process is micro-crack initiation, propagation, breakthrough and collection, in the end, resulting in rock failure. Rock fracture toughness characterizes the resistance to crack initiation and propagation, which is an important parameter in the mechanical properties of rock materials. It has an irreplaceable role in the rock mechanics theory research and practical applications.[1] Rock deformation and failure usually involves water in practical engineering such as tunneling, mining and rock excavation. Water–rock interaction is an important factor affecting the safety and stability of geotechnical engineering.[2] Rock masses are often in a state of cyclic drying and wetting due to the ground water level changing or for other reasons. It is closely related with water–rock interaction, such that a lot of geological disasters occurred in the past few decades such as landslides, debris flow, ground subsidence and collapse, etc. The safety and stability of geotechnical engineering under water–rock interaction is increasingly becoming the focus of attention.

In the recent years, the influence of cyclic drying and wetting on the physical and mechanical properties of rock materials have been studied by many researchers.[3–8] The physical properties of rock mainly include bulk density, specific gravity, apparent porosity, P-wave velocity, etc., whereas the mechanical properties of rock materials mainly focus on uniaxial compressive strength, shear strength, cohesion resistance, elastic modulus, and so on. The results indicate that the physical and mechanics properties of rock materials have a different degree of deterioration after cyclic drying and wetting. The influence of water content on rock mechanical parameters was investigated by Taibi et al.[9], Török et al.[10] and Erguler et al.[11] Gautam et al.[12] pointed out rocks with higher clay contents slake more rapidly and extensively under natural climatic conditions than those with lower clay contents. Nara et al.[13] investigated the effects of relative humidity and temperature on subcritical crack growth in igneous rock with double-torsion specimens. Although Tang et al.[14] and Deng et al.[15,16] conducted a series of experimental studies of the mechanical properties of rock fracture under water–rock interaction with three pointed bending specimens, they mainly focused on the pure mode I fracture toughness for rock materials after short or long term soaking with aqueous solution or chemical solution.

However, so far, little has been reported on the study of the influence of cyclic wetting and drying on the mode I fracture toughness and tensile strength for rock materials. The aim of this paper is to undertake an experimental study on the influence of cyclic wetting and drying on the mode I fracture toughness and tensile strength of sandstone, and discuss the relationship between mode I fracture toughness and tensile strength of sandstone after cyclic wetting and drying. The crack propagation laws have also been studied in this paper in order to provide a theoretical basis for stability analysis in geotechnical engineering under complex conditions.

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2. Experimental methods

The central cracked Brazilian disc (CCBD) specimen has been extensively employed to investigate the fracture behavior of different brittle materials, because it can facilitate the realization of pure mode I, pure mode II and mixed mode loading by changing the loading angle, besides which the stress intensity factors have analytic solutions.[17,18] We test pure mode I fracture toughness of sandstone after wetting–drying cycles with CCBD specimens. And the Brazilian splitting method is used to measure the tensile strength of sandstone after different number of wetting–drying cycles. The Brazilian disk nominal diameter $D=75$ mm, nominal thickness $B=25$ mm, the nominal crack relative length $\alpha=0.6$, and the groove width is about 1 mm for each specimen. A total 30 specimens are divided into 2 groups for testing the pure mode I fracture toughness and tensile strength of sandstone.

2.1. Stress intensity factors for the central cracked Brazilian disc

A schematic diagram of the CCBD specimen diametrically loaded by a pair of concentrated forces is shown in Fig. 1. The thickness of the disc is B and the radius is R. The crack length is $2a$, and the loading angle is β, which is the angle between the crack line and the loading direction. Dong et al.[18] obtained analytic solutions of the stress intensity factors for the central cracked Brazilian disc under combined loading conditions by using the weight function method.

$$K_I = \sigma\sqrt{\pi a}\left[f_{11} + 2\sum_{i=1}^{n} A_{1i} f_{1i} \alpha^{2(i-1)}\right] \tag{1}$$

$$K_{II} = 2\sigma\sqrt{\pi a}\sum_{i=1}^{n} A_{2i} f_{2i} \alpha^{2(i-1)} \tag{2}$$

The normalized stress intensity factors F_I and F_{II} can be written in the following forms:

$$F_I = \frac{K_I}{\sigma\sqrt{\pi a}} = f_{11} + 2\sum_{i=1}^{n} A_{1i} f_{1i} \alpha^{2(i-1)} \tag{3}$$

$$F_{II} = \frac{K_{II}}{\sigma\sqrt{\pi a}} = 2\sum_{i=1}^{n} A_{2i} f_{2i} \alpha^{2(i-1)} \tag{4}$$

where $\alpha=a/R$ and $\sigma=F/(\pi BR)$, and α is defined as the crack relative length. The expressions for the coefficients f_{11}, A_{1i}, f_{1i}, A_{2i} and f_{2i} are given by Dong et al.[18] Generally speaking, in order to obtain more accurate results, the value of n which is related to the crack relative length α should be larger enough. However, we find that when the crack relative length $\alpha \leq 0.9$, the value of n ranging from 60 to 100, there is virtually no difference. That is to say, it is very accurate when $n = 100$. So, the value 100 of n was used in all the calculations.

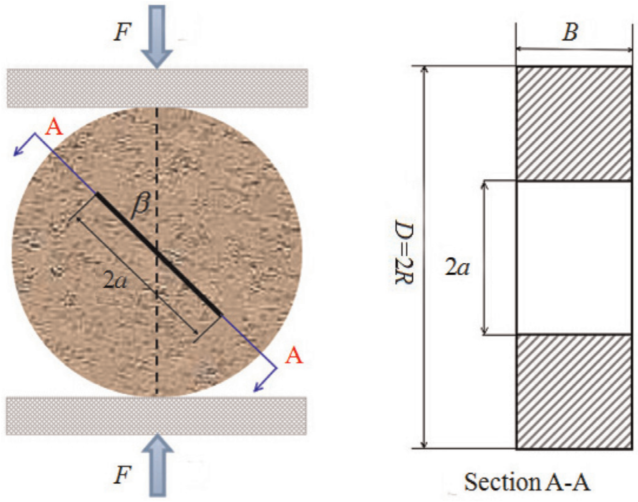

Fig. 1. Diagrams of the CCBD specimen under compression.

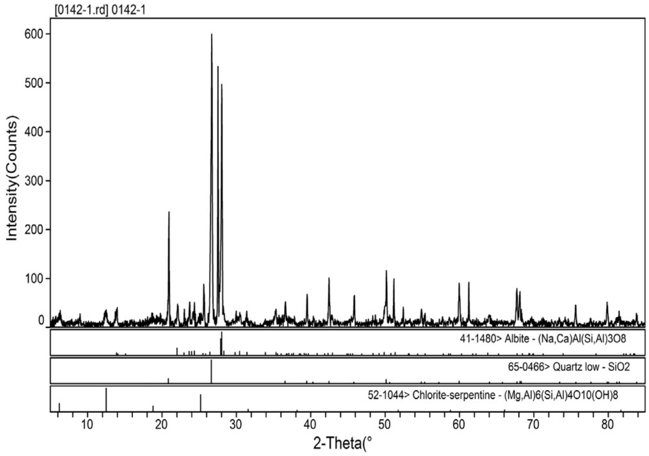

Fig. 2. The results of X-ray diffraction analysis.

2.2. Specimens preparation and testing process

The sandstone for this experiment was produced in Ziyang City, Sichuan Province, China. The mineralogical composition of this sandstone determined by X-ray diffraction (XRD) analysis (Fig. 2) indicates that this rock is mainly composed of quartz, albite, chlorite and serpentine. The CCBD specimens were used for pure mode I fracture toughness testing. Specimen processing included the following steps. Firstly, the sandstone cylinders were obtained from the rock mass by drilling cores, and then cutting them into pieces and grinding the two end faces with a grinding disk. Disk specimens of about 75 mm in diameter and 25 mm in thickness were obtained. After that, the disk specimens were fixed in a special fixture for processing a herringbone groove crack by coplanar milling with a cutter disc. On this basis, the herringbone part of both sides were sawn with a diamond saw blade, and extended to the root of the groove, and finally, the CCBD specimens were obtained.

Wetting and drying cycles were performed by submerging the specimens in water for 48 h, then putting the samples into an oven with the temperature controlled at 105 °C to dry for 24 h, and then cooling to room temperature, which was regarded as a single wetting–drying cycle. The specimens were subjected to 1, 3, 5, and 7 wetting–drying cycles in the laboratory. After that, the sandstone specimens which went through setting times of the wetting–drying cycles were submerged in water for 48 h for testing. For the intact sandstone specimens which did not go through cyclic wetting and drying, they were regarded as going through 0 wetting–drying cycle.

The experimentation was conducted in the Fundamental Mechanics Laboratory of Sichuan University. An electronic universal material testing machine was used for loading, and the loading mode was a displacement control. According to[19,20], we choose a loading rate of 0.05 mm/min for all specimens. The specimens were loaded until the final fracture and the complete load–displacement data were recorded during each test.