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Experimental study on mechanical properties and failure modes of low-strength rock samples containing different fissures under uniaxial compression

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ABSTRACT

Uniaxial compressive tests (UCS) were carried out to investigate the influence of pre-existing fissure geometry parameters (various dip angles, lengths, widths, and numbers) on the mechanical properties and deformation failure modes of low-strength rock samples. The results suggested that UCS, elastic modulus and axial peak strain were reduced by pre-existing fissures, but the reduction degree was strongly associated with the pre-existing fissure geometry. In addition, the UCS and elastic modulus of the low-strength rock samples were very sensitive to fissure dip angle and number, while the fissure number had the greatest effect on both of them. The axial peak strain was mainly influenced by the fissure dip angle. Moreover, due to the influence by the pre-existing fissures, the stress-strain curves of low-strength rock specimens usually changed from rapid drop to multistage decline, and even to horizontal extension slow decline. This indicated that low-strength specimens usually can change from brittle failure to ductile failure, and even had ductile flow deformation damage occurring under the influence of the pre-existing fissures. This change did not occur in high-strength rock mass. The fracture morphology of low-strength rock specimens was primarily affected by the fissure dip angle, and the influence of the fissure number on the fracture morphology was constrained by the fissure dip conditions, while the fissure length and width had fairly little effects on the fracture morphology of low-strength rock samples. This paper may provide new insights into the principle features of rock failure under uniaxial compression for future studies.

1. Introduction

There exists joint fractures of various scales in the engineering rock mass, which have significant effects on the mechanical properties and instability failure of the rock [1–3]. Therefore, it is of great significance to study the influence of joint cracks on rack strength, deformation and failure characteristics. In recent decades, in order to better understand the deformation and failure modes of jointed rock masses, researchers from various countries have conducted a large number of relevant experimental studies.

Since Bombolakis [4] studied the failure characteristics of precracked specimens under uniaxial compression, considerable amount of precracked rock experiments have been performed in the laboratory to investigate the strength and deformation behaviors. These studies primarily focused on the mechanical properties of precracked specimens with single [5–7], double [8–11] or multiple

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[1,12,13] rectangular flaws under uniaxial, biaxial or triaxial compression. Compared with the uniaxial and biaxial compression tests, the triaxial compression tests are rarely seen, mainly because that the triaxial compression test cannot directly observe the initiation and expansion of the new cracks, although it can simulate the real environment of the rock mass. Materials used to make the precracked specimen can be divided into two categories of rock-like materials and true rock blocks. There are a variety of rock-like materials, such as glass, gypsum, cement and various mixed ratio materials [3]. At the same time, methods for pre-existing fissures mainly include hydraulic cutting, laser cutting, blade cutting and pre-buried fissure, etc. [14]. The first three methods are mainly used for processing real rock specimens, while pre-buried fissures are generally applied to rock-like material specimens. Considering the production cost and technical requirements of the specimen, blade cutting and pre-buried fissure are usually used.

In recent years, many typical experimental studies have been described as follows: Shen [15] researched crack initiation in rock-like material and reported three types of material failure: shear failure, tensile failure, and mixed failure. Yang et al. [16,17] investigated the strength and deformation properties of precracked marble under conventional triaxial compression and uniaxial compression. They found that intact samples and defective samples had different deformation properties after peak stress, and peak strength and failure mode depended not only on the fissure geometry but also on confining pressure. Wong and Einstein [18] reviewed previous studies and summarized the effects of fissure geometry (fissure angle, ligament length and angle) on the cracking process and coalescence patterns for Carrara marble specimens containing two open fissures. Yang and Jing [6] performed the uniaxial compression experiments for the sandstone samples containing one fissure to study the influence of single fissure length and angle on the strength and deformation failure behavior. Xiao et al. [19] studied the failure characteristics of marble with two pre-existing transfixion cracks under triaxial compression. They concluded that the anti-wing crack was the main form of crack, which affected the final failure mode of the specimen. In addition, the failure mode of the specimen was altered from brittle failure under low confining pressure to ductile failure under high confining pressure. However, most of the above experimental studies were mainly limited to the conventional compression tests of hard rock mass on pre-fissured specimens, whereas the research on mechanical properties and failure modes of low-strength rock samples with pre-existing fissures remains rare. In the nature world, low-strength rock masses often contain more primary joints and cracks than high-strength rock mass, and are more likely to cause secondary crack initiation and expansion, resulting in overall instability and failure of rock mass.

Therefore, it is very important to study systematically the mechanical properties and failure modes of low-strength fissured rock mass. To better understand the deformation, strength, and crack coalescence pattern of low-strength rock samples, conventional uniaxial tests were carried out on sandy mudstone specimens with different fissures geometry (fissure dip angle, fissure length, fissure width and fissure number). The experimental results can be used to improve and supplement the mechanical properties and failure modes of fractured rock mass.

2. Uniaxial compression test

2.1. Specimen preparation

At present, there is no clear definition of low-strength rock mass in the world. In this paper, rock masses with UCS less than 30 MPa were defined as low-strength rock masses. On the contrary, they were high-strength rock masses. The low-strength rock mass selected by this test was sandy mudstone with an average UCS of 27.3 MPa, taken from a coal mine in Sichuan Province. It was difficult to obtain specific fissures in real rocks and to make specific cracks by real rocks. Therefore, in this paper, rock-like materials were used to carry out experimental research on related aspects. Many experiments [20,21] have found that there is a high similarity between the mechanical parameters and related research results of rock-like materials and rock materials, indicating that it is feasible to replace rock materials with rock-like materials for studying the mechanical properties and failure modes.

Based on a series of indoor matching tests, this paper selected cement mortar with mass ratio of cement (32.5 grade):sand (80 mesh):water of 1.0:1.0:0.4 to configure sandy mudstone rock-like material. Pre-existing fissures were through-opened fractures, which were made by pre-buried steel bars. In addition, during the solidification process, a thin layer of cement condensate, which has a very low strength and was easily cracked when stressed, was formed on the surface of rock-like materials. This will affect the observation of the actual fracture of the specimen. Therefore, the cylinder specimens were obtained by drilling a hole in a square specimen of concrete to avoid the effect of the surface condensate layer on the test result. Fig. 1 shows that the difference between the macro and micro structure of the surface condensate layer and internal material of a rock-like sample.

According to the method proposed by the International Society for Rock Mechanics [22], cylindrical specimens had a diameter of 50 mm and a height of 100 mm. Various types of rock-like samples are shown in detail in Fig. 2. The fissure geometry of pre-fractured specimens is defined as follows: α is the inclination angle of fissure, 2a and 2b are the length and aperture of the fissure, respectively, and 2L is the rock bridge length, as shown in Fig. 2. Moreover, pre-existing fissures were located in the middle of the specimens to minimize the influences of end friction on the tested sample. Fig. 3 shows the stress-strain curves and fracture patterns of intact rock-like samples and sandy mudstone specimens under uniaxial compression, with good consistency on mechanical properties and failure modes, which also proves the feasiblility to use rock-like materials samples instead of sandy mudstone samples for further research.

To study the effect of different geometric pre-existing fissures on the mechanical properties and failure modes of sandy mudstone specimens, four kinds of experiment schemes have been designed in this paper: (1) The single-fissured specimens have different inclination angle; The fissure length 2a is 15 mm and the fissure aperture 2b is 2 mm. The fissure angle α are 0°, 15°, 30°, 45°, 60°, 75° and 90°, respectively. (2) The single-fissured specimens have different lengths. The fissure aperture 2b is 2 mm and the fissure angle α includes three cases of 0°, 45° and 90°. The fissure length 2a are 10 mm,15 mm and 20 mm, respectively. (3) The single-fissured specimens are with different apertures. The fissure length 2a is 15 mm and the fissure angle α includes three cases of 0°, 45° and 90°.