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Formation and fractal characteristics of main fracture surface of red sandstone under restrictive shear creep

Hongbao Zhao[a,b], Huan Zhang[a,*], Huahua Li[c], Feihu Wang[a], Mian Zhang[a]

[a] School of Resource and Safety Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China
[b] State and Local Joint Engineering Laboratory for Gas Drainage & Ground Control of Deep Mines, Henan Polytechnic University, Jiaozuo, Henan 454001, China
[c] Changsha Engineering & Research Institute Ltd. of Nonferrous Metallurgy, Changsha, Hunan 410001, China

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ABSTRACT

Taking red sandstone specimen as the research object, this paper makes a rather systematic research on the formation and morphology of the main control fracture surface of the red sandstone under restrictive shear creep based on the basis of fractal theory by using three major self-designed research devices, that are, shear creep experimental device for soft coal or rock material, three-dimensional automatic measure and control experimental device for microstructure evolution based on micro-analysis, and three-dimensional mesoscopic monitoring software for dynamic evolution of micro-structure on the surface of coal-rock. The results show that restrictive shear creep of red sandstone experiences three stages, from the initial, steady to accelerated creep stage. The mechanism of creep action is the crystal slip under shear creep load and the slip due to dislocation. The formation of the main crack on the surface of the red sandstone under restrictive shear creep consists of four kinds of crack propagation modes: merging propagation, tensile propagation, intergranular propagation, bypassing crystal propagation. The changes of the profile along the shear direction are great in the distribution of the fracture surface, which shows a double crest trend in the second half, but the profile along the vertical shear direction declines relatively gently, slightly lower in the middle; in addition, the complexity of the roughness in the main fracture surface of the red sandstone specimen along the shear direction is greater than that in the vertical shear direction. A new method is proposed to calculate the fractal dimension of the fracture surface, and based on this method, it is found that the fractal characteristics of the main fracture surface of the red sandstone specimen show that the fractal dimension along the shear direction increases first and then decrease, and appears maximum value in the middle. And the changes of fractal dimension of the vertical shear profile are smaller than that in the shear direction, so does the fractal dimension.

1. Introduction

As the high-speed railway, highway and the construction of various hydropower projects are built, various types of rock slopes have emerged in a large number showing a high-steep trend.[1–3] Rock material is a kind of special porous medium with a large number of microstructures, such as pores and fissures.[4–8] The existence of a large number of microstructures results in extremely complex development and development pattern with a feature of strong non-linearity in the process of rock failure. The initiation and occurrence of the instability slip of the slope body can be considered as the development process of the critical rock mass of the slope body under the state of restrictive shear creep,[9,10] Besides, the initiation and occurrence of the instability slip of the slope body are inseparable with the initiation and propagation of the new crack in the main fracture surface of the key rock mass in the slope body. In particular, the initiation and propagation of the main crack of the fracture surface will determine the startup and occurrence of the instability slip of the slope body. Meanwhile, the failure characteristics of the rock mass in the slope body are extremely complex, and it is difficult to describe accurately by the traditional geometrical method. Therefore, it is very necessary to adopt the advanced experimental methods and theories to study the initiation, propagation and morphological characteristics of the main fracture surface of key rock mass in the mechanical environment of the slope body, which will be of important theoretical guidance significance to the prediction and prevention of the instability slip of the slope.

Many scholars at home and abroad in this field have conducted large quantity of research work, and they have gained rich achieve-

* Corresponding author.
E-mail address: zhanghuanvip01@163.com (H. Zhang).

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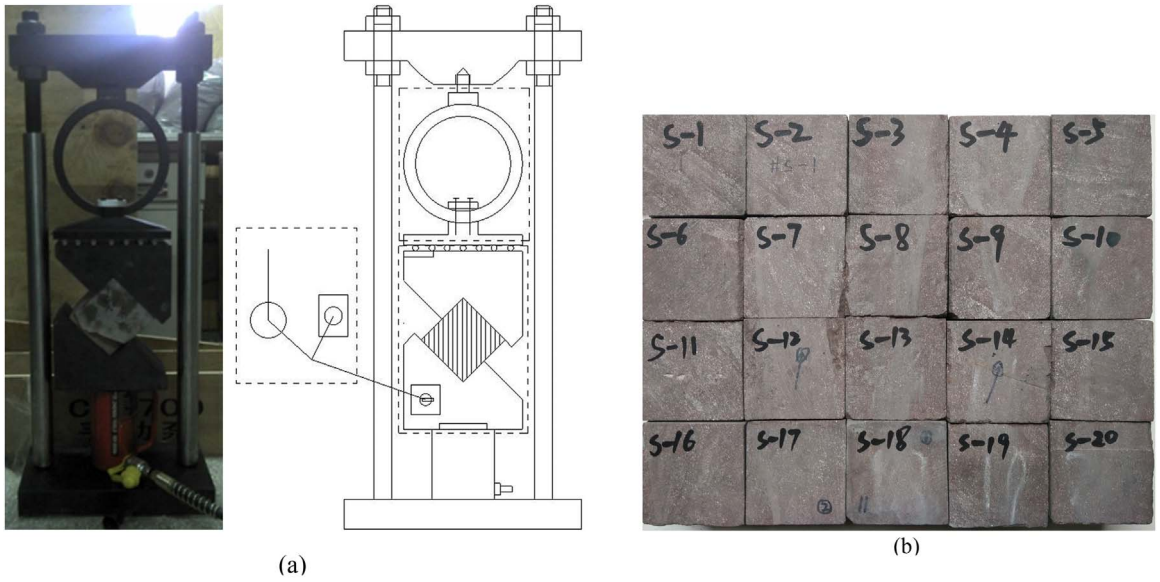

Fig. 1. Experimental device and specimens. (a) Experimental device of shear creep; (b) Specimens.

ments. For example, Huang et al. studied the relationship between microscopic morphological characteristics of marble fracture surface and unloading rock mass strength under high stress unloading, suggesting that the main fracture surface of rock specimen roughness increases with the increase of unloading rate.[11] He et al. carried out the study on stability discriminant of slope and position determination of potential sliding surface based on upper bound theorem, proposing a theoretical method to determine the potential rupture surface of the slope.[12] Wang et al. conducted a study on the prediction the potential rupture surface for high cut slope and the reinforcement of pre-embedded piles, and proposed a method of predicting the potential fracture surface and identifying the stability in advance for high cut slope.[13] Wang et al. studied the shape and stability of fracture surface of the slope under earthquake loading, concluding that the potential fracture surface of the slope is between the linear fracture surface and the logarithmic spiral fracture surface.[14] Saada et al. deals with the stability analysis of a water-saturated rock slope by means of the kinematic approach of limit analysis theory, holding a view that the rock strength properties are modeled by a modified Hoek–Brown failure criterion.[15] Zhou et al. conducted a study on the non-Euclidean model of deep rock failure under nonconforming deformation. Based on the free energy density and equilibrium equations and the deformation nonconforming conditions, a new non-Euclidean model was proposed.[16] Liu et al. studied the failure modes and strength characteristics of fractured rock mass under lateral pressure, considering that the failure modes of fracture specimen under lateral pressure mainly include initial fracture initiation, lateral splitting failure and surface spalling failure.[17] Zhou et al. conducted experimental study on the effect of fracture location and size on the failure of rock mass, and taken the view that the influence of joint position and size on the comprehensive shear strength might be caused by the joint strength of the joint and rock bridge and the damage degree of rock bridge.[18] Zhang et al. conducted an experimental study on the impact toughness and failure mode of fractured rock mass, finding that the larger the specimen size, the more broken the specimen and the more irregular the section.[19] Kang et al. set up an evolution model of concrete damage surface under freeze-thawing conditions, using damage mechanics to quantify the damage caused by freezing and thawing and achieved the establishment of the evolution equation.[20] Hu et al. studied the double-shear theory of rock strength and failure angle under triaxial compression, agreeing that the double-shear theory has obvious advantages in analyzing the strength characteristics of rock, but there are still some shortcomings in the analysis of rock failure surface,[21] and so on. Although the research works are numerous and the achievements are rich, little attention has been paid to simplify the rock mass in slope to restrictive shear creep, nor the law of fracture surface development and morphological characteristics. Therefore, this paper takes the red sandstone from the typical slope as the research object, and makes a systematic analysis and research on the formation and morphological characteristics of the main fracture surface under the condition of restrictive shear creep.

2. Material and methods

2.1. Experimental device

The experimental studies in this paper were all conducted in relevant laboratories of China University of Mining and Technology (Beijing). The main equipments used therein are self-developed with an independent intelligent property, includes “a kind of weak coal-rock material shearing creep experimental equipment”, “a three-dimensional automatic measurement and control experimental device for microstructure evolution based on micro-analysis” and “a three-dimensional mesoscopic monitoring software for dynamic evolution of micro-structure on the surface of coal-rock.”.

The shear creep experimental device of weak coal and rock material is composed of loading mechanism, shear mold, dead load auxiliary mechanism, macro-mesoscopic observation mechanism and frame, which can be used to complete the restrictive shear experiment, shear creep experiment and other work, as shown in Fig. 1.

The three-dimensional automatic measurement and control experimental device for microstructure evolution based on micro-analysis is composed of the ranging fine-tuning institutions, monitoring and positioning system, dynamic data acquisition system, lifting agencies, racks. Characterized by features of small size, simple operation, high accuracy in positioning, good performance and stability, this device can actualize the following functions including three-dimensional plane high precision movement, plane dynamic positioning, and plane fracture dynamic guidance. as shown in Fig. 2.

The three-dimensional mesoscopic monitoring software for dynamic evolution of micro-structure on the surface of coal-rock mainly includes user login, test information, macroscopical collection, dynamic display, mesoscopic acquisition, post-processing, and crack identification and alarm. The software can realize three-channel data