Effect of Loading and Unloading on Steady-State Creep Rate of Single-fracture Rocks with Different Angles

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Abstract. Soft rock-like specimens with different single-fracture angles were prepared by using similar materials. Uniaxial and triaxial creep tests and confining pressure unloading tests were carried out for single-fracture rock-like specimens with different angles. The results show that the steady-state creep rate shows a parabolic trend with the change of angle under the same load. The steady-state creep rate increases first with the increase of angle, then decreases with the increase of angle. The steady-state creep rate peaks at about 30 degrees, and the steady-state creep rate of the complete specimen is the smallest.

1. Introduction

Rock rheological properties have always been an important part of rock mechanics research. For a long time, many scholars at home and abroad have focused on the uniaxial compression and triaxial compression creep characteristics of complete specimens. With the increasing pace of resource exploitation in our country, the mining depth of many coal mines deepens one after another, and the geological conditions and roadway support problems that people are facing are becoming more and more serious. In addition, with the increasing construction of our country's civil and hydraulic engineering, the scale of the project is getting larger and larger, and the corresponding underground and surface rock mechanics conditions, especially rheological characteristics, are becoming more and more complex. In order to observe for a long time, strictly control experimental conditions and eliminate secondary factors, we need to understand the rheological properties of fractured rocks more deeply. In the past, scholars mainly focused on the constant confining pressure, exploring the axial deformation of graded loading under axial pressure. The slope effect and both sides of roadway in practical engineering are examples of confining pressure unloading. Therefore, it is of great significance to study the constant confining pressure of fractured rock and the influence of confining pressure on the axial deformation.

2. Specimen preparation and application instrument

Real soft rock is a porous medium with natural defects. Its structure and properties are complex, and it is difficult to core in situ, and the properties of collected rock samples are discrete. The research object of this paper is to use cement, River sand, water and other materials to prepare similar material specimens with certain uniaxial compressive strength, which are called soft rock-like. The preparation device and crack-like soft rock specimens are shown in Figure. 1 and 2. According to the experimental results of predecessors, the ratio of river sand, cement and water is determined as (mass ratio 2:1:0.13).
The experiment was completed in the Mechanical Research Center of Qingdao University of Science and Technology with TAW-200 electronic multi-functional mechanical testing machine. The axial and confining pressures of the tester are controlled by servo motors, which can control the loading of force and displacement and complete the triaxial high temperature rheological test of rock, as shown in Figure 3.

3. Triaxial Creep Test of Single-fissure Rocks with Different Angles
According to the axial and confining pressures designed in the scheme, the specimen is first subjected to a certain pre-pressure, and then an appropriate amount of axial and confining pressures are applied to the specimen. Here, the axial pressure can exert the same pressure on the specimen according to the confining pressure, and the loading rate remains constant during the loading process. After the deformation stability of the specimen under constant pressure, the specimen is subjected to the same axial pressure at the same rate to the first stage. The stress level is then maintained constant, and when the creep curve can confirm that the specimen enters the steady state creep, loading or unloading to the next stress level, and so on, until the end of the test.

3.1. Creep test under axial compression
The creep curve of rock under constant stress can be divided into three stages: decay creep stage, stable creep stage and accelerated creep stage: decay creep stage, in which the rate of change decreases gradually; in stable creep stage, the creep rate becomes stable; in accelerated creep stage, the creep rate of this stage shows accelerated growth state, and accelerated creep will lead to rock-like. Rapid failure of stone specimens. Creep loading is divided into four grades (10kN, 20kN, 25kN, 30kN). The longer the axial compression is, the longer the time to reach the steady creep rate of rock-like specimens is. Figure 4 shows the creep curves of triaxial graded loading of rock-like materials. The creep curves of crack specimens and complete specimens at different angles have no accelerated creep stage, and the strain of complete specimens is the smallest. From the creep rate diagram of Fig. 8 under confining pressure from different angles, it can be seen that the steady creep rate under triaxial and uniaxial creep States presents the same trend, that is, the steady creep rate increases first and then decreases with the increase of angle, the right steady creep rate peaks at 30 degrees left, and the steady creep rate of the complete specimen is the smallest.
From Figure 4 and 5, it can be seen that the axial stress of the same material increases while the creep strain does not increase under the same stress state. It can be explained that there may be some gaps between the particles and the particles in the specimen during the manufacture of similar materials. During the first loading process, some cracks close, so the second loading is more productive than the first loading. The creep strain is small.

3.2. Creep test under confining pressure unloading

When the creep deformation of the specimen tends to be stable, the creep unloading can be divided into three grades (3MPa, 2MPa, 1MPa). As shown in Figure 6, the specimens with 0, 30 and 45 degrees of cracks have larger strains, of which the change of 30 degrees is the most obvious, and the creep strain of the complete specimens is the smallest. Taking the confining pressure unloading to 1MPa as an
example, it can be seen from the analysis of the experimental results in Figure 7 that the steady creep rate of the specimens with different angles of cracks and integrity has the same trend as that of uniaxial creep and triaxial creep. The steady creep rate first increases with the increase of the angle, then decreases with the increase of the angle, and the steady creep rate peaks around 30 degrees. The steady creep rate is the smallest.

\[ c(t) = a + bt^c \] 

\[ \frac{d(c)}{dt} = b \cdot ct^{c-1} \]

In the formula, \( t \) is the time of constant loading, \( a, b \) and \( c \) are the fitting constants. Triaxial creep fitting is made in Figure 8 and Triaxial confining pressure unloading creep fitting in Figure 9.

**Figure 6.** Tri-axle graded unloading creep

**Figure 7.** Creep rates at different angles under confining pressure unloading
Assuming that the loading time of specimens is 12 hours, the steady creep rate of 12 hours is obtained by creep rate formula (2). The fitting curve is analyzed. The results show that the steady creep rate of single crack specimens increases first and then decreases with the increase of angle, and the steady creep rate of complete specimens is the lowest. On the one hand, the fitting creep formula (1) can fit the creep model of single crack specimens, and on the other hand, the fitting creep rate of complete specimens is

On the one hand, the accuracy of the rule is verified by experiments (the steady creep rate of single crack specimen increases first and then decreases with the increase of angle, and the steady creep rate of complete specimen is the lowest).

4. Conclusion

In this paper, uniaxial and triaxial creep tests and confining pressure unloading tests are carried out for single-fissure rocks with different angles. It can be concluded.

1) Studying the steady-state creep rate of cracks with different angles, the exponential equation of creep rate is obtained. It is concluded that the exponential equation can not only describe the instantaneous deformation, but also has good agreement with the attenuation creep and steady-state creep stages. It is an ideal fitting model for the creep curve of single-crack specimens.

2) Under the same load, the steady-state creep rate shows a parabolic trend with the change of angle. The steady-state creep rate increases with the increase of angle first, then decreases with the increase of angle. The steady-state creep rate peaks at about 30 degrees, and the steady-state creep rate of the complete specimen is the smallest.

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