

Research on the Mechanical Properties of Hard Rock

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Abstract: Large hydropower stations in the western region of China play very important roles in the development of local economy, and most of them locate in complex geological conditions, the deeper the rock is buried, the more obvious the geothermal phenomenon is, and the geothermal phenomenon does great damage for the underground construction. In order to study the mechanical properties of hard rock, some tests on granite have been accomplished. Through the uniaxial compression test, the triaxial compression test and the triaxial compression temperature creep test, some mechanical properties are obtained: (1) The peak strength of the granite is 92.9MPa in the uniaxial compression test, 291.0MPa in the triaxial compression test, 260MPa in the triaxial compression test when $T=25^{\circ}\text{C}$, 220MPa in the triaxial compression test when $T=50^{\circ}\text{C}$, 200MPa in the triaxial compression test when $T=70^{\circ}\text{C}$. (2) Compared with the triaxial compression test, when the specimen is broken, the increased percentage of the axial strain of the temperature creep test is respectively 37% when $T=25^{\circ}\text{C}$, 53.3% when $T=50^{\circ}\text{C}$, 80.6% when $T=70^{\circ}\text{C}$. And the value of the lateral strain is respectively 20% when $T=25^{\circ}\text{C}$, 59.5% when $T=50^{\circ}\text{C}$, 101% when $T=70^{\circ}\text{C}$. (3) A threshold exists during the creep of the gneissic granite, which is affected by temperature. The temperature increases the creep deformation of the rock.

1. Introduction

Large hydropower stations in the western region of China play very important roles in the development of local economy, and most of them locate in complex geological conditions, where the magmatism is frequent and intrusion is developed. The surrounding rock of the diversion tunnels tends to be unstable under the magmatism, and the high temperature steam erupts from the rock fractures, which will further destabilize the rock mass, such as deformation increase and strength reduction. This phenomenon is known as “geothermal phenomenon”. Generally speaking, the deeper the rock is buried, the more obvious the geothermal phenomenon is. Moreover, the geothermal phenomenon does great damage for the underground construction, and many scholars have dedicated to the study of failure mechanism caused by high temperature. Shao et al. ^[1] studied the effect of temperature on the mechanical behaviour of Strathbogie granite under unconfined stress conditions. The results showed that the increasing temperature reduces the stress thresholds for crack initiation and crack damage and extends the duration of stable crack propagation. Liu et al. ^[2] conducted the dynamic compressive tests of sandstone at seven temperatures in the range of room temperature to 1000 °C and five impact velocities in the range of 11.0-15.0 m/s by using the SHPB test system improved with high temperature device, and the results showed that the temperatures the strain rates affecting dynamic compressive strength and peak strain most are 800°C and 1000°C respectively, while at 1000°C and



room temperature the strain rates affect dynamic compressive strength and peak strain weakest. Yang et al.^[3] carried out uniaxial compression tests to evaluate the effect of high temperature treatments (200, 300, 400, 500, 600, 700 and 800°C) on the crack damage, strength and deformation failure behavior of a granite, and the results showed that the cracking process of granite depended on the heat treatment temperature. Ding et al.^[4] studied the AE signal nonlinear characteristics of thermally damaged sandstone samples under uniaxial compression, and the results showed that after treatment at different temperatures the AE signals were positively correlated with the stress. Chen et al.^[5] used uniaxial compression and three-point bending to measure the macroscopic mechanical properties of granite, which was exposed to high temperatures before measuring, and the results indicated that the uniaxial compressive strength (UCS), Young's modulus and fracture toughness of the granite specimens decrease with an increase in heat treatment temperature up to 800 °C, above which there is no obvious change. Muhammad et al.^[6] studied the effect of elevated temperatures on the mechanical properties of limestone, quartzite and granite concrete, which were subjected to temperatures ranging from 25 to 650 °C for a duration of 2 h, and the results indicated that the mechanical properties of concrete are largely affected from elevated temperatures and the type of coarse aggregate used.

So, how the deformation and strength will change on earth as the granite specimen creep under high temperature, high axial stress and high confining pressure. According to practical condition of engineering, high temperature creep tests on granite are done to research the characteristics of creep deformation and creep strength under the complex conditions of different high temperatures and different high stresses. So as to find out the failure mechanism.

2. High temperature creep test

2.1. Test Condition

Take an important large hydropower station with geothermal phenomenon for instance, the intrusion is composed of a gneissic granite, with hard quality and good integrity. The average temperature of the surrounding rock in diversion tunnel is over 75°C, and the maximum temperature even up to 110°C. Many tunnel sections arise high temperature steam, with gas temperature between 160°C and 170°C.

The specimens used in this test are all taken from the diversion tunnel with embedded depth of more than 1000m, and they are designed as cylinder with a height of 100mm and a diameter of 50mm. The rock automatic three-axis servo rheometer self-developed completely by Shandong university will help to do the high temperature creep test, which is composed of main engine, pressure chamber, loading device, computer control system and other components. The maximum test force along axial direction is 1000KN with an accuracy of $\pm 1\%$, while the maximum confining pressure is 50MPa with an accuracy of $\pm 0.5\%$. The warming system comprises two parts, a pressure chamber and a heating ring, and the highest permission temperature is 120°C an accuracy of $\pm 0.1^\circ\text{C}$.

2.2. Test method

The experiment was divided into three parts. Firstly, the uniaxial compression test was carried out; Secondly, the triaxial compression test was carried out, and the confining pressure was designed as 20MPa according to the in-situ stress; Finally, the triaxial compression temperature creep test was carried out, and the confining pressure was also designed as 20MPa.

The purpose of the test is to find out how the temperature to influence the creep deformation of the granite. And then the test methods are introduced respectively.

From the uniaxial compression test, the results show that the peak strength of the granite is 92.9MPa, the residual strength is 4.1MPa. Moreover, we can obtain the elasticity modulus is 52.3GPa, deformation modulus is 38.2GPa and the Poisson's ratio is 0.24. When the specimen is broken, the axial strain is about $1.18 \times 10^{-2}\epsilon$, the lateral strain is about $-3.11 \times 10^{-2}\epsilon$.

In the triaxial compression test, the stress path is designed as follows: First of all, loading the confining pressure to the desired value of 20MPa. And then, loading the axial stress continuously until

the specimen is broken.

From the triaxial compression test, the results show that the peak strength of the granite is 291.0MPa, the residual strength is 125.6MPa, internal friction angle is 56° , and the cohesion is 14.25MPa under the confining pressure of 20MPa. Obviously, the triaxial compression stress - strain relation curve is divided into three parts-stable stage, unstable stage and broken stage. In the stable stage, stress - strain relation curve is similar to a straight line, and we can obtain the elasticity modulus is 55.8GPa, the deformation modulus is 51.3GPa and the Poisson's ratio is 0.26. In the unstable stage, the stress is changing, and it arrives the peak strength, and then, the stress of the specimen reduces sharply. In the broken stage, the bearing capacity of the specimen reduces to the minimum, the specimen is broken, and the stress arrives its residual strength. When the specimen is broken, the axial strain is about $1.65 \times 10^{-2}\epsilon$, the lateral strain is about $-2.05 \times 10^{-2}\epsilon$. Here, ϵ represents the strain of diverse direction.

3. Test results

In this work, the stress path is designed as loading the axial stress step by step, and keeping an constant confining pressure in the meanwhile. The testing scheme is designed as three types of temperature (25°C, 50°C, 70°C) with 20MPa as the confining pressure.

Test procedure is as follows:

Firstly, using the heat shrink sleeve to seal the specimen and the setting blocks on both ends, and then installing the fiber axial and lateral displacement sensors in order to monitor the deformation of the specimen.

Secondly, installing the packaged specimen and the temperature sensor into the pressure chamber, and then putting the heating ring on the outside of the pressure chamber.

Thirdly, Opening computer control system, loading an set temperature, at the same time, loading stress at a rate of 50N/s up to the scheduled value of confining pressure. Waiting until the deformation tends to be constant, loading the axial stress at the same rate. Starting the computer control system to record the test data when the deformation trends to be stable.

Finally, loading the next stress level until the former creep deformation being stable, and the interval of records are different at different stages, generally, every 10 to 20 minutes at the preliminary stage, every 1 to 5 minutes when the deformation is unstable, and every 1 to 10 seconds when near the destruction. Ending the test till the specimen is broken, and saving the data.

Data processing is a key link before test analyzing. Using computer software and other data processing software to deal with the huge amount of data, and then obtaining the different axial creep deformation curves under different conditions of confining pressure (written as σ_3 in figure) and temperature, as shown in Figure 1.

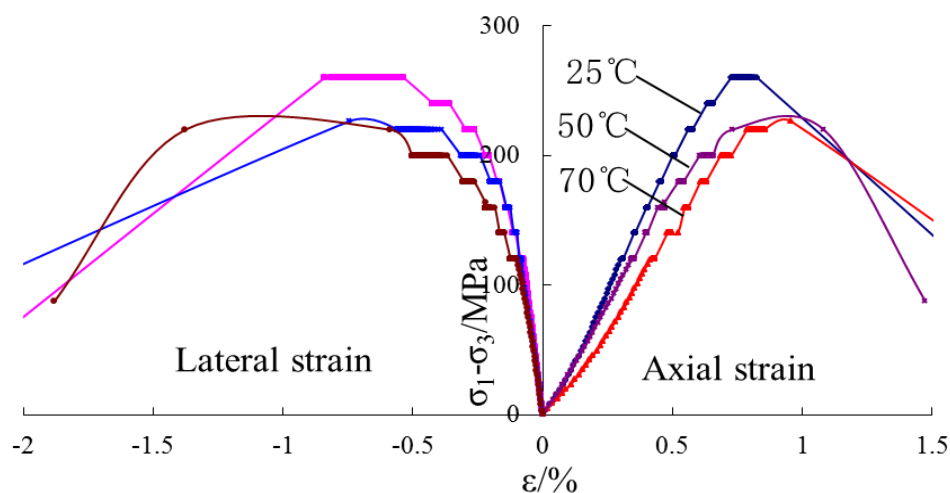


Figure 1. The axial creep deformation curves of gneissic granite specimen under different conditions of confining pressure and temperature ($\sigma_3=20\text{Mpa}$)

The increased percentage of the temperature creep test compared with the triaxial compression test is shown in Table 1.

Table 1. The increased percentage of the temperature creep test compared with the triaxial compression test

	Axial strain	Increased percentage	Lateral strain	Increased percentage
Triaxial compression test, T=25°C	$1.65 \times 10^{-2} \varepsilon$	/	$-2.05 \times 10^{-2} \varepsilon$	/
The temperature creep test, T=25°C	$2.26 \times 10^{-2} \varepsilon$	37.0%	$-2.46 \times 10^{-2} \varepsilon$	20%
The temperature creep test, T=50°C	$2.53 \times 10^{-2} \varepsilon$	53.3%	$-3.27 \times 10^{-2} \varepsilon$	59.5%
The temperature creep test, T=70°C	$2.98 \times 10^{-2} \varepsilon$	80.6%	$-4.12 \times 10^{-2} \varepsilon$	101%

All of the above shows that high temperature and high stress level both have significant influence on the creep properties of the rock, the higher the temperature and stress level, the more drastic the rock breaking, and the greater the harm.

4. Conclusions

In this article, some tests on granite have been accomplished, through the analysis of the deformation, main research conclusions are as below:

- (1) A threshold exists during the creep of the gneissic granite, which is affected by temperature. When at the same confining pressure condition, the higher the temperature, the smaller the threshold.
- (2) The temperature increases the creep deformation of the rock, the higher the temperature, the greater the creep deformation, and the faster the deformation development.
- (3) The peak strength decreases with the increase of temperature at the same confining pressure condition.
- (4) The axial strain and the lateral strain of the temperature creep test are much larger than that of the triaxial compression test.
- (5) The test results can help offer significant experimental supports in terms of the long-term stability, design and construction of the similar kind of engineering.

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