Creep Characteristics of Sandstone after Thermal Shock

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Abstract. To study the creep characteristics of sandstone after thermal shock, the sandstone specimens were subjected to thermal shock treatment, and the uniaxial creep test was carried out on the treated specimens, the change rule of the creep characteristics of sandstone with the thermal shock temperature was analyzed, and the mathematical relationship between the steady state creep rate and the thermal shock temperature was established. The results show that: the onset temperature of thermal shock damage to sandstone is between 300 and 400 degrees Celsius, the degree of sandstone damage with the thermal shock temperature is nonlinear growth, macroscopic manifestation of uniaxial compressive strength reduction, creep deformation and creep rate increase; the effect of thermal shock on the creep strain of sandstone is mainly concentrated in the steady state creep stage, and the influence range is mainly concentrated between 400 and 700 degrees Celsius; the fitting function can better describe the relationship between the steady state creep rate of sandstone and the thermal shock temperature. The research results are of great significance for long-term deformation law prediction of sandstone after thermal shock.

Keywords: sandstone; thermal shock; damage; creep characteristics

1 Introduction

When a rock heats up or cools down dramatically, a temperature gradient occurs within it, resulting in temperature stresses that cause thermal shock damage to the rock[1]. This phenomenon is widely found in engineering practices such as mine fire fighting and deep geothermal energy development. The rock will not be damaged immediately after the damage, but the internal damage fissures gradually develop and penetrate, and the rock continues to creep, and eventually form macro-damage, triggering engineering disasters. Therefore, the creep characteristics of rocks after thermal shock have important research value.

In recent years, scholars at home and abroad have carried out a lot of research on the mechanical properties of rocks after thermal shock. Xi et al. [2]-[3] found that the deterioration of mechanical properties of granite after thermal shock is due to the thermal rupture phenomenon in the cooling process, and the mechanical strength is mainly affected by the thermal shock velocity and the thermal shock factor;

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Kahraman[4], Zhu et al.[5] found that due to the heat transfer coefficient and the role of the water-rock interaction, there are large differences in the degradation of the mechanical properties of rocks by thermal shock with different cooling mediums; Sengun[6], Yang et al.[7] found that the differences in the mechanical properties of different rocks after thermal shock are due to different microstructures, mineral compositions. Wu et al.[8] ,Li et al.[9] investigated the relationship between the mechanical properties of rocks after thermal shock and their microscopic fracture characteristics.

In summary, scholars have made a lot of achievements in studying the mechanical properties of rocks after thermal shock. However, the existing results are mainly focused on the transient mechanical properties of rocks, and there is still a lot of research space for the creep properties of rocks after thermal shock. In view of this, this paper selects the common sandstone in the formation as the test material, carries out the thermal shock treatment and uniaxial creep test on sandstone, researches the change rule of sandstone's creep characteristics after being subjected to thermal shock at different temperatures, and establishes the mathematical relationship between the steady-state creep rate of sandstone and the temperature of thermal shock.

2 Creep Characterization of Sandstone after Thermal Shock

2.1 Test Methods

The tests were conducted on yellow sandstone from Jungar Banner, Inner Mongolia, China, the rock was polished into standard cylindrical specimens with a diameter of 50 mm and a height of 100 mm. Before the thermal shock treatment, the specimen is put into the 105°C constant temperature oven to dry for 12h, then the specimen is put into the resistance furnace, and heated to 300°C, 400°C, 500°C, 600°C, 700°C, 800°C at a rate of 5°C/min respectively, the furnace temperature is raised to the target temperature, and the constant temperature is kept for 1h to ensure that the inside and outside of the rock have reached the target temperature, then the specimen is taken out and Put the specimen into the cooling bucket with the water temperature of 25°C to cool down, take out the specimen after 1h, and put it into the 105°C constant temperature drying oven again to dry for 12h, to complete the thermal shock treatment. The TAW-2000 electro-hydraulic servo tester produced by Chaoyang Testing Machine Factory was used to carry out uniaxial compression test and uniaxial compression creep test on the original specimens and 6 groups of sandstone specimens after thermal shock at different temperatures. The test equipment and process are shown in Figure 1.

Firstly, uniaxial compression test was carried out on sandstone after thermal shock, and the test results are shown in Table 1. The creep deformation of the rock before complete destruction mainly occurs in the initial creep, steady state creep stage, so 70% of the uniaxial compressive strength of the sandstone as the target stress of the creep test to carry out the uniaxial compression creep test for 168h, to ensure that the creep curve of the sandstone has the initial creep and steady state creep stage. Creep test adopts single-stage loading, the loading method adopts stress control, the loading rate is 100N/s, the stress reaches 70% of the uniaxial compressive strength and then remains unchanged, the creep test curve is shown in Figure 2.

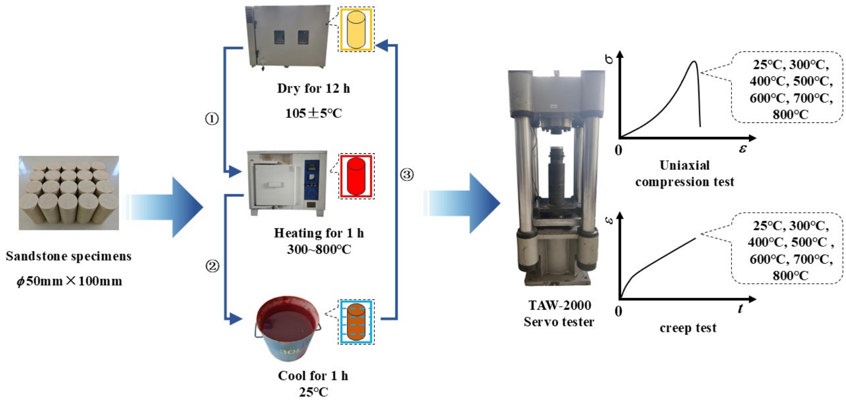

Fig. 1. Testing equipment and process.

Table 1. Uniaxial compressive strength of sandstone

Temperature/°C	25	300	400	500	600	700	800
Uniaxial compressive strength /MPa	45.7	44	41.1	38.3	33.8	30.4	28.8

2.2 Analyzing Test Results

The Effect of Thermal Shock Temperature on Creep Deformation of Sandstone. As can be seen from the curve in Figure 2, creep occurs in the rock at a lower stress level, and only the initial creep and steady state creep stages appear in each set of curves, and no accelerated creep stage occurs, with the increase of thermal shock temperature, the instantaneous strain and creep strain of each group of specimens gradually increased, and the relationship between creep strain and thermal shock temperature is shown in Figure 3. Transient and creep strains in sandstones subjected to thermal shock at 300°C do not change much compared to the original rock specimen, 300 °C thermal shock did not cause significant damage to the specimen; when the thermal shock temperature of 400 °C, the specimen transient and creep strain increased significantly, in the rock inside the production of a more obvious thermal shock damage to the rock deformation of the force characteristics of the impact of the more significant, it can be seen that the onset temperature of thermal shock damage in sandstone is between 300°C and 400°C. With the thermal shock temperature continues to rise, the specimen transient and creep strain also continues to increase, but the growth of creep strain between adjacent temperatures gradually decreases, it can be seen that as the thermal shock temperature increases, the increase in thermal shock damage of sandstone between adjacent temperature levels gradually decreases. Among them, the creep strain of the specimen with a thermal shock temperature of

600 °C increased significantly compared with that of the specimen with a thermal shock temperature of 500 °C. According to the research of Xi[10], this is due to the fact that the quartz minerals in the rock will be transformed from the α phase to the β phase when heated up to 573°C, and the volume of the minerals will increase significantly, which will produce greater damage inside the rock.

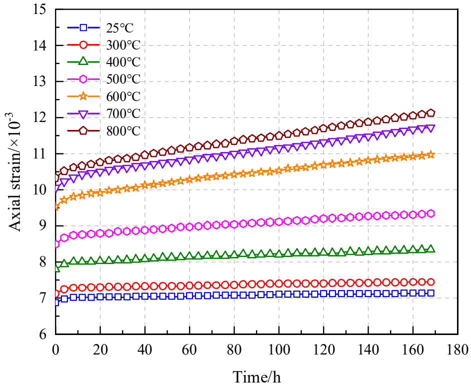

Fig. 2. Uniaxial creep curve of rock.

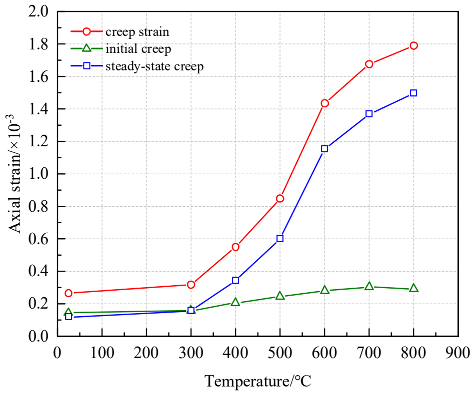

Fig. 3. Change of strain with thermal shock temperature.

From Figure 3 initial creep and steady state creep with thermal shock temperature change curve can be seen, thermal shock temperature is low, the initial creep of sandstone with the thermal shock temperature increases nearly stable, in the thermal shock temperature of 400 °C ~ 800 °C, with the increase in thermal shock temperature, the initial creep of the specimen first approximate linear growth and then tend to stabilize; steady state creep of sandstone with the increase in thermal shock temperature is nonlinear, the growth rate is decreasing trend, of which the growth between 500 °C ~ 600 °C is larger, from the above it is known that this is the result of the phase transformation of quartz minerals leads to the increase of rock damage. It can be seen that the effect of thermal shock on the creep strain of sandstone is mainly concentrated in the steady state creep stage, and the influence range is mainly concentrated in the 400 °C ~ 700 °C, after which the creep strain of sandstone tends to stabilize gradually with the increase of thermal shock temperature.

The Effect of Thermal Shock Temperature on the Steady State Creep Rate of Sandstones. Steady state creep rate of sandstone after thermal shock is shown in Figure 4, it can be seen that with the increase of thermal shock temperature, sandstone steady state creep rate is nonlinear growth, growth rate with the increase in thermal shock temperature is first increased and then decreased trend. In order to quantify the description of the relationship between the rock steady state creep rate and the thermal shock temperature, the experimental results were fitted and the fitted curve is shown in Figure 4, equation (1) is the expression for the fitted curve.

$$\dot{\varepsilon} = 9.05 - \frac{8.29}{1 + \exp\left(\frac{T - 537.04}{70.25}\right)} \qquad R^2 = 0.99 \tag{1}$$

Where, $\dot{\varepsilon}$ is the creep rate, T is the thermal shock temperature.

From the fitted curves and correlation coefficients, it can be seen that the function can better describe the relationship between the steady state creep rate of sandstone and the thermal shock temperature.

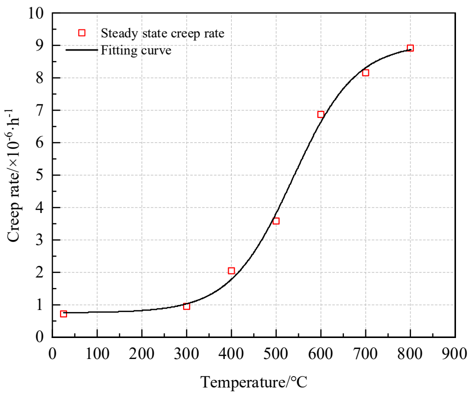

Fig. 4. Change of steady creep rate with thermal shock temperature.

3 Conclusions

The sandstone specimens were subjected to thermal shock treatment and uniaxial creep test, and the creep curve of sandstone after thermal shock were obtained. Accordingly, the changing rules of instantaneous strain, initial creep and steady state creep of sandstone were analyzed, and the mathematical relationship between steady state creep rate and thermal shock temperature was established, with the following main conclusions:

(1) Thermal shock sandstone mechanical properties with thermal shock temperature changes occur significantly, with the thermal shock temperature increases, sandstone uniaxial compressive strength nonlinear decrease. Creep test, with the increase of thermal shock temperature, sandstone creep strain nonlinearly increased but the increase in the amount of gradual reduction, creep strain in the initial creep change is small, the increase is mainly reflected in the steady state creep stage.

(2) The overall trend of the steady state creep rate of sandstone is similar to the creep strain. As the thermal shock temperature increases, the steady-state creep rate of the sandstone increases nonlinearly, gradually decreasing increase between neighboring temperatures. The relationship between steady state creep rate and thermal shock temperature of sandstone can be quantitatively described by fitting the experimental result, the theoretical value and the experimental value of the match is good.

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