Testing Study on the Triaxial Compressive Strength of Medium-grained Sandstone after High Temperature

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Abstract. The triaxial compressive strength of medium-grained sandstone after different high temperature about on 25°C、400°C、800°C and 1000°C be researched by the servo-controlled testing machine RMT-150B. The test results show that: (1) it is still a strong liner relationship between the triaxial compressive strength of medium-grained sandstone after high temperature and the confining pressure, its confining coefficient is a constant, and the theoretical value of uniaxial compressive strength is expressed by the quadratic polynomial on the high temperature; (2) its internal friction is a constant without change to high temperature, and the cohesive strength be controlled by high temperature and its expression be given. (3) The theoretical formula about triaxial compressive strength of medium-grained sandstone after high temperature be established, and it accurately reflects the relationship between the strength and temperature, confining pressure.

Introduction

The differences of rock's physical and mechanical properties between normal temperature state and after high temperature has been gradually realize, and, the change law about rock mechanics after high temperature be researched with people pay attention to the change of rock mechanical properties after high temperature in the high temperature engineering field. The rock mass, wave velocity, elastic modulus, uniaxial tensile strength and splitting tensile strength of rock after high temperature be analyzed by the rock mechanics test [1-10]. In the three axis test, the stage of deformation and deformation characteristics and the failure mode of the granite specimen be studied by Wan Zhijun [11] using the conventional three axis test, The basic mechanical properties of sandstone on strength, elastic modulus, cohesion and internal friction angle were analyzed by Yin Guangzhi [12]. The wave velocity, rebound value and the strength of the sandstone and the failure mode of the sandstone be studied by Li Jianlin [13]. the variation law of the cohesive force, the internal friction angle and the elastic modulus of the sandstone after high temperature was studied by Li Xiaoshuang [14].

The wave velocity, the mass and the triaxial compressive strength of sandstone samples after high temperature is studied in Shihuoshan tunnel of the Xinjiang Production and Construction Corps. The research results as assessment about the tunnel surrounding rock stability after fire and repair reinforcement design reference.

Triaxial compressive test of rock after high temperature

(1) Rock specimen preparation

The rock sample come from Shihuoshan tunnel of the Xinjiang Production and Construction Corps, its lithology is sandstone. The sample is processed by the standard cylinder specimen of 100mm and length 50mm, as Fig.1, its geometry size and apparent quality accord with standard requirement [15].

(2) Heating and testing of test specimen

The test specimen was heated by the KSW-5D-12 type electric furnace, the heating rate was 10°C /min, and the temperature was maintained constant temperature for 4.0h, and then, natural cooling to room temperature in the furnace, the samples were made to different high temperature test specimen.

4 different temperature specimen were carried out at room temperature (25°C), 400°C, 800°C and 1000°C.

Fig.1 Rock specimen partly

The triaxial compression test was carried out on the mechanical servo test machine of the RMT-150B rock mechanics (as Fig. 2), and the confining pressure was divided into 4 grades: 5MPa, 10MPa, 15MPa and 20MPa.

The test specimen after high temperature and its failure mode is shown in Fig. 3

Fig.2 Rock test system RMT-150B

Fig.3 Shapes of rock specimen after experiment

Test results and data analysis

(1) Triaxial compressive strength

The relationship between the triaxial compressive strength and the confining pressure is shown in Fig.7, as shown that the strong linear relationship on the macro between the triaxial compressive strength and the confining pressure in 4 different temperature test, and it is conform to the typical triaxial compressive strength form of Mohr-Coulomb [16], as listed in Eqn. (2).

$$\sigma_1 = \frac{1 + \sin \varphi}{1 - \sin \varphi} \sigma_3 + \frac{2C \cos \varphi}{1 - \sin \varphi} \quad (1)$$

Where, σ_1 : triaxial compressive strength, MPa; σ_3 : confining pressure, MPa; C: cohesive force, MPa; φ : internal friction angle of rock, °.

Then, according to the form of Mohr-Coulomb strength, the triaxial compressive strength of rock specimen after high temperature is as Eqn. (2).

$$\sigma_1 = K(t) \sigma_3 + \sigma_0(t) \quad (2)$$

Where, $\sigma_0(t)$: theoretical value of uniaxial compressive strength, MPa; $K(t)$: confining pressure coefficient. They are functions of temperature t.

The confining pressure coefficient and the theoretical value of uniaxial compressive strength could be got as follow.

① Confining pressure coefficient

According to the Eqn. (2), $\sigma_0(t)$ 、 $K(t)$ are constant when the temperature t is fixed, because of them are only functions of temperature t, and, $\sigma_0(t)$ is the function of σ_3 only in the Eqn. (2), so we could know that the confining pressure coefficient $K(t)$ is the slop of Eqn. (2) in condition of

temperature t fixed. Therefore, the value of $K(t)$ could be get by linear regression fitting to test data of different temperature, and list in Tab.1.

Fig.4 Relation between the triaxial compressive strength and confining pressure after different high temperature

Tab.1 Value of $K(t)$ in different high temperature

t (°C)	Fitting formula	K
400	$y = 4.8 \sigma_3 + 40$	4.8
800	$y = 4.87 \sigma_3 + 58$	4.87
1000	$y = 4.77 \sigma_3 + 42$	4.77

On the basis of tab.1, we could get the result that the value of $K(t)$ is a constant because maximum gap is only 0.1 and 2% of minimum. The value of $K(t)$ is 4.81 as Eqn. (3)

$$K = (4.8 + 4.87 + 4.77) / 3 = 4.81 \quad (3)$$

② Theoretical value of uniaxial compressive strength

When substitute Eqn. (3) into Eqn. (2), we could get the theoretical value of uniaxial compressive strength in different confining pressure and different high temperature, and the relation between theoretical value of uniaxial compressive strength and temperature show in Fig. 5. It shows that the theoretical value of uniaxial compressive strength is influenced by temperature, and it increased with the temperature increased first and then reduced at the temperature of 800°C. So, the temperature 800°C could be regarded as a control threshold value of the change on the theoretical value of uniaxial compressive strength.

Therefore, the function between the theoretical value of uniaxial compressive strength and temperature t could be got by the two polynomial fitting with the control threshold value, as in Eqn. (4).

$$\sigma_0 = \frac{801 - t}{|801 - t|} \times 1.2 \times 10^{-5} t^2 + 0.02t + 32 \quad (4)$$

Where, when $t = 801$, $\frac{801 - t}{|801 - t|} = 1$.

The triaxial compressive strength of rock after high temperature could be got when substitute Eqn. (3) and Eqn. (4) into Eqn. (2), and it is as Eqn. (5)

The relationship between the triaxial compressive strength theoretical value of Eqn. (5) and the test data of rock after high temperature as in Fig. 6, and shows that the value of Eqn. (5) could reflect the change law of the triaxial compressive strength of rock after high temperature, agreement with the test data.

③ Cohesive force, internal friction angle of rock

The cohesive force value and the internal friction angle value of rock could be got from Eqn. (1) and Eqn. (5), then as shown in Eqn. (6) and Eqn. (7). We know that the internal friction angle of rock after high temperature is a constant value 41° , and the cohesive force of rock after high temperature is influenced by the temperature t .

Fig.5 Relation between $\sigma_0(t)$ and t

Fig.6 Comparison between theoretical value and test value

$$\sigma_1 = 4.81\sigma_3 + \frac{801-t}{|801-t|} \times 1.2 \times 10^{-5} t^2 + 0.02t + 32 \quad (5)$$

③ Cohesive force, internal friction angle of rock

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$$\varphi = \sin^{-1} \frac{K-1}{K+1} = 41^\circ \quad (6)$$

$$C = \frac{801-t}{|801-t|} \times 0.274 \times 10^{-5} t^2 + 0.005t + 7.306 \quad (7)$$

Summary

The triaxial compressive strength and the confining pressure of medium-grained sandstone after high temperature still showed a linear relationship, and could be described by the Mohr-Coulomb formula, and the confining pressure coefficient is a constant value as 4.81, the theoretical value of uniaxial compressive strength of rock after high temperature is influenced by the temperature t and be described by Eqn. (4). The triaxial compressive strength of medium-grained sandstone after high temperature could be expressed by Mohr-Coulomb formula with the temperature t and the control threshold value, and could reflect the change law of the triaxial compressive strength of medium-grained sandstone after high temperature. The internal friction angle of medium-grained sandstone after high temperature is a constant value 41° , and the cohesive force of medium-grained sandstone after high temperature is influenced by the temperature and be described by Eqn. (7).

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