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Investigation of the Effect of Fissure Angle and Temperature on the Strength and Deformation of Rock-like Material

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Abstract: In order to investigate the effect of fissure and temperature on deep-seated rock, uniaxial compression experiments were conducted on rock-like material with different fissure angle at different temperatures. We investigated the influence of fissure angle and temperature on strength and the influence of fissure on failure mode of the rock. Also, we simulated the uniaxial compression experiment of rock-like material with ABAQUS. The results of experiments and simulations confirmed that the strength of rock-like material decreased with increasing temperatures and the strength decreased first then increased with increased fissure angle. The crack initiation started from the tips of the pre-existing fissure and we could speculate via the simulation that the reason of the crack initiation was stress concentration on fissure tips.

1. Introduction

There are plenty of fissures and cracks in rock mass, which may result in the decrease of strength and the stability decline of underground engineering. The rock mass in deep is influenced by high geotemperature and high crustal stress, meanwhile, the strength and creep characteristics are different from rock mass in shallow circumstances. There are plenty of scholars had paid their attention to the investigation of the mechanical property on different kind of rock mass under different factors. As for the factor of rock cracks, Yang et al.[1] investigated the influence of fissure angle to the creep characteristic for rock-like material. Pan et al.[2] established the anisotropic viscoelastic-plastic creep model which applied to granite with cracks. Brantut et al.[3] investigated the influence of initial damage on creep strain rate of sandstone, which found that the bigger the initial damage was, the bigger the creep strain rate was. Zhang et al.[4] studied the influence of thermal stress on the rock mass strength of single and multiple fissures rocks. Huang et al.[5] investigated the influence of fissure angle on the strength of sandstone. Wang et al.[6] found that the angle of pre-existing fissure had significant influence on the strength of rock-like material and the pre-existing fissure had most significant influence when fissure angle was 45°.In recent years, with the excavation development of coal and mental mine, more and more scholars had paid the efforts to the influence of temperature on the rock mechanics characteristics. Mohamadi et al.[7] found that the strength (both peak strength and residual strength) of sandstone increased first then decreased with elevated temperature; Burghignoli et al.[8] found that temperature had less influence on the strength and deformation of different kind of clays when temperature changed from 20 to 60℃. Xu et al. [9] investigated the influence of high temperature (from 25 to 1000℃) to the rock mechanics parameters of granite, which found that both strength and cohesion decreased with increased temperature. Cekerevac et al. [10] found that the kaolin transformed from plasticity to brittleness due to the effect of temperature. Meanwhile, the shear strength and

IOP Conf. Series: Materials Science and Engineering **780** (2020) 052007 doi:10.1088/1757-899X/780/5/052007

elasticity modulus was increased.

The investigation of the influence of temperature and fissures on rock mass mechanics properties merely focused on the single factor of those two factors. There are few scholars had devoted their efforts to the investigation of the combined effects of temperature and fissures on rock mass mechanics properties. So, we study the influence of temperature and fissure angle on the deformation and strength of rock-like material which combined those two factors at the same time.

2. Preparation of specimens and testing procedure

The specimen is rock-like material in this investigation and the ratio of sand, cement, gypsum powder and water is 2:1:0.36:0.36. The size of the standard test specimen is 50 mm in diameter and 100 mm in length, which follow the Chinese standard of *Standard for test methods of engineering rock mass (2013)*. The end face nonparallelism error of specimen is less than 0.05mm, and the diameter error is less than 0.3mm and the deviation of the end face from the axis of the specimen is less than 0.25°. The location of pre-existing fissure is in the middle of the specimen and the fissure angle are 0°, 30°, 45°, 60°, 75° and 90°, respectively. The prepared specimens are shown in Fig. 1.

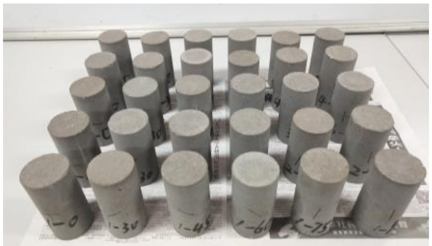


Fig.1 The prepared specimen

Fig.2 Temperature and humidity chamber

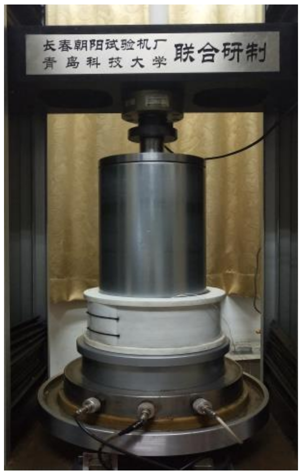


Fig.3 TAW-200 Material mechanics testing machine

First, the specimen should be dried in air condition and the dying time last for 28 days. In order to confirm that all the specimens are dried eventually, the specimens should be treated by temperature and humidity chamber (shown in Fig.2) before uniaxial compression test. The compression tests are performed by TAW-200 material mechanics testing machine (shown in Fig.3) and the test temperature range from 20℃ (room temperature) to 60℃. The temperature increment of the heating device is 2℃/min, which is to guarantee the temperature homogeneity of the whole specimen. The target temperature should be kept for 2 hours before compression test to confirm that the temperature is uneven inside and out. The compression test are performed with the loading rate of 50N/s until the specimen failure and the stress-strain curves are recorded simultaneously.

3. The influence of fissure angle and temperature on rock strength

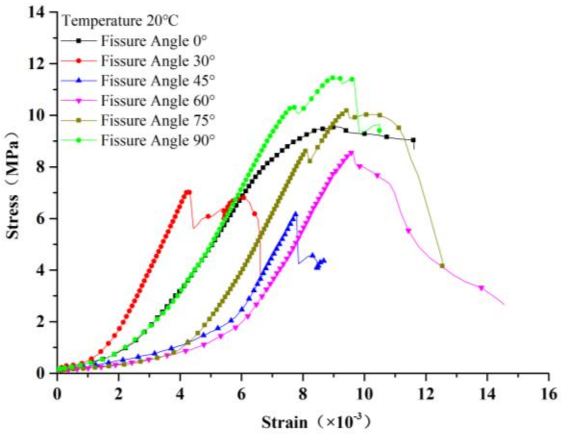


Fig.4 The stress-strain curves of different fissure angle (20°C)

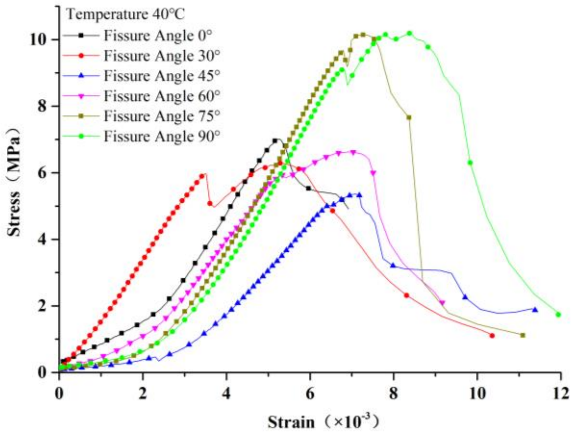


Fig.5 The stress-strain curves of different fissure angle (40°C)

We conducted the uniaxial compression tests under different temperatures for rock-like material with different fissure angle. In this paper, we selected the results of 20 and 40°C to explain the influence of fissure angle on rock strength. The stress-strain curves for 20 and 40 °C were shown in Fig. 4 and Fig.5. We could find that when fissure angle were 0° and 45°, the stress increased with strain before the peak stress, then the stress decreased with elevated strain until the specimen failure. However, there was a strength dropoff when the stress was closed to peak stress at the fissure angle of 30, 60, 75 and 90°, then the stress increased with strain to the peak stress. The reason of the strength dropoff could be attributed to the close of pre-existing fissure, which contributed to the decline of lad capacity, and then the load capacity was enhanced once the fissure closed completely. Therefore, we found that the stress increased with strain after the strength dropoff.

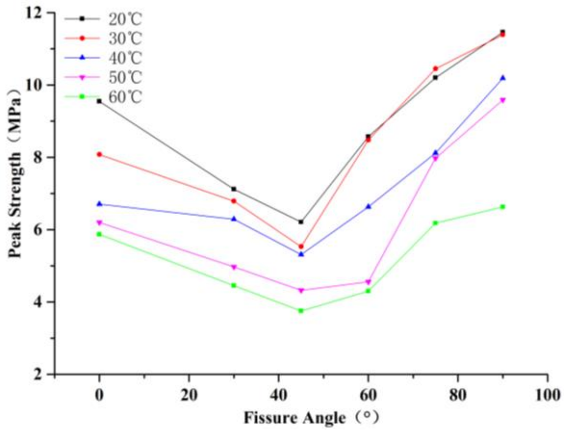


Fig.6 The tendency of peak stress with fissure angle

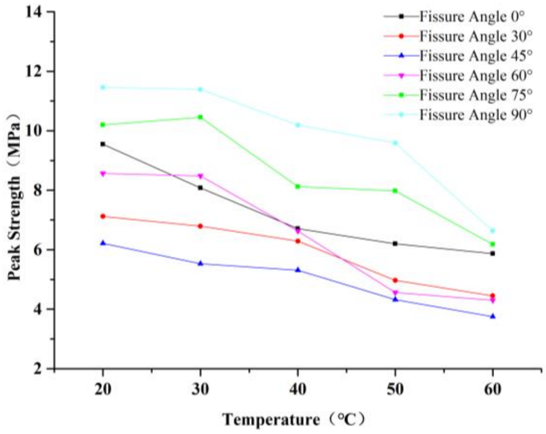


Fig.7 The tendency of peak stress with temperature

The tendency of peak stress with fissure angle and temperature were shown in Fig.5 and Fig.6. We could see from Fig.5 that the peak stress increased first then decreased with the increasing of fissure angle for all temperatures, and the minimum peak stress of all temperatures occurred when fissure angle was 45°. We could conclude that the strength of rock like material was influenced by fissure angle and the strength was influenced most significant when fissure angle was 45°. We could see from Fig.6 that the peak strength decreased with elevated temperature. The reason of this phenomenon could be attributed to thermal stress which promoted the development of initial cracks and the

IOP Conf. Series: Materials Science and Engineering **780** (2020) 052007 doi:10.1088/1757-899X/780/5/052007

derivation of new microcracks. The specimen failed eventually due to the accumulation of microcracks around the pre-existing fissure tips.

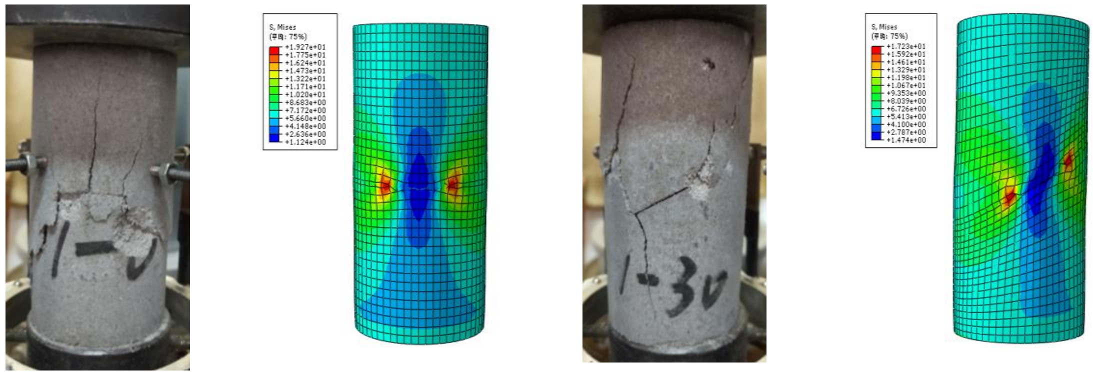
4. The influence of fissure angle on rock deformation

We conducted a serious of uniaxial compression tests on rock-like material with fissure under different temperatures, which found that the failure mode of specimen were the same at all temperatures. The influence of fissure angle on rock deformation could be illustrated by the failure mode at 20°C. The failed specimen and the simulation results were shown in Fig.8. We could see from failed specimen that the cracks started from the tips of pre-existing fissure at all kinds of fissure angle, which meant the derive of cracks could be attributed to the stress concentration on fissure tips. And the cracks developed along the direction of the primary stress, which meant the evolution of cracks were driven by primary stress. This phenomenon was consistent with the deformation of components with initial cracks in fracture mechanics. Under the action of axial stress, the growth of the crack at the tip of the initial crack was mainly attributed to the phenomenon of stress concentration. When the initial crack grown to a certain extent, the brittle crack would accelerate its growth until the material failure [11].

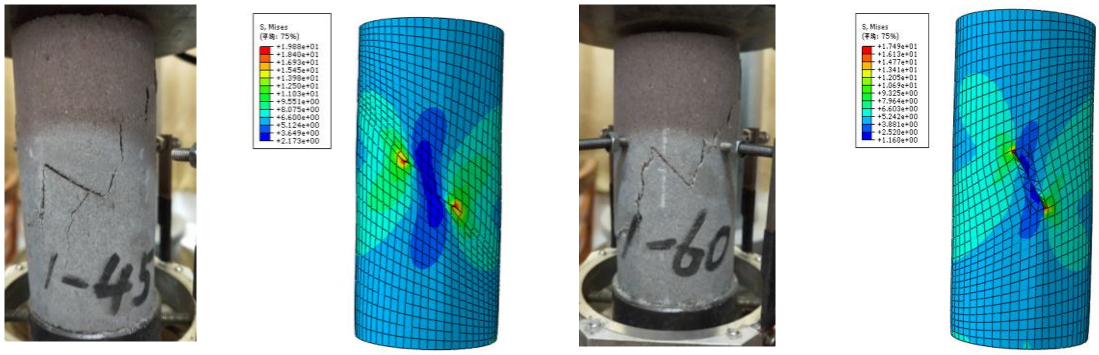
Tab.1 The mechanical parameter

Mechanical Parameter	Elasticity Modulus	Poisson's Ratio	Axial Load	Size of the Fissure（Length x Width x Depth）
Value	20000 MPa	0.25	6kN	20×1×35mm

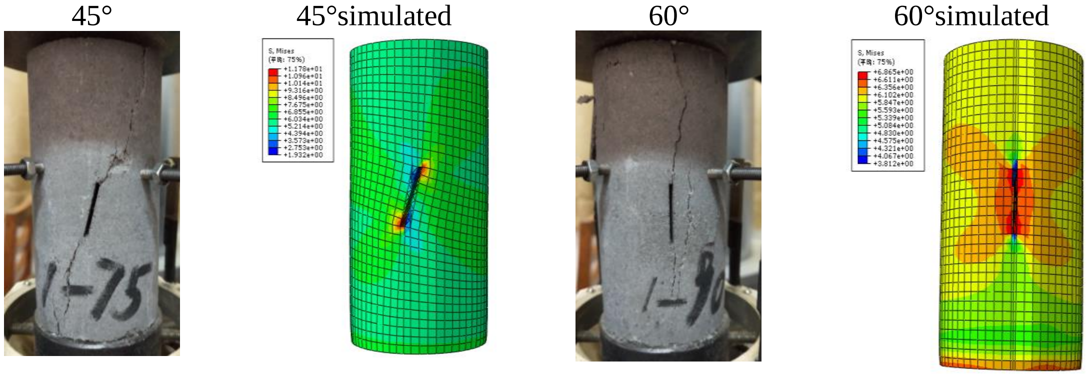
In order to verify that the derivation and growth of new cracks at the initial crack tip were caused by stress concentration, the uniaxial compression test process of pre-existing fissure rock-like specimens with different inclinations was numerically simulated. Since our numerical simulation mainly focused on the stress distribution before crack failure, we only simulated the test process of elastic deformation stage of rock. We assumed that elastic deformation occurred in the elastic stage, the mechanical parameters were shown in Tab.1, and the simulation results were shown in Fig.8. We could see the simulation results from Fig.8 that the maximum stress of all specimens occurs on the tips of the fissure in uniaxial compression test. And it could be found that the numerical simulation results were completely consistent with the test results by comparison with the crack of the test specimen. The tips of the pre-existing fissure was the area of stress concentration. Therefore, the new crack originated from the tip of the crack and extended along the direction of the primary stress. According to the numerical fitting results, the maximum stress corresponding to the fracture angle from 0° to 90° was 19.27, 17.23, 19.88, 17.49, 11.78 and 6.865MPa, respectively. In other words, the maximum stress value occurred at the tips of the fissure angle 45°. It meant the specimen failed first when fissure angle was 45° at the same loading condition, which consisted with the test result that the smallest peak stress occurred when fissure angle was 45°.



a) Fissure Angle 0° b) Fissure Angle 0°simulated c) Fissure Angle 30° d) Fissure Angle 30°simulated



e) Fissure Angle 45° f) Fissure Angle 45°simulated g) Fissure Angle 60° h) Fissure Angle 60°simulated



i) Fissure Angle 75° j) Fissure Angle 75° simulated k) Fissure Angle 90° l) Fissure Angle 90°simulated

Fig.8 Compassion of experiment results and numerical simulation results

5. Conclusions

In this paper, uniaxial compression tests of rock-like materials with different pre-existing fissure at different temperatures are carried out to study the effects of temperature and fissure angle on the strength and failure modes of rock-like materials. The research shows that both temperature and fissure angle have an effect on the strength of rock-like rocks, which is embodied in the following aspects:

1) The strength of rock-like material decreased first then increased with the increase of fissure angle at all temperatures and the minimum strength occurred at fissure angle 45°. The strength had a short attenuation stage at the fissure angle of 30°、60°、75° and 90°, which was due to the loading capacity of the rock decreased instantly when the pre-existing fissure was closed and rose after the crack closed. The strength of rock-like material gradually decreased with the increase of temperature

IOP Conf. Series: Materials Science and Engineering **780** (2020) 052007 doi:10.1088/1757-899X/780/5/052007

at all kinds of fissure angle. The main reason was that the increase of temperature generated thermal stress, which lead to the acceleration of the derivation and expansion of new cracks inside.

2) For all rock-like specimens containing per-existing fissure, the cracks started from the fissure tip, and the growth direction started from the tip of the pre-existing fissure and extended to the direction of the primary stress. By comparing with the results from numerical simulation, we found that this phenomenon is mainly caused by the stress concentration at the tip of pre-existing fissure under the action of axial stress. In addition, the stress decreased gradually from the crack tip to the main stress, which was consistent with the crack expansion direction in the experiment.

Acknowledgments

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