Experimental study on uniaxial compression after creep characteristics of similar soft rock containing cross cracks

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Abstract. In order to study the creep phenomenon and failure law of rock materials containing cracks, uniaxial compression test and uniaxial compression test after creep are carried out on similar soft rock samples containing different angles of cross cracks, and the differences of rock mechanical properties after two tests are compared and analyzed. Results show that creep effect increases the compactness of the internal structure of the sample, the elastic modulus improve, enhance the ability of resistance to elastic deformation, the peak strength increases, and 15° cross crack sample is more seriously damaged, 30°, 45° and 60° cross crack samples generate deeper and longer crack propagation and broken degree is lower, 75° and cross sample produce fewer cracks.

1. Introduction
In deep rock mass engineering such as coal seam mining, the surrounding rock of roadway in the state of equilibrium is disturbed by mining action such as blasting, which not only exists the development and expansion of the original cracks in the rock mass, but also generates a large number of mining-induced cracks due to the rock strata movement in the goaf of the ore bed. The strength of rock mass is weakened by cracks, and there are hidden dangers of geological disasters such as rockburst and collapse. The length, number, occurrence, connection and external stress of cracks in the rock are different, which in turn affect the strength of the rock, the expansion and development of cracks and the stability of the rock mass to different degrees.

Nolen-hoeksema et al. [1] has prefabricated oblique cracks in marble and conducted uniaxial compression test to study the influence of cracks on rock strength, and observed the initiation, expansion and development of new cracks at the crack tip under the action of external forces. Wang Yongyan et al. [2] has prepared single crack similar rock samples containing different angles and analyzed the influence of different crack angles on the main mechanical parameters of single crack samples. Tang Hongmei et al. [3] has discussed the relationship between strength and the angle and length of the single crack. Pu Chengzhi et al.[4] has introduced the relative cracks aperture, studied the crack failure mechanism under uniaxial compression of similar rock materials with single horizontal cracks, and established the relationship between relative cracks aperture and failure mode. The above researches are mainly carried out for single crack rock samples. Jiang Mingjing et al. [5] has discussed the propagation and coalescence mechanism of double crack rocks by using discrete element method. According to similarity theory, Zhang Bo et al. [6] has made two cross-crack rock samples with primary and secondary
cracks and different angles between cracks, and conducted uniaxial compression test to study the influence of multiple combinations of cross-crack rocks on failure modes and mechanical parameters. Dang Shuo [7] has prepared similar rock samples with single crack and T-shaped cross-crack using gypsum material, carried out uniaxial compression test and uniaxial cyclic loading test, and recorded the whole process of the failure of the samples, and obtained the changing rules of the strength and failure mode of the samples with different crack occurrence. At present, uniaxial compression of crack rock has been well studied, but the stress of underground rock mass is complex and cannot be limited to the uniaxial compression of rock. Wang Yongyan et al.[8] has carried out single and triaxial compression tests and confining pressure unloading tests on the similar samples of single crack rock, and found that the steady creep rate of the crack rock samples was greatly affected by the angle, so they proposed a creep equation suitable for the single crack rock materials. Hu Bo et al.[9] has conducted uniaxial long-term compression creep test on the single crack red sandstone sample of 45°, and found that the sample does not accelerate the creep failure stage, and established the damage creep model based on the effective stress principle. Fabre et al. [10] has conducted uniaxial compression and creep tests on mudstones containing weak surfaces with different angles. Although creep of rock is the most common phenomenon in geotechnical engineering, in practical engineering, the surrounding rock of goaf roadway is suddenly affected by blasting, excavation and other large external forces, and the original equilibrium state is broken, which is manifested as the stress condition of compression after creep action. Qin Nan [11] et al. has carried out uniaxial compression test on the rock sample with single crack after uniaxial creep action, and obtained the stress-strain curve, strength and creep expansion and evolution rules of the sample after creep action. CAI Yanyan et al. [12] has respectively performed uniaxial compression on the marble containing cracks and original rock samples after creep, and obtained rules of the deformation, strength characteristics and mechanical parameters of marble through comparison. But there are few reports on uniaxial compression of similar soft rock samples with cross cracks after creep.

Rocks are composed of pores between solid minerals and mineral particles, and they have random internal defects with complex internal structure and large discreteness. Moreover, it is difficult to prefabricate cracks in natural rocks, which is not conducive to qualitative and quantitative research on the creep characteristics of rocks. In order to study the creep phenomenon and failure law of crack rock material more directly, This study makes up similar soft rock samples containing different angles of cross cracks, and carries out the uniaxial compression test and the uniaxial compression test after uniaxial creep, compares and analyzes the differences of rock mechanical properties after two tests, to study the influence of the mining strength characteristics of roadway surrounding rock and so on has certain significance.

2. Preparation for similar material test

2.1. Preparation of rock-like samples

The similar soft rock is the test sample of rock-like materials with certain compressive strength prepared by cement, river sand, gypsum, fly ash, paraffin and other materials in a certain proportion. The raw material and ratio of this study are river sand: cement: water =2:1:0.11.Fig.1 is a schematic diagram of structure and dimensions of prefabricated cross-crack mold. The angles (θ) of the prefabricated cross crack sample are 15°, 30°, 45°, 60°, 75°, cross and full sample.
2.2. Test equipment

The prefabricated cross-crack sample (Fig.2) is cured by RPH-80 programmable constant temperature and moisture test box. The creep test is completed by TAW-200 electronic multifunctional material mechanics testing machine (axial load range is 0-200kN, confining pressure loading range is 0-30kN), as shown in Fig.3, uniaxial compression test after uniaxial creep test is performed on full samples and samples with cross cracks at different angles. Force loading method is adopted at a loading rate of 50 N/s. Uniaxial creep test uses four-level loading method. The stress level of the stage loading is determined by the peak strength measured by the uniaxial compression pre-test, and the loading time of each stage is 2 h.
3. Analysis of experimental results

3.1. Stress-strain curve analysis

Fig. 4 shows the stress-strain curve of uniaxial compression test, and fig. 5 shows the stress-strain curve of uniaxial compression test after creep. There are four stages of initial compaction, elastic deformation, plastic deformation and failure in the stress-strain curves of the two tests. Due to the effect of creep, the original internal micro-cracks have been compacted and closed. In fig. 5, the initial compaction stage is less obvious than uniaxial compression test. As shown in fig. 5, the samples destroyed by uniaxial compression after creep action mainly suffer brittle fracture, that is, the stress-strain curve of the samples falls rapidly after peak, and the sound of "bang" could be obviously heard when the samples were destroyed, which also indicates that the internal structure of the samples after creep action is more compact.

3.2. Peak strength analysis

Draw the comparison relation about peak intensity, as shown in Fig. 6. After uniaxial creep and then uniaxial compression, the order of the peak strength of the cross-crack samples is as follows: full>30°>45°>60°>15°>75°>cross, the highest peak intensity in the full sample is 14.12 MPa, the minimum peak intensity of the cross sample is 6.47 MPa, in addition to the peak strength of the 15° cross-crack sample after uniaxial creep is smaller than that under uniaxial compression, the other sample after creep peak strength are increased, the peak strength shows a tendency to decrease with the increase of the angle of the cross crack. This indicates that after the creep action, the internal structure of the sample becomes more compact, and the compactness of the sample is enhanced, resulting in the increase of peak strength. By comparing the peak strength under uniaxial compression, it is found that the peak strength decreases with the increase of crack angle as a whole whether the sample undergoes creep or not.
3.3. Elastic modulus analysis
Draw the comparison relation about Young's modulus, as shown in fig.7. After uniaxial creep and then uniaxial compression, the elastic modulus of the cross-crack samples is ordered as follows: cross>full>45°>60°>30°>15°>75°, the maximum is 3.26GPa, and the minimum is 2.25GPa. Compared with the elastic modulus of uniaxial compression, the elastic modulus of samples after uniaxial creep is improved, indicating that the elastic modulus of the samples is strengthened and their resistance to elastic deformation was enhanced after creep action.

3.4. Failure mode analysis of sample
Fig 8 is the failure sample of the uniaxial compression test, and fig 9 is the failure sample of the compression after uniaxial creep. 15° cross-crack sample is damaged all by the prefabricated crack tip along the axial extension and extension in the two tests, because of the poisson effect, sample produces the transverse tensile stress under axial compressive stress, and the 15° cross crack significantly decreases the tensile-resistant limit, transverse tensile stress is greater than the tensile-resistant limit and tensile failure, the poisson effect more apparent after creep, transverse tensile stress increases, therefore, the sample is damaged more severely when re-compressed after creep, and there are obvious flaky and massive drops, and the peak strength of the 15° cross-crack sample after creep is lower. The peak strength of the sample after creep compression of 15° cross crack is lower. The 30°, 45°, and 60° cross-
crack samples produce axial primary cracks at the crack tip, but the cracks grow deeper and longer when compressed after creep, and the broken degree is lower, indicating that sample inside is more compact under uniaxial creep test. The failure modes of the 75° cross-crack sample and the cross sample are the same in the two tests. The 75° and cross samples produce cracks that expanded from the tip of the crack and were parallel to the axial force, resulting in axial crushing. The full samples mainly suffer from inclined shear failure and the cracks become less after creep action.

4. Conclusion

Uniaxial compression test and uniaxial compression test after uniaxial creep action are carried out on similar soft rock samples with different angles of cross cracks, and the experimental results and failure modes obtained are compared and analyzed. The main conclusions are as follows:

(1) The initial compaction stage of the stress-strain curve of uniaxial compression test after uniaxial creep action is less obvious than that of the uniaxial compression test, and brittle failure mainly occur, with post-peak drop, indicating that the internal structure of the sample after creep action was more compact.

(2) After uniaxial creep and then uniaxial compression, the order of the peak strength of the cross-crack samples is as follows: full>30°>45°>60°>15°>75°>cross. Except for the sample with a smaller angle of 15°, the peak strength of the sample decreases with the increase of the angle of the cross crack. With or without creep, the peak strength decreases with the increase of crack angle.

(3) After uniaxial creep and then uniaxial compression, the order of the elastic modulus of the cross crack samples is as follows: cross>full>45°>60°>30°>15°>75°. After creep, the elastic modulus of the crack samples is improved, the ability of resistance to elastic deformation is enhanced.

(4) During the uniaxial compression test after creep and uniaxial compression test, the 15° cross crack samples mainly suffered tensile failure, but after creeping, the samples are more severely damaged when are compressed, and the peak strength is lower. The cross crack samples at 30°, 45° and 60° produce the primary crack along the axial direction at the crack tip, but the crack propagation is deeper and longer and broken degree is lower. When they are compressed after creep, the 75° and cross samples generate cracks that expand from the crack tip and are parallel to the axial force, resulting in axial
crushing. The full samples mainly suffer from inclined shear failure and the cracks become less after creep action.

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