Study of the temperature dependence of the uniaxial creep property of similar material of new soft rock

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Abstract. Using the experimental method, the experimental research of creep properties were conducted under different temperature ranging from 10°C to 60°C. The similar material of new soft rock consists of paraffin, which can obtain that the deformation contains the instantaneous elastic deformation and creep deformation through the uniaxial creep experimental results. And thus the increase of temperature has great influence on the creep characteristics of similar soft rock according to the creep curve of similar soft rock at 10°C and 60°C. With the increase of temperature, the slope of the stress-strain curve of similar soft rock is increasing, while the average of the creep modulus is decreasing, which means that the capacity of resist deformation is reduced. Therefore, the creeps law of high-temperature and short-time can be shown the creep phenomenon of low-temperature and long-time, and further shorten the creep experimental cycle.

1. Introduction
Soft rock engineering stability control problem is always one of the major problems of coal mine production and construction in China. With the increase of mining depth and the complexity of geological conditions, the problem of soft rock tunnel support becomes increasingly serious. Soft rock rheology mainly led to the instability of surrounding rock of soft rock supporting engineering. Rock creep law is the main law reflecting its timeliness deformation. With the further development of deep engineering, the underground environment becomes more complex, temperature is closely related to the time effect of soft rock deformation [1-5]. The effect of temperature on the rock creep properties has great significance for engineering safety assessment and prediction. Researches of the temperature effect on rock creep at present are as follows: Wawersik W R [6] pointed that high temperature increased creep strain and creep rate of rock salt. Li J G [7] took sandrock as an example and analyzed that temperature effect should be considered in the design of deep soft rock engineering by experiment. Wang Y C [8] analyzed the study on creep law of deep soft rock under thermal-mechanical-chemical coupling effect and explored its mechanism, and thus established visco-elastic-plastic nonlinear creep model of considering temperature and chemical PH value influencing factor deep rock. Xi B P [9] pointed that steady-state creep rate and temperature of layered salt rocks comply with index correlation. Liu Q S [10] proposed the temperature has large influence degree for different rock rheological according to uniaxial compression test under three gorges granite specimen.

The experimental research of temperature on creep property mainly concentrated on the hard rock or great-intensity soft rock. While the creep has long experimental cycle and requires high temperature, which can’t ensure the experiment safety. The paper chooses a paraffin wax as cementing agent,
40-mesh river sand as aggregate to configure a kind of similar soft rock material instead of soft rock prototype material, which can reflect the creep law under lower temperature and shorter time and greatly save the experiment period. And thus study the experiment research for creep property of similar soft rock under different temperature, which can provide an important basis to predict long-term stability and security in prototype engineering of soft rock.

2. The experimental process

2.1. The preparation of similar soft rock specimen and determination of physical parameters
Due to better thermal sensitive, the paper chooses weak cementation named paraffin as similar material cementing agent, which can simulate the lower intensity and bigger deformation the plastic of plastic destructive rock mass. The aggregate [11] chooses 40 mesh river sand; the auxiliary material chooses gypsum and industrial iron power, the proportion of paraffin, river sand, gypsum, iron powder is respectively 1:6:1:1. The experiment quickly put the material into the prepared mold and compacted after stirring evenly the ingredients under the constant 100 ℃, then put the specimen in the constant temperature and humidity environment, and cool and cure them under room temperature to avoid temperature effect on the forming specimen. The specimens are the cylinder of 50 mm diameter and 100 mm height.

![Figure 1. Part of the preparation of similar specimens in the incubator curing.](image)

As shown in figure 1, similar specimens are done uniaxial and triaxial compression experiments under room temperature by the TAW - 200 electronic multi-function material mechanics testing machine and obtained the experimental test value of compressive strength, elastic modulus, Poisson's ratio. The experiment uses KD2 Pro Thermal characteristics analyzer (America), which can measure the thermal conductivity coefficient of similar soft rock. Take the visual density of the prototype material \( \rho = 2.4 g/cm^3 \), the visual density of the model material \( \rho = 2g/cm^3 \), the volume-weight similar scale \( C_\rho = \rho_p/\rho_M = 1.2 \) and the geometry similar scale \( C_L = 16 \) [12] and can be obtained the calculated value of similar material physical parameters based on the similar theory [13,14]. As shown in table 1, in this paper, the preparation of the similar material can better satisfy the similarity criterion, which means that the prototype materials have high similarity.

| Table 1. Calculation and experimental values of physical parameters of similar materials. |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| compressive strength /MPa | tensile strength /MPa | elasticity modulus /Gpa | Poisson's ratio | Cohesion /MPa | internal friction angle /° | Density /g/cm³ | heat conductivity coefficient W/m.k |
| Calculated value | 0.23~4.1 | 0.05~2.0 | 0.46~1.1 | 0.09~0.3 | 0.1~1.56 | 20~40 | 2 | 0.479 |
| experiment | 3.12 | 0.76 | 0.48 | 0.31 | 1.17 | 38 | 1.987 | 0.472 |
2.2. Creep experiment

- Laboratory equipment

The experiment uses TAW - 200 electronic multi-function material mechanics testing machine and the high-low temperature environment test chamber developed by mechanics research center of Qingdao University of Science and Technology (figure 2) can provide high and low temperature environment, stress and strain material data, which can realize automatic temperature control, the highest temperature can reach 200°C. Set the experiment temperature is respectively 10°C, 20°C, 30°C, 40°C, 50°C, 60°C, put every three specimens in temperature box. Heat up rapidly and do creep experiments when reaching the set temperature, the experimental results take the average of the three specimens and ignore the influence on error specimen.

![Figure 2. TAW-200 Electronic multifunctional materials mechanical testing machine, temperature box.](image)

| Loading method | Temperature/°C | Load/MPa       |
|----------------|----------------|----------------|
| step loading   | 10             | 1, 1.5, 2, 2.5 |
|                | 20             | 1, 1.5, 2, 2.5 |
|                | 30             | 1, 1.5, 2     |
|                | 40             | 0.25, 0.5, 0.75, 1 |
|                | 50             | 0.15, 0.2, 0.25, 0.3, 0.35, 0.5 |
|                | 60             | 0.1, 0.15, 0.2 |

- The experiment method and parameter setting

Load and time on the same sample keeps continuous step by step and obtains creep curves of specimen under different stress level by hierarchical load creep experiment scheme. This experiment scheme can avoid discrete factors of the specimens and maintenance. The hierarchical load conditions under different temperatures are shown in table 2 and each load can keep 2 h.
3. The experimental results and analysis

From figure 3 can be seen the creep curve of similar material specimen at different temperature. Take 10°C and 60°C as example to better describe the creep properties of similar soft rock and can be seen from figure 3(a) that the axial strain of similar soft rock showed the law of decelerating creep and stable creep stage in the four stress level in 2 h, and with the increase of the loading stress level, the creep strain increases, the creep value for stress level of 2.5 MPa (0.0083) is more than 2 times to 1.0 MPa (0.004). Similar soft rock showed the deceleration creep and stable creep stage and deceleration creep accounted for the main part in the low-stress level of 0.1 MPa and 0.15 MPa from figure 3(f) at 60°C. In the level of 0.25 MPa, similar soft rock started showing accelerated creep stage and exhibited...
plastic failure even if the stress was still low. Compared the creep curves at two temperature, the temperature has a huge impact on the creep properties of similar soft rock and the creep value under 0.1 MPa in 2 h is 2.5 times to the creep value under 2.5 MPa in 2 h.

The creep data such as the stress value, strain value, time and temperature after 1 h were extracted from the similar soft rock creep characteristic data, and then the stress-strain curves under different temperatures were plotted. As can be seen in the figures 4 and 5:

![Creep stress-strain curves of similar soft rock at different temperatures (1 h).](image1)

**Figure 4.** Creep stress-strain curves of similar soft rock at different temperatures (1 h).

![The average creep modulus varies with temperature (1 h).](image2)

**Figure 5.** The average creep modulus varies with temperature (1 h).

The stress-strain curve of similar soft rock is linear, and the temperature has little effect on the stress-strain relationship of similar soft rock at 20℃ and below; the stress-strain curve is upward migration with the temperature rising, and the higher the temperature is, the greater the magnitude of the offset is. To reflect the effect of temperature on the creep deformation capacity of the similar soft rock, define the reciprocal of the straight slope of stress-strain curves as the average creep modulus. Obviously, as the average creep modulus are constantly reduced, the decrease in 30-40℃ is particularly evident with the temperature increasing.

During the experiment, the similar soft rock showed large deformation and crept damage under high-temperature environment and low-stress level within a short time. Due to this feature, we can characteristic the creep condition in high temperature and short time instead of low temperature and long time, which greatly shortens the test cycle of indoor model test and can better simulate the rheological properties of soft rock.

4. Conclusion

- The uniaxial creep experimental results of similar rock show that the deformation of similar soft rock contains the instantaneous elastic deformation and creep deformation. The creep curve of similar soft rock only shows decay creep and constant creep law within 2 h under 10℃ and 2.5 MPa stress, while under 60℃ and 0.25 MPa stress, the creep law shows acceleration within 2 h, and it can be seen that the increase of temperature has great influence on the creep characteristics of similar soft rock.

- Under normal temperature (20℃), the strain curve of similar soft rock is basically linear, with the increase of temperature, the slope of stress-strain curve of soft rock is increasing, and the soft rock creep is more sensitive to the load. With the increase of temperature, the average of the creep modulus is decreasing. It means that the capacity of resist deformation is reduced. According to this feature, the creeps law of high-temperature and short-time can be shown the creep phenomenon of low-temperature and long-time, and further shorten the creep experimental cycle.

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