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Study on Physical Properties and Energy Evolution of Natural Gypsum Rock under Freeze-thaw Cycles

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Abstract: The physical and mechanical properties, microstructure deterioration characteristics and damage mechanism of natural gypsum rock under freeze-thaw cycles were studied by using a self-developed programmed freeze-thaw experimental device, results showed: Compared with that before freeze-thaw, with the increase of freeze-thaw cycles, the surface dissolution of gypsum rock samples becomes more obvious, the longitudinal wave velocity decreases linearly, the uniaxial compressive strength and elastic modulus decrease exponentially, the compaction stage of stress-strain curve is significantly prolonged, and the plasticity of post-peak failure process is enhanced. With the increase of axial strain, the total input energy curve rises at a faster rate, and the elastic energy curve also rises, but the rising rate slows down significantly after the freeze-thaw cycle, and the dissipation energy curve gradually evolves from a smooth rise to an ' S ' type. The research results have reference significance for the construction scheme design and frost damage prevention of gypsum surrounding rock tunnels in cold regions.

Keywords: Gypsum rock; Freeze-thaw cycle; Physical mechanics; Energy evolution.

1. Introduction

With the implementation of the western development strategy, infrastructure construction projects continue to advance to high-cold and high-altitude areas, the complex natural climate conditions along the way have caused a severe test to the engineering life, and a large number of tunnels in cold regions have potential safety hazards due to freezing damage. The alternation of day and night and seasons in the alpine region causes periodic changes in temperature, which are manifested in the form of freeze-thaw cycles, accelerating the weathering process of buildings and rock bodies. Therefore, the research on the deterioration and damage mechanism of rock materials under freeze-thaw cycles has great reference value for the construction of cold regions and the protection of cultural relics.

Domestic and foreign scholars have carried out a large number of indoor experimental studies on the freeze-thaw damage of rock materials, and achieved a lot of results. Zhang Huimei et al [1] compared the degradation mode and mechanical properties of sandstone and shale after freeze-thaw cycles, and concluded that the difference of initial meso-structure of rock leads to the difference of final macroscopic properties. Wang et al [2] discussed the coupling effect of freeze-thaw cycles and chemistry on concrete in cold regions, and considered that the coupling effect was more serious than the single effect. Lu Xiang et al [3] carried out freeze-thaw cycle experiments in different temperature ranges, and concluded that the lower the freeze-thaw temperature, the more significant the deterioration of mudstone by freeze-thaw cycles; Han et al [4] studied the damage degradation mechanism and physical and mechanical properties of sandstone under the coupling of different chemical solutions and freeze-thaw cycles. Luyani et al [5] explored the variation of anisotropy of rock strength and deformation parameters with confining pressure and freeze-thaw cycles, and analyzed the influence of bedding angle and freeze-thaw action on the failure mode of rock samples. Al-Omari et al [6] explored the influence of critical saturation and pore size distribution on the degree of freeze-thaw damage of limestone. Maxim et al [7] revealed the water-ice phase transition law and freeze-thaw damage mechanism in closed pores by measuring the temperature and strain of limestone during freeze-thaw process and combining with micro-CT technology. In addition, in the study of energy evolution law in the process of rock failure. Chen et al [8] found that with the increase of rock-coal height ratio, the ability of external energy to transform into elastic energy increases, and the macroscopic cracks increase and the degree of dynamic appearance increases after the failure of the combined sample. Ma Depeng et al [9] studied the failure energy evolution characteristics of coal samples under different unloading confining pressure rates, and found that the faster the unloading confining pressure rate, the greater the increase rate of the coal sample damage curve; Su Hongyan et al [10] found that the curing temperature will affect the energy index level in the study of cement-based tailings cemented backfill. Chen et al [11] calculated and analyzed the energy conversion and dissipation mechanism of jointed specimens during uniaxial compression failure.

In summary, experts and scholars at home and abroad have carried out a lot of work on freeze-thaw damage of rock in cold regions, and have obtained many practical research results. However, in practice, it is very likely that the construction of tunnel projects in cold regions will need to pass through gypsum-containing rock strata. Therefore, the freeze-thaw cycle test and physical and mechanical test of natural gypsum rock are carried out in this paper.

2. Energy calculation principle

The failure of rock specimen under axial stress is the result of the work done by the testing machine. When ignoring the heat exchange in this process, the axial force has the

following relationship with the energy generated by the work of the sample:

$$U = U_d + U_e \quad (1)$$

$$U = \int_0^{\varepsilon_P} \sigma_i d\varepsilon \quad (2)$$

Where U is the input energy, Ue is elastic strain energy, Ud is dissipation energy; ε_P is the peak strain; σ_i is the stress in the loading process, and dε is the strain element. Ue is calculated as follows:

$$U_e = \frac{{\sigma_P}^2}{2E_i} \approx \frac{{\sigma_P}^2}{2E_0} \quad (3)$$

As shown in Figure 1. The value of U can be calculated by integrating the stress-strain curve, the triangle area with the unloading curve as the oblique edge is Ue. Then the subtraction of U and Ue is Ud.

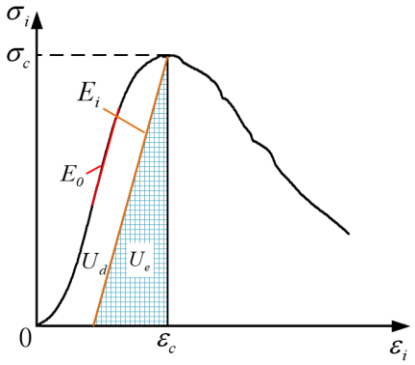


Figure 1. Schematic diagram of energy calculation

3. Gypsum rock freeze-thaw mechanics experiment

3.1. Sample preparation



Figure 2. Gypsum rock samples

The gypsum rock is gray or gray-white mixed dense block, they were processed into a standard sample of Φ50 × 100 mm by water drilling, and polished to both ends of the parallelism is less than 0.05 mm. All samples were dried at 45°C for 48h in the oven to remove the free water inside the gypsum rock sample, and then placed in pure water for 72h to reach saturation. The basic physical parameters of the samples shown in Table 1.

Table 1. Sample parameters before and after saturation

State	*m*/g	ρ/g·cm^{-3}	v_P /m·s-1	ω/%
Desiccanted	450.92	2.345	4725	-
Saturated	453.92	2.363	4644	0.66

3.2. Freeze-thaw cycle test

The prepared samples were divided into four groups: A, B, C and D. The samples in group A were directly subjected to mechanical tests, and the samples in groups B, C and D were used as freeze-thaw groups, corresponding to 15,30,45 freeze-thaw cycles, respectively. Put the freeze-thaw samples into the freeze-thaw equipment, set the freeze-thaw temperature-20°C~20°C, 24hours for a cycle. Whenever a predetermined number of freeze-thaw cycles is reached, the longitudinal wave velocity measurement and uniaxial compression test are performed on the samples.

3.3. Strength characteristics of freeze-thaw gypsum rock

Under the action of freeze-thaw cycles, the original cracks inside the gypsum rock samples gradually expand, and new cracks gradually sprout. With the continuous freeze-thaw cycles, the samples will eventually disintegrate and lose strength due to crack coalescence. In order to study the influence of freeze-thaw cycle on the mechanical properties of natural gypsum rock, uniaxial compression test was carried out.

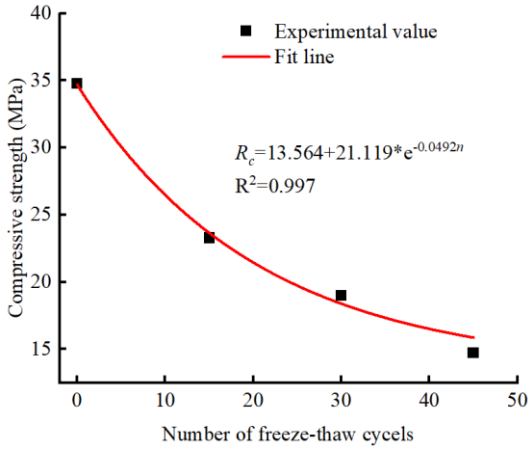


Figure 3. Relationship between compressive strength and freeze-thaw cycles

After experiencing different freeze-thaw cycles, the strength variation of the sample is shown in Figure 3. It can be seen that the strength of the sample decreases exponentially with the increase of the number of freeze-thaw cycles. It can be seen that the freeze-thaw effect has a great influence on the mechanical properties of gypsum rock, especially the mechanical index of gypsum rock in the first 15 freeze-thaw cycles.

4. Research on energy evolution law

In order to explore the energy evolution law of natural gypsum rock samples under different freeze-thaw cycles, a typical curve was selected from the stress-strain curves of samples in groups A, B, C and D, and calculate U, Ue and Ud.

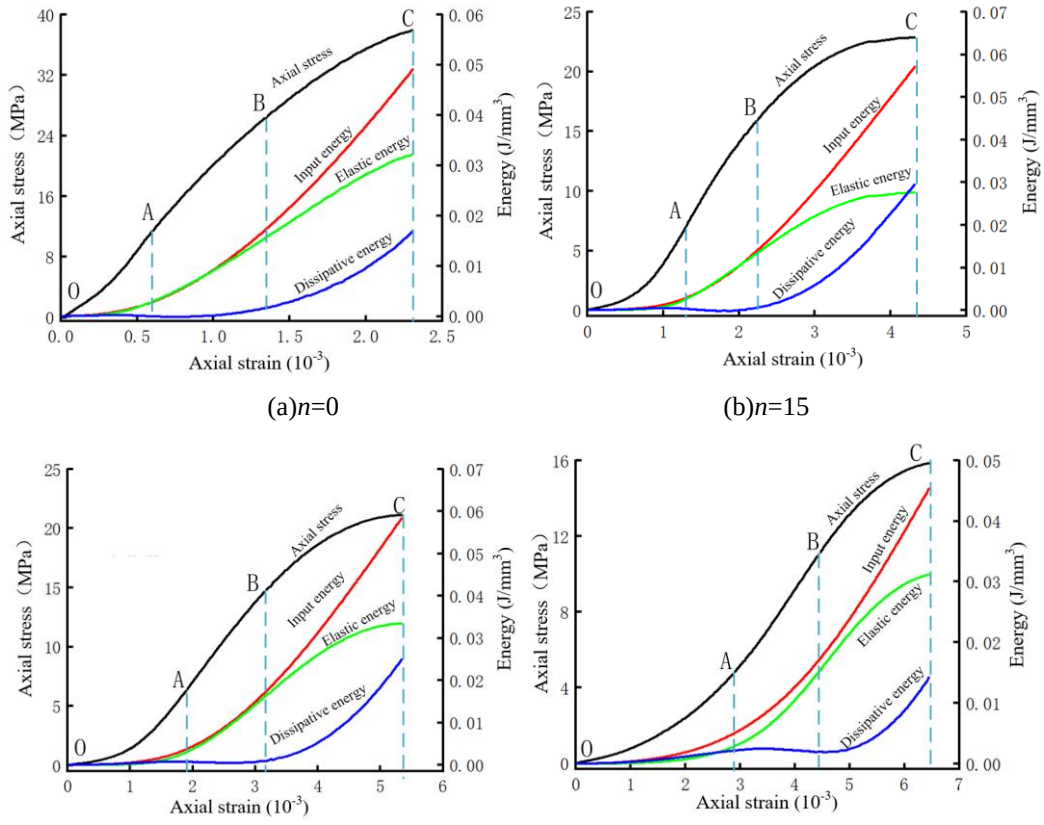
Figure 4 shows the variation of stress, U, Ue and Ud with strain under the same loading conditions. The three stages before the peak stress are discussed as follows:

Compaction stage (OA), with the increase of the number of freeze-thaw cycles, U continues to increase, increasing by 76.8% before freeze-thaw during the 45 cycles, while Ud reaches 43.1% of U in this stage, which is about twice the increase of 30 cycles, while Ue changes little.

Elastic stage (AB), it can be seen from the figure that the U and Ue curves basically coincide with the U after 0,15,30 freeze-thaw cycles, but there is a tendency to separate, and there is obvious separation after 45 cycles. U and Ud of this stage decrease with the increase of the number of cycles, while Ue does not change much.

Yield stage (BC), with the increase of the number of freeze-

thaw cycles, U and Ud still show the law of increasing first and then decreasing, while the increase rate of Ue becomes gentle under the action of freeze-thaw, but the Ue accumulated in this stage changes little. Under the same load condition, more energy is needed to drive the crack propagation, which leads to the increase of dissipation energy.



(a)*n*=0 (b)*n*=15

(c)*n*=30 (d)*n*=45

Figure 4. Energy Evolution Law of Each Stage under Different Cycle Times

5. Conclusion

In this paper, the freeze-thaw cycle test of natural gypsum rock was carried out. The macroscopic damage characteristics and mechanical properties of gypsum rock after 0,15,30,45 cycles were studied respectively, and the energy evolution law of gypsum rock samples under load conditions was emphatically analyzed. The research results have important engineering reference value for the stability of surrounding rock of gypsum rock tunnel and gypsum mine slope in cold region. The main conclusions are as follows:

(1) After freeze-thaw cycles, the uniaxial compressive strength and elastic modulus of gypsum rock samples decrease exponentially, and the decrease is the largest in the early stage of freeze-thaw. The failure mode gradually changed from brittle failure to ductile failure with the increase of freeze-thaw cycles.

(3) With the increase of the number of cycles, U and Ud increase first and then decrease, and Ue fluctuates within a certain range. With the increase of axial strain, the total input energy curve rises at a faster rate, elastic energy curve also rises, and the dissipation energy curve gradually evolves from a smooth rise.

Acknowledgements

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