Effect of Freeze-thaw on the Shear Strength of Soil-rock Mixtures

Shenqi Yang[a] and Wen Sun[b*]

Department of Civil Engineering, Lanzhou Jiaotong University, Lanzhou, China

E-mail: [a]2775485673@qq.com; [b]sunwen@lzjtu.edu.cn
*Corresponding author.

Abstract. In order to study the mechanism of shear strength deterioration of soil-rock mixtures under frost-thaw action, the frost-thaw soil-rock mixtures were studied by nuclear magnetic resonance (NMR) and triaxial shear tests. The results show that the shear strength deterioration of soil-rock mixtures with varying moisture rates is different under frost-thaw action, and the higher the moisture content, the more serious the deterioration of shear strength. The porosity increases first and decreases and increases, and the pore structure first developed from micropores and mesopores to macropores, and then macropores collapsed to evolve into micropores. The evolution of the structure of pores in soil-rock mixtures can better respond to the changes in shear strength and can better reveal the deterioration mechanism of shear strength.

Keywords: freeze-thaw cycle; soil-rock mixture; strength deterioration; evolution of pore structures

1 Introduction

With the increasing construction of water conservancy projects in the seasonal frozen soil area in western China, and the stability of the soil-rock mixture slope under the action of frost-thaw is becoming increasingly prominent, which seriously threatens the safe operation of water conservancy projects. Currently, numerous scholars have studied the influence of shear strength of soil-rock mixtures with different stone contents under frost-thaw action. Zhou et al. [1,2] discovered the mesoscopic interface damage phenomenon of soil-rock mixtures caused by frost-thaw, and established the correlation between the shear strength change and the soil-rock interface damage coefficient under frost-thaw action. Liu et al. [3] found that the change of pore structure can well reflect the deterioration of strength. Tang et al. [4] found that the deterioration of the shear strength of soil-rock mixtures under frost-thaw action was caused by the changes in skeleton structure caused by different stone contents. Li et al. [5] analyzed the relations of pore volume structure and shear properties under frost-thaw action by test. The presence of water in the soil-rock mixture will lead to the phase transition of ice and water

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during the frost-thaw process, which will change the original skeleton structure of inside the sample, thereby affecting the shear strength. Therefore, the paper and carries out the triaxial shear test and NMR test Reveal the deterioration mechanism of shear strength of soil-stone mixture under the action of frost-thaw, and provide scientific theoretical basis for the occurrence of frost-thaw hazard in slope project.

2 Test Protocol

2.1 Specimen Preparation

In this experiment, a typical mixed soil sample of silty clay and breccia in a project on the Qinghai-Tibet Plateau was selected, and the reshaped soil sample with a stone content of 35% was obtained by treating the soil sample, and its optimal moisture content was 9.62%. According to Ref. [6], soil-rock mixture samples with moisture content of W=8%, 10%, 12% and 14% and dimensions of Φ50 mm × 100 mm were prepared, as shown in Fig.1. The freezing temperature is set to -15 °C, the thawing temperature is set to 20 °C, and the time is 12 hours for frost-thaw cycle test.

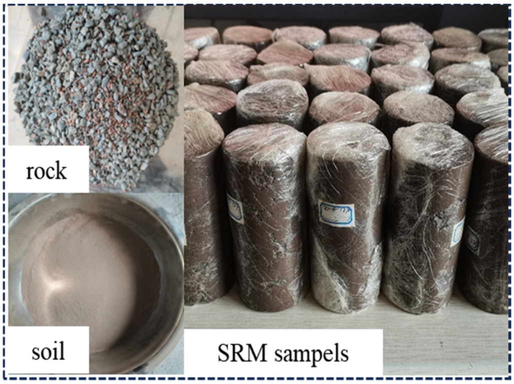

Fig. 1. Preparation of SRM samples

2.2 Triaxial Shear Test

The samples that have undergone different frost-thaw cycles will be subjected to triaxial shear tests using a fully automatic triaxial shear apparatus and data acquisition system. According to the "Standard for Soil Test Methods" (GB/T 50123-2019) [7], the shear rate is set to 0.2mm/min, and the confining pressure was 100kPa, 150kPa and 200kPa.

2.3 NMR Test

Nuclear magnetic resonance (NMR) technology can quickly and accurately monitor changes in pore distribution and microstructural information such as free water pores in porous media [8]. Therefore, NMR experiments are used to study the pore structure of soil rock mixtures under different frost-thaw conditions. The T_2 spectrum was obtained by NMR test. And the distribution of the T_2 spectrum represents the pore distribution, and the total signal intensity in the T_2 spectrum reflects the pore size [9].

3 Analysis of Test Results

3.1 Changes in Shear Strength Characteristics

The changes in the shear strength of soil-rock mixtures with varying moisture contents under frost-thaw action are shown in Fig.2. From Fig.2, When W>9.62%, the shear strength decreases, then increases and then decreases with the amount of frost-thaw cycles. Increase in shear strength after the 3rd frost-thaw, rebound phenomenon, and continued cumulative decrease in shear strength after the 6th freeze-thaw. When W<9.62% the shear strength gradually decreases with the increase of the amount of frost-thaw cycles. Because in the frost-thaw process, the more obvious the ablation and migration of ice crystals during the ice-water phase transition process in the specimen with higher moisture content, the greater the effects of frost-thaw on the pore volume, and the faster the shear strength decays.

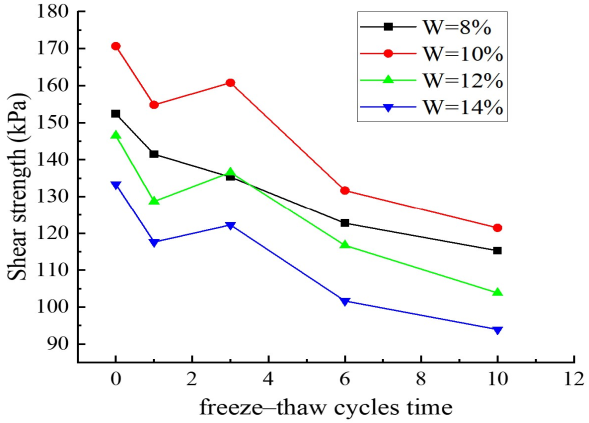

Fig. 2. Change in shear strength under frost-thaw action

3.2 Changes in Shear Strength Parameters

Based on test results, the variation in shear strength parameters is calculated as shown in Fig.3. It can be obtained from Fig.3 that when the moisture content is high, the internal friction angle and cohesion first decrease with the increase of the amount of freezing and thawing cycles, and then increase and then decrease, and decrease with the increase of moisture content. Because the higher the water content, the greater the degree of forming, developing and migrating ice particles in the frost-thaw cycle, and the forming and developing of ice particles destroys the bond between particles, leading to a decrease in the adhesive force, and the migration of ice crystals makes the size, structure and morphology of the particles inside the specimen undergo a significant change, leading to a decrease in the angle of internal friction [10]. When W=10%, the attenuation rates of cohesion and internal friction angle after the 10th freeze-thaw cycle were 11.48% and 6.91%, indicating that the influence of frost-thaw cohesion was more significant.

3.3 Pore Structure Evolution

The T_2 spectral curve (taking a W=10) and the porosity change obtained by NMR test are shown in Fig.4. It can be analyzed from Fig.4, after the 1st frost-thaw, the micropores and mesopores develop to macropores and porosity increases. Following the 3rd frost-thaw cycle, the amount of micropores increased, the internal structure was reorganized, and the macropores collapsed to form many micropores, resulting in the decrease of porosity and the development of uniform pore distribution [11]. Micropore number decreased after the 6th frost-thaw, mesopore and macroporous number increased, microporous porosity developed to macroporous porosity, and porosity continued to increase. After the 10th frost-thaw, the changes of the peaks are small, and the pore structure basically tends to be stabilized.

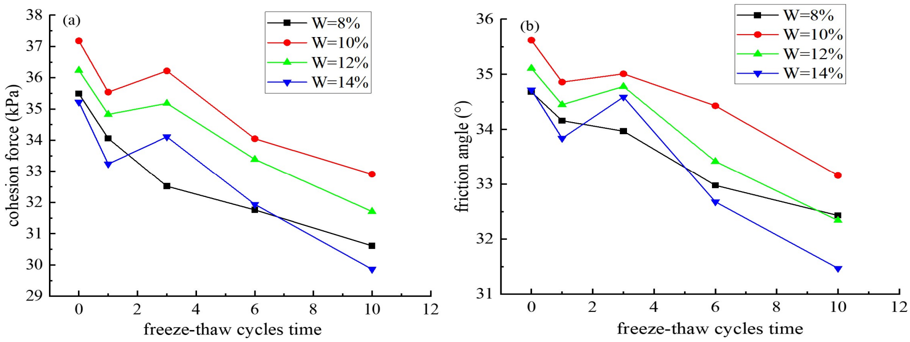

Fig. 3. (a) The change in cohesion; (b) The change in the angle of friction

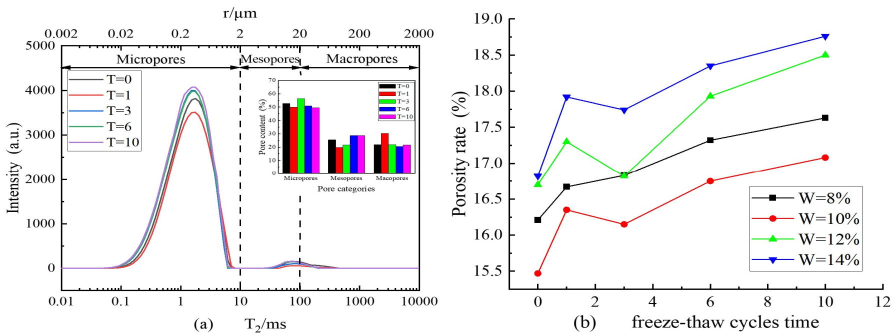

Fig. 4. (a) T_2 spectrum curve of W=10% soil-rock mixture; (b) Changes in internal porosity

4 The Shear Strength of Soil-Rock Mixtures Deteriorates under Frost-Thaw Action

Following the 1st frost-thaw, the formation of ice crystals within the specimen led to the extrusion of soil particles to form aggregates, which disrupted the original soil-stone structure and weakened the interlocking capacity of the blocks and led to the decrease of the overall strength. After the 3rd frost-thaw, the water film in the cracks of aggregates was transformed into ice, and the aggregates ruptured, leading to the dislocation and slumping of the internal skeletal structure, which reduced the number of macropores and enhanced the stability of the overall structure; some of the soil grains adhered to the surface of the blocks and stones to form a block and stone as the core and have a certain degree of rigidity of the inclusive body to enhance the adhesion and friction between the blocks and stones occlusion effect, which led to an increase in cohesion and the angle of internal friction. After the 6th and 10th frost-thaw, the soil particles on the periphery of the inclusion structure continued to peel off, but the skeleton structure remained basically unchanged, the porosity gradually improved. In this process, the greater the moisture content, the higher the sensitivity to frost-thaw [12], the internal pore structure change greater, and results in a more significant degradation of the shear strength under frost-thaw action

5 Conclusion

This article studies the mechanical properties of soil rock mixtures under freeze-thaw action from a macroscopic perspective through triaxial shear tests and nuclear magnetic resonance tests, and investigates the evolution of pore structure inside soil rock mixtures under freeze-thaw action from a microscopic perspective. The influence of freeze-thaw action on the shear strength of soil rock mixtures is analyzed, and the specific conclusions are as follows:

(1) In the process of frost-thaw, the shear strength firstly decreases and then increases and then decreases, and the higher the water content decreases more obviously, and the effect of frost-thaw on the cohesion is more pronounced.

(2) Under the frost-thaw action, the pores first increased, then decreased and then increased. The pore structure first developed from micropores and mesopores to macropores, and then macropores collapsed to micropores.

(3) In the frost-thaw process, the deterioration of shear strength is caused by the change of internal pore structure caused by ice-water phase transition, and the higher the moisture content, the more obvious the deterioration.

Clarify the deterioration mechanism of shear strength of soil-rock mixtures under frost-thaw action is clarified, it can effectively prevent the happening of slope frost-thaw hazard.

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