Characteristics for Microstructure Changes of Unsaturated Coal-bearing Soil under Dry-Wet Circulation

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Abstract. The macroscopic mechanical properties of soil are essentially determined by its microstructure, which is a comprehensive manifestation of the external microstructure of soil. This paper conducts microscopic tests on coal-bearing soil with different moisture content under dry-wet circulation conditions, and uses Image-Pro Plus software to preprocess and image the SEM images of coal-bearing soil samples to characterize the size and orientation of coal-bearing soil particles and pores. The microstructure parameters of average diameter and orientation frequency of shape and orientation are quantitatively analyzed, revealing the change rule of the microstructure parameters of unsaturated coal-bearing soil under dry-wet circulation.

Keywords. Coal-bearing soil, microstructure parameters, dry-wet circulation, microscopic tests.

1. Introduction
There are many coal-bearing strata along the Chang (Nanchang)-Li (Shangli) highway. Generally, coal-bearing strata and their weathering are collectively referred to as coal-bearing soil. This type of soil has uneven soft and hard soil layers and interlayer cementation, poor and loose structure, rapid weathering after excavation, and softening, disintegration, and loss of strength when exposed to water [1-3]. Due to the large-area exposure of coal-bearing strata in this section of the road and the effect of rainfall, the cutting slope has suffered multiple landslides during the cutting of the road, causing huge economic losses to the road during the construction period [4]. Therefore, studying the change mechanism for the engineering mechanical properties of coal-bearing soil can provide reliable basic data for coal-bearing soil slope construction and roadbed treatment, and has important engineering practical significance.

The macroscopic mechanical properties of soil are essentially determined by its microstructure, which is a comprehensive manifestation of the external microstructure of soil [5-10]. If you want to deeply understand the macro-mechanical properties of coal-bearing soil, it is necessary to conduct quantitative research on the micro-structure parameters of coal-bearing soil at the micro level. This paper selects two microstructure parameters: average diameter and orientation frequency to study the microstructure characteristics of unsaturated coal-bearing soil after drying and wet cycles.

2. Research Method
This study is on the size and orientation of coal-bearing soil particles and pores under dry-wet circulations. The microstructure parameters used are average diameter and orientation frequency.
In engineering geology, the size of soil particles and pores is measured by their diameter. When the IPP software quantitatively analyzes the SEM image of coal-bearing soil samples, it measures the area of complex-shaped soil particles and pores, and then takes the diameter of a circle equal to the area of the soil particles or pores as the average diameter of the particles or pores. The calculation formula can be expressed by equation (1):

\[
D = \sqrt{\frac{4S}{\pi}}
\]  

(1)

The angle between the major axis of the particle unit or the pore and the horizontal axis is called the orientation angle of the measuring object. With a certain angular density, 180° is divided into several parts, and the frequency at which the orientation corner enters each interval is calculated as the orientation frequency, as shown in equation (2). This paper defines 10° and divides 180° into 18 orientation angle intervals, which are used to represent the frequency of particle unit or pores in each orientation angle interval:

\[
F(\alpha) = \frac{n_\alpha}{n}
\]  

(2)

Where \(n_\alpha\) is the number of particle units or pores within the directional corner \([\theta_i, \theta_{i+1}]\) and \(n\) is the number of particle units or pores.

3. Experimental Research Process

According to 93% compaction degree of the maximum dry density of compaction test, the coal-bearing soil samples with dry density of 1.669g / cm\(^3\) were prepared. In this paper, the prepared soil material is pressed into a large round sample with a diameter of 100 mm and a height of 40 mm by pressing the sample. Then the samples were placed in a water tray and saturated with water. The saturated samples were placed in the room at constant temperature (20°C) after air drying in the environment, the humidifier was used to spray the surface of the sample and the capillary action was used to promote the bottom surface of the sample to absorb water. The moisture absorption process of the sample was simulated to make the sample saturated. The plastic film was used to seal the sample for at least 24 h. At this point, a dry-wet circulation is completed, and the above steps are repeated to complete 0-4 dry-wet circulations. Figure 1 shows the surface morphology of the prepared large round sample after moisture absorption, dehumidification. After each dry-wet circulation, samples with moisture content of 21%, 17%, 13% and 9% were selected. Soil strips with a width of about 10 mm and 15 mm were taken from each group of samples with moisture content. The frozen soil samples were quickly frozen for more than 36 hours in a -80 degree refrigerator and were taken out and put into the sample room of the vacuum freeze sampler. The non crystaline ice was sublimated by the vacuum freeze-drying method to make the non crystalline ice sublimated. The dried samples were carefully broken off to make a cube sample with a side length of 5mm. The gold coated soil samples were put into the sample room of the scanning electron microscope for shooting. The pictures with magnification of 2000 times were selected in this study. Figure 2 is the microcosmic test samples of coal-bearing soil.

![Figure 1](image1.png)

**Figure 1.** Surface morphology of large round sample after four cycles of moisture absorption and dehumidification: (a) large round shape, (b) saturated large round sample, (c) saturated large round sample to be dried, (d) large round sample after drying.
4. Experiment Results and Analysis

4.1. Particle Unit and Quantitative Evaluation of Pore Size

Figure 3 and figure 4 show the variation of micro particle unit and average pore diameter of unsaturated coal-bearing soil samples during different dry-wet circulation. The results show that with the increase of dry-wet circulation, the content of particles with particle size less than 5 μm increases, and the content of particles with particle size of 5-10μm does not change much, while that of particles larger than 10 μm decreases. The main reason is that the large diameter particles will be broken after repeated drying and wetting cycles, which will increase the percentage of small particles in other ranges.

The average diameter of pores is mainly in the range of 0.5-1μm, 1-2μm and 2-5μm. With the increase of dry-wet circulation, the content of pores decreases in the range of 0.5-1μm, and increases in the range of 1-2μm and 2-5μm. The main reason is that the smaller pores gradually connect into larger pores due to the effect of dry-wet circulation.
Figure 4. The percentage of pore diameter varied with the dry-wet circulation.

4.2. Quantitative Evaluation of Particle Unit and Pore Orientation Frequency

The orientation frequency of particle unit and pore in remolded coal-bearing soil under different dry-wet circulation is shown in the figure 5 and figure 6. It can be seen that the grain unit and pore orientation angle of coal bearing soil have certain distribution in each interval, and the orientation angle is mainly distributed between $-10^\circ$ and $10^\circ$ so it has certain orientation. With the increase of the number of dry wet cycles, the directional frequency increases in the range of $-10^\circ$ to $10^\circ$ with higher orientation frequency.

Figure 5. Particle oriented frequency distribution.
5. Conclusion

(1) Scanning electron microscope (SEM) was used to observe the microstructure of unsaturated coal measures soil under the condition of dry wet cycle, and IPP software was used to analyze and process the microstructure images. The changes of two microstructural parameters, including average diameter and orientation frequency of soil particles and pores, were analyzed after 0-4 dry-wet circulation.

(2) After repeated dry-wet circulations, the large diameter coal-bearing soil particles will be broken, which will increase the percentage of small particles in other ranges, and also make the smaller pores gradually connect into larger pores.

(3) The soil particle and pore orientation angle of coal-bearing soil have certain distribution in each interval. More particles will arrange in horizontal direction, and the orientation of pores depends on the orientation of particles.

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