Study on Micro-Structure and Macro-Mechanical Properties of Bush-Restored Tailings Soil

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Abstract. Taking the tailings pond repaired by sea buckthorn as an example, the effects of shrub restoration on the microstructure and corresponding macroscopic mechanical properties of tailings soil were studied. Phytoremediation and non-phytoremediation of tailings soil were studied by means of scanning electron microscopy, consolidation, infiltration and shear tests. The results show that: Under the action of phytoremediation, the tailing particles have developed from loose and disorderly to compact and orderly. The distribution of tailings soil aggregates tends to be uniform, and the average particle size of tailings soil aggregates has increased slowly and steadily. The time of phytoremediation increased, but the compressibility and permeability of tailings soil decreased gradually. The compressive modulus of tailings soil was increased gradually. The cohesion of tailings soil was increased firstly and then decreased, but it was greater than that of unrepaired tailings soil. Internal friction angle of tailings soil was the trend of decreasing first and then increasing.

Keywords: Phytoremediation, Tailings soil, SEM, Mechanical properties

1. Introduction

Phytoremediation has obvious ecological and environmental benefits. It has become a research hotspot in academia [1]. At present, scholars have done a series of related researches on phytoremediation and ecological soil consolidation. Based on the model, Fan C C [2] analyzed the effect of plant roots on soil shear resistance. Ghestem M [3] and others analyzed soil mechanics by using root morphology and structural characteristics of three kinds of plants. Alejandro [4] and others quantitatively analyzed root reinforcement and failure modes under different hydrological conditions. Lionel [5] and others studied the mechanical responses of different root forms and soil types. At present, the research on macro and micro effects of Phytoremediation on tailing soil has not been carried out, and the mechanism of Phytoremediation on mechanical properties of tailing soil needs to be further explored. In order to study the restoration effect of Typical Shrub plants (Hippophae rhamnoides) of different tree ages on the soil of tailings pond, SEM, compression, permeability and shear tests were carried out.

The microstructure and macroscopic mechanical characteristics of tailings soil under phytoremediation were analyzed, and the microscopic variation mechanism was expounded, which provided the basis for the ecological remediation and treatment of tailings dam.
1.1. In Situ Sampling
Hippophae rhamnoides, a typical species in the ecological restoration of the tailings pond of Bengang group Waitoushan iron mine, was determined. In the plant rhizosphere soil located in 6 steps of the tailings pond (numbered A-F in sequence) with restoration age of 1, 4, 10, 16, 22 and 28 years, the samples were collected. At the same time, unrepaired dry beach area was collected, which was recorded as K. The layout of the site sampling area was shown in figure 1.

Figure 1. The map of situ sampling.

5-8 plant plots were selected on each step of the tailings dam, and 0-2cm surface impurities were removed every 100m, and rhizosphere soil samples were collected with a ring knife at the center of plants in each plot; At the same time, the same method was used to collect the tailings plain soil samples in the reservoir area, which were bagged and sealed, and then sent to the laboratory for treatment.

1.2. Experimental Methods
(1) Micro detection: 1) After gold spraying, representative elementary bodies and intergranular pores were searched by SU8010 scanning electron microscope, and different multiples were amplified for detection. 2) Determination of void ratio and aggregate morphology: Image-Pro Plus (IPP) software was used for quantitative analysis of sample SEM images. 3) Aggregate determination: Wet screen method is adopted.

(2) Macro detection: According to the standard GB/T50123-2019 for soil test method [6], the specimen preparation and direct shear, consolidation and permeability tests were carried out for step A-F and zone K.

2. Microstructure Analysis

2.1. Qualitative Analysis of SEM Results
From the electron microscope image, the information of pores and particles in the 500 times image was the most comprehensive. Therefore, taking 500 times image as an example, image processing and information extraction analysis were carried out. SEM images of 500 times of sampling points in different repair periods were shown in figure 2.
Figure 2. SEM image of 500 times of sampling points in different repair periods.

It can be seen from figure 2 that with the increase of plant age, the pore and structure of tailings particles have changed significantly. The main performance is that the space between the particles of tailings soil is shrinking, and there are aggregates in the tailings soil, the particles are rearranged, and the particle size aggregates increase. With the time effect of plant restoration increasing, it gradually appears as edge-side contact, point-surface contact, and edge-surface contact. When Hippophae rhamnoides was repaired for 10 years, the tailings particles developed in the form of edge-side or face-surface contact, as shown in figure 2 (f). It indicates that long-term phytoremediation has an effect on soil morphology.

2.2. Quantitative Analysis of SEM Results

Through the IPP digital image processing technology, the SEM characterization image is quantitatively analyzed, and the gray value of the gap is artificially set as the threshold value, so that the soil particles and the pores are clearly distinguished [7]. The 500 times binary image of the sampling points in different repair periods is quantitatively analyzed, as shown in figure 3.
2.2.1. Void Ratio. The relationship curve between the age of different steps and the average void ratio was shown in figure 4. The particle void ratio of the unrepaired tailings soil is 1.54, mainly the intergranular pores. With the increase of plant age, the pore ratio of tailing matrix gradually decreases to 0.93, and the tailing soil particles are loose and gradually orderly. The void develops from intergranular to granular pores, and the pore diameter inside the pellets decreases continuously.

Figure 4. Curve of different ages and average porosity ratio.

Figure 5. Curve of different ages and aggregate index.

Particle size and distribution of soil aggregates were quantitatively analyzed using soil structural stability index average weight diameter (MWD), geometric mean diameter (GMD), and content of water-stable aggregates (R0.25). GMD, MWD, R0.25 relation curve of tailings soil particles at different repair ages is shown in figure 5. It can be seen from figure 5 that the content of R0.25, MWD and GMD of unrepaired tailings soil in area K is 15%, 0.2 and 0.15 respectively. After phytoremediation, MWD and GMD increased first and then tended to be stable, and R0.25 showed a stable growth trend. In area F, the tailings particles reach R0.25 for 47%, MWD is 0.42, GMD is 0.29, and the growth rates are 213.33%, 110%, 93.33% respectively. The results show that the average diameter of tailings aggregate increases, the aggregate distribution tends to be uniform [8], and the stability and water erosion resistance gradually increase.

3. Analysis of Macroscopic Mechanical Properties

3.1. Compression Performance
The curve of the relationship compression coefficient of tailings soil and the age was shown in figure 6. The relationship curve between permeability coefficient and age was shown in figure 7.
It can be seen from figure 6 that with the increase of plant restoration age, the compression coefficient of tailings soil shows a downward trend under both pressures, and the compression coefficient of 100-200 pressure > 200-400 pressure. It can be seen from figure 7 that with the increase of age, the permeability Coefficient of tailings soil shows a decreasing trend, with the maximum range of 32.57%. Microscopic mechanism analysis on the change of permeability of tailings soil: according to the results of SEM, in the process of plant restoration, the average particle size of aggregates increases, the particle contact increases, the void volume decreases. With the increase of phytoremediation time, the compressibility and permeability coefficient of tailings soil are decreased.

3.2. Cohesion
The curves of cohesion and internal friction angle with different recovery years were obtained by direct shear test, as shown in figures 8-9.

It can be observed in figure 8 that with the increase of plant restoration age, cohesion increases rapidly at first and then decreases gradually. The cohesion of the plant repaired tailing soil was higher than that of the unrepaired tailing soil. The maximum increase rate of cohesion was 58.33%, and the minimum increase rate is 25.83%. According to SEM results, it can be seen that plant action tailings particles from loose disorder to gradual orderly. As a result, the void ratio of particles decreased, the attraction between adjacent tailings particles increases, and the cohesion increases. In the growth process, secretions act as cement, which plays a role in binding soil particles, promote the close combination of roots and particles, increase root soil friction and cohesion [9]. However, with the increase of the age of phytoremediation, larger diameter aggregates gradually appear in the soil particles, and the particle size of tailings soil increases, resulting in the decrease of cohesion.

3.3. Internal Friction Angle
Figure 9 showed that the internal friction angle decreased first and then increases gradually with the increase of plant restoration age. Compared with the unrepaired tailing soil, the internal friction angle decreased by 3.14% and increased by 14.98%. According to the results of SEM, it can be seen that the decrease of internal friction angle was mainly at the early stage of phytoremediation, and the arrangement of tailings soil particles gradually develops from disordered loose structure to orderly structure. Although the main mineral components quartz and calcite remain unchanged, the content of
each mineral component was increased, the contact form was increased, the friction between the root system and the particles was reduced, the tailings aggregate was not formed, the inter particle force was reduced, and the internal friction angle was reduced. However, with the increase of growing age, the root and soil particles arranged in a certain [10] form into the root soil complex, and the root soil bite force increased, With the continuous growth and development of root system, the surface area of root per unit volume increases [11], the void ratio between particles decreased, the root soil friction increases, and the internal friction angle increases.

4. Conclusion
The microstructure and mechanical characteristics of tailings soil under shrub restoration of different tree ages were studied, and the evolution characteristics and action mechanism of the microstructure of tailings soil were discussed. The conclusion is as follows:

(1) The soil contact of tailings without phytoremediation is mainly indirect contact, point-point contact and edge-edge contact. The structure is disordered and the large gap between particles is relatively large. With the increase of phytoremediation age, the contact form between particles is increasing, and point-surface contact, edge-surface contact and surface-surface contact gradually appear. Phytoremediation is significant.

(2) Under phytoremediation, it could improve the structure of soil voids and the formation of aggregates.

(3) As the reinforcing material of the tailings, the root of seabuckthorn can significantly improve the cohesion of the tailings. As the growth age of seabuckthorn increases, the compressional permeability coefficient of the tailings soil gradually decreases, and the maximum decreases are 26.12% and 32.57%. The cohesion increased first and then decreased, but both of them were greater than the cohesion of the unrepaired tailings, with the maximum increase of 58.33% and the minimum increase of 25.83%. The internal friction Angle first decreased and then increased, with the maximum increase of 14.98%.

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