Three-dimensional Reconstruction of Meso-structure of Tailings Sand Based on CT Scanning

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Abstract: Tailings sand is an artificial three-phase bulk medium after beneficiation. It is difficult to reflect its true three-dimensional micro structure through physical and mechanical tests and numerical simulations. In this paper, based on micro-CT, the high-resolution scanning of tailings sand samples is used to obtain two-dimensional slices with a resolution of 6.16μm. The three-dimensional reconstruction of the two-dimensional slice was visualized by the gray threshold method of Avizo 3D visualization software, and the three-dimensional pore structure of the tailings sand sample was quantified and characterized. The results show that the tailings sand sample has rich pore development and good pore connectivity. The porosity of the 1000-layer two-dimensional section of the tailings sand sample changes obviously, but the porosity shows an increasing trend. The variation range is from 7.01% to 12.03%. The average value is 9.74%; the pore distribution of the tailings sand sample is mainly small pores of 0-20μm, supplemented by 20-80μm pores, and the smallest number of pores larger than 80μm.

1. Introduction

Tailings sand as the raw material for the accumulation of tailings dam, its structural and physical and mechanical properties have an important impact on the stability of the tailings dam. At present, many scholars have made many achievements in the study of the structure and physical and mechanical properties of tailings sand.

Many scholars have focused on the study of tailings sand at the macro level. Some research has been carried out at the microscopic level, and there are few studies on the three-dimensional mesostructure of tailings sand. In recent years, high-resolution X-ray computed tomography (micro-CT) has been widely used as a non-destructive technique, allowing 3D imaging and analysis of internal features of various objects.[1]. This technology has been widely used in rock and soil research, but the application of tailings sand as a special soil is almost blank. The paper uses the nanoVoxel-3000 micro-CT test analysis system to perform CT scans on tailings samples. After digital image processing, the three-dimensional reconstruction of the tailings sand sample is performed by Avizo 3D visualization software, the characteristics of the pore structure of the tailings sand sample were analyzed from the microscopic direction, which provided an effective method for the study of the micro structure and physical and mechanical properties of the tailings sand.

2. Test Tailings Sand Material

The tailings sand materials used in the test are all on-site sampling of an iron tailings pond. According to the analysis results of the laser particle size analyzer, the particle composition of the tailings sand material is shown in Table 1, and the gradation curve is shown in Figure 1. It can be seen from Figure 1 and Table 1 that the fine particle content of less than 0.075 mm is between 15% and 50%, according to the classification of sand soil in the Geotechnical Test Regulations (SL237-1999) [2], it is named as silty sand (SM). It can be seen from Figure 1 that Coefficient of nonuniformity Cu of the tailings sand material is greater than 5, that is, the size of the coarse and fine particles in the tailings sand is very different, and the fine particles are easily filled in the pores formed by the coarse particles to form a better skeleton structure.

Table 1: Particle composition of tailings sand.

Particle composition /%			Coefficient of nonuniformity Cu	Coefficient of curvature Cc	Soil sample code	Soil sample name
Sand/mm	silt/mm	Clay/mm				
2~0.075	0.075~0.005	<0.005				
69.7	20.71	10.59	25.50	6.84	SM	silty sand

Notes: Coefficient of nonuniformity Cu =d60/d10, Coefficient of curvature Cc =(d30d30)/(d10d60) [3]

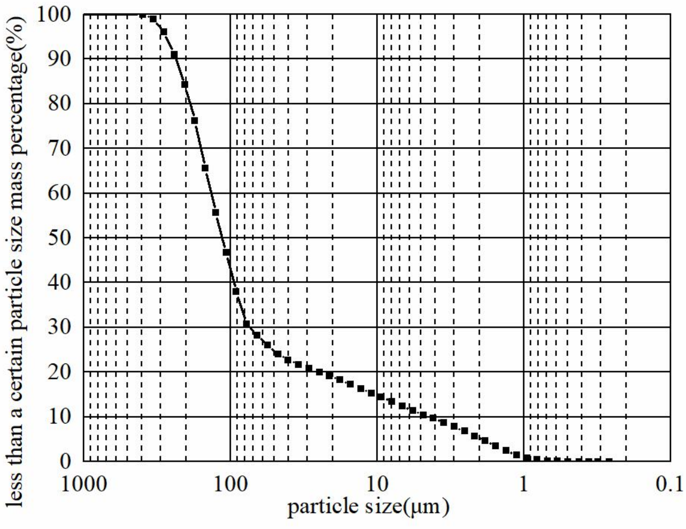

Figure 1: Particle-size distribution curve of tailings sand.

3. Experiments of Micro-Ct Scanning

3.1.Scanning Equipment and Plan

This test used nanoVoxel-3000 micro-CT, as shown in Figure 2. The instrument features secondary optical amplification technology, the highest resolution up to 0.5μm, and advanced non-destructive 3D imaging capabilities and image analysis capabilities, enabling 3D visual characterization of the material's internal microstructure without loss. In this test, the tailings sand material was filled in a transparent acrylic round tube test vessel with a height of 30 mm, an inner diameter of 10 mm and an outer diameter of 14 mm. The size of the tailings sand sample was a cylindrical sample of Φ10 mm×30 mm. The scanning area of the sample is a height of 10 mm-20 mm, and the scanning mode adopted for the sample is a full diameter scanning, as shown in Figure 3.

3.2.Scanning Parameters and Results

In this test, the test voltage of micro-CT is 140kv, the test current is 70μA, the exposure time is 0.42s, the distance from the source to the sample is 13.6mm, and the distance from the source to the flat panel detector is 279.6mm. The resolution is 6.16 μm, that is, the characteristics of pores with a pore diameter greater than 6.16 μm and tailings sand particles can be resolved. And this experiment uses a cone beam continuous scanning method, the scanning rate is 0.25 ° / frame, a total of 1440 projections. The sample was longitudinally cut into 1536 layers, each layer having a thickness of 6.16 μm, and finally a 1536-layer 1800×1800 pixels two-dimensional slice was obtained.

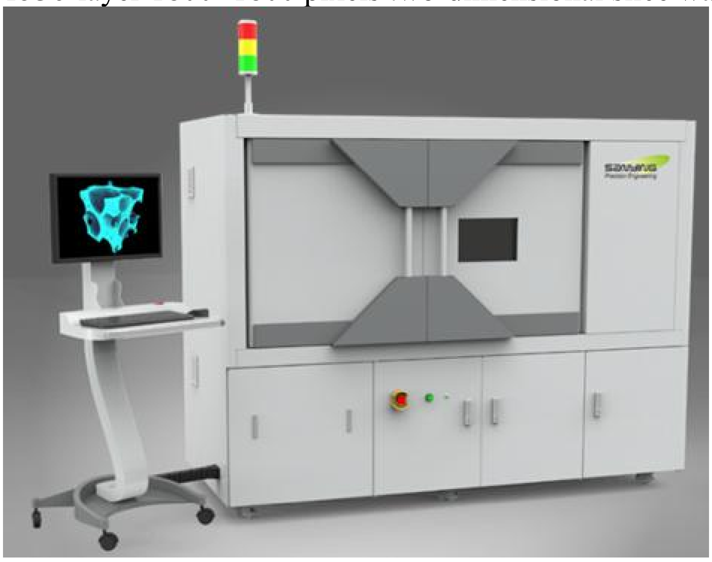

Figure 2: nanoVoxel-3000 micro-CT system.

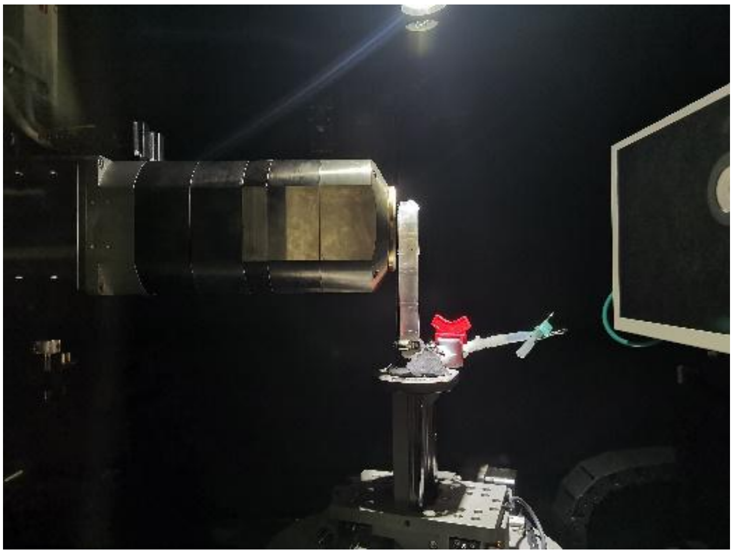

Figure 3: Tailings sand sample scanning.

4. Digital Image Processing

Projection data obtained by micro-CT scanning cannot be directly displayed, and image reconstruction is required to convert it into a two-dimensional CT slice. When a radiographic projections of the object are already taken and available, a reconstruction algorithm can be used to calculate the X-ray attenuation within a stack of 2D slices.Therefore, it can perform three-dimensional reconstruction of objects by using some software packages, such as Avizo, 3DMA, and Fiji [1]. However, two-dimensional slice images of tailings sand samples obtained by cone beam scanning are affected by various types of system noise and artifacts. In order to improve the quality of the slice and ensure more accurate scanning results, it is necessary to filter and de-artifact the image through some software packages and crop the two-dimensional slices with cone shadows, such as Minics, vg studio max 3.0 and so on. After the digital image processing such as de-artifact and filter, the original data is cropped to obtain a 1000-layer 1800×1800 pixel two-dimensional slice for quantitative analysis of tailings sand particles and pore structure in the tailings sand sample. The typical two-dimensional slice is shown in the Figure 4.

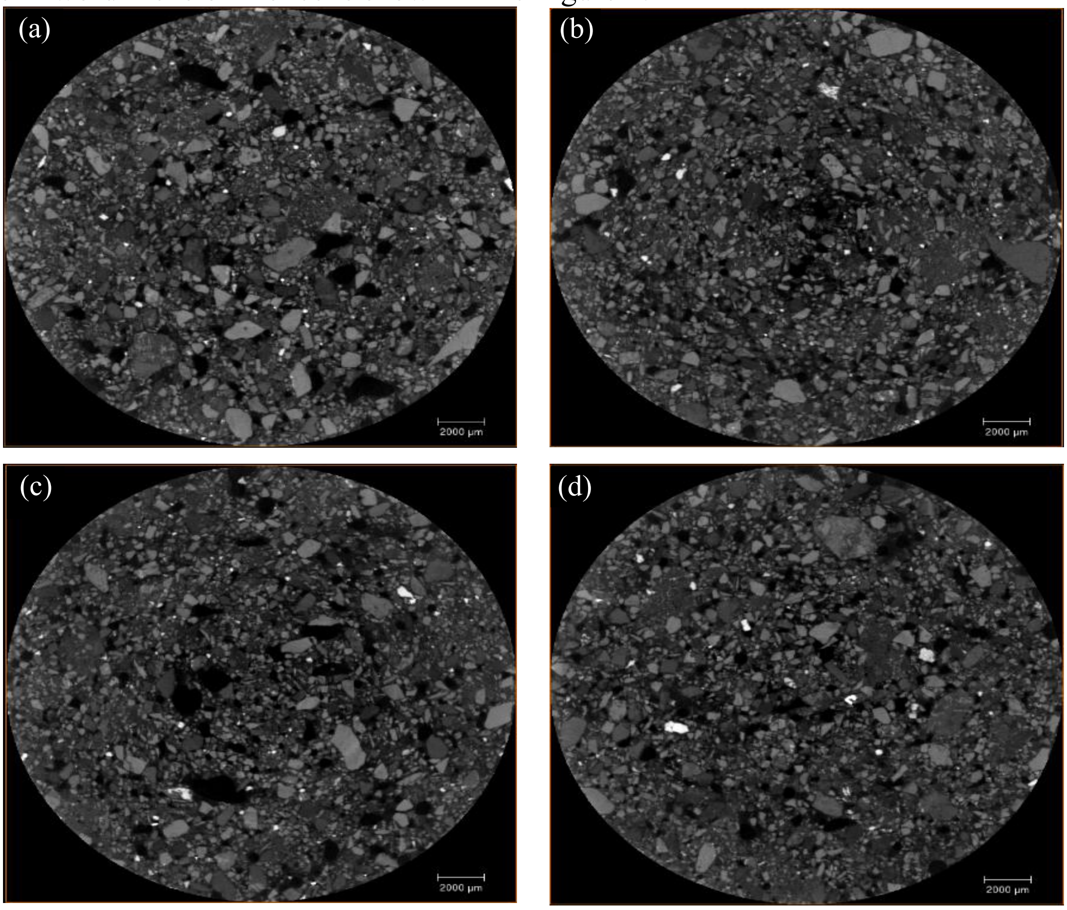

Figure 4: Representative CT slice of tailings sand samples

(a) Slice 200;(b) Slice 400;(c) Slice 600;(d) Slice 800.

5. 3D Visualization of Tailings Sample

The two-dimensional image obtained by CT scan is binarized by threshold segmentation, and the distribution characteristics of tailings sand particles and pores can be obtained. The further work is to transform the 2D slice data into a 3D image through an iterative reconstruction algorithm to realize the 3D visualization of the tailings sand sample. The 3D visualization of the tailings sand sample is mainly obtained by micro-CT scanning to obtain 2D sequence slices, and the 2D sequence slice is 3D visualized by the Volume Rending module in Avizo 3D visualization software.

5.1.Principle of 3D Reconstruction

3D visualization includes both face rendering and volume rendering. Compared with face rendering, volume rendering can more intuitively observe the overall structure of the 3D data field and obtain more image information. The Avizo 3D visualization software direct volume rendering module Volume Rending is a very intuitive method for visualizing 3D scalar fields. And This module provides with a hardware-accelerated implementation, which uses 3D texture hardware, to allow for real-time rendering. The process of volume rendering is to assume that each point in a data volume is assumed to emit and absorb light. The amount and color of emitted light and the amount of absorption is determined from the scalar data by using a Colormap which includes alpha values. Then the resulting projection from the points in the data volume is computed. Default colormaps for volume rendering are provided with the distribution and can be edited using the colormap editor.

5.2.Three-dimensional Reconstruction Results of Tailings Sand Samples

In this paper, the 3D visualization of tailings sand samples is performed using the Avizo 3D visualization software direct volume rendering module Volume Rending, as shown in Figure 5. It can be seen from Figure 4 that water and air correspond to a low gray value, that is, a dark portion in the figure, and the tailings sand particles correspond to a high gray value, that is, a brighter portion in the figure, so that Therefore, it is possible to distinguish the distribution of pores and tailings sand particles in tailings sand samples. The tailings sand sample has obvious heterogeneity, and the pore distribution is relatively discrete from the outside of the sample.

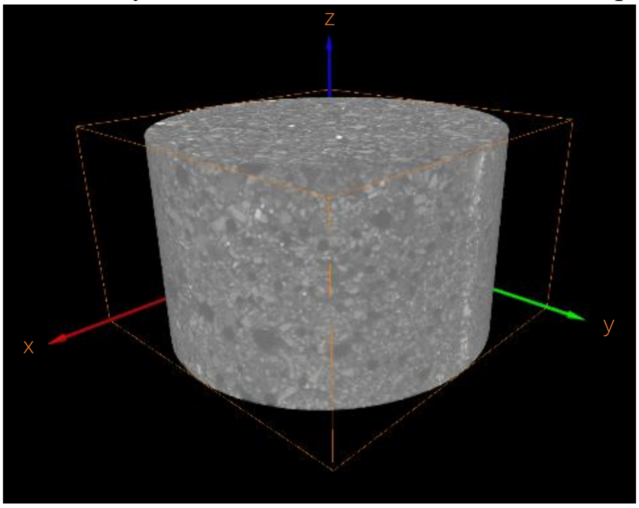

Figure 5: 3D illustration of the tailings sand sample.

6. Three-dimensional Reconstruction of Pores in Tailings Sand Samples

Based on the previous digital image processing, in order to obtain the pore structure model of the tailings sand sample, the image threshold segmentation method is used to binarize the gray image, as shown in Figure 6. Based on the experimental and theoretical calculation of the void ratio e, the optimal segmentation threshold is determined. The porosity calculated by the Avizo 3D visualization software is consistent with the porosity of the tailings sand sample, avoiding the error caused by the quantitative selection of the threshold due to improper selection of the threshold [4]. Then, the whole pore structure and connected pore structure of the tailings sand sample are extracted, the test data is output, and the layer-by-layer porosity and pore size characteristics are quantitatively analyzed, as shown in Figure 7.

It can be seen from Figure 6 that the overall pore structure of the tailings sand sample is rich in development, the pores are distributed throughout the sample, and the pore shape is diverse; the connected pore structure runs through the entire tailings sample along the seepage direction, and has a tendency to develop from the center to the edge of the sample.

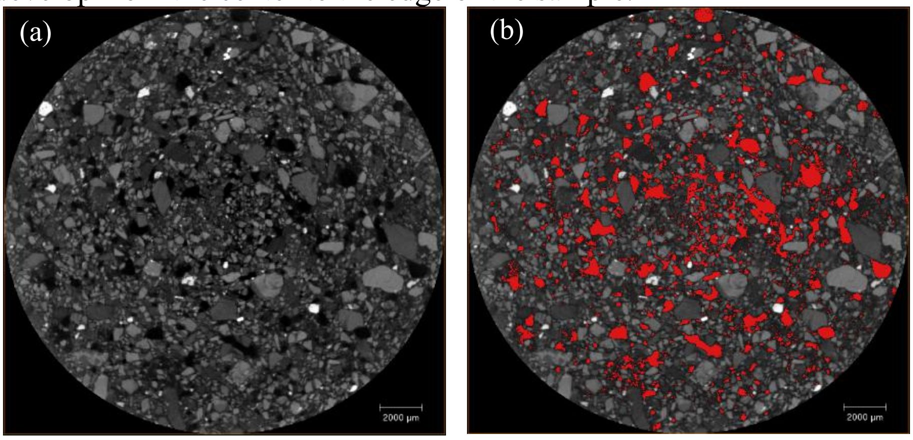

Figure 6: Threshold segmentation of tailings sand sample.

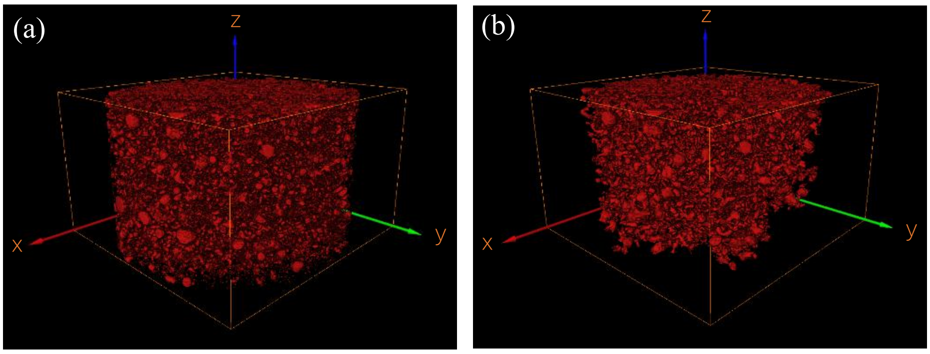

Figure 7: (a) 3D pore structure of the tailings sand sample

(b) 3D connected pore structure of the tailings sand sample.

6.1. Quantitative Characterization of Pore Structure of Tailings Samples

The two-dimensional slice obtained by Micro-CT analysis, based on the pore data extracted by the threshold segmentation of Avizo 3D visualization software, can distinguish the porosity distribution of the layer-by-layer two-dimensional slice in the entire tailings sample, as shown in Figure 8. It can be seen from Figure 8 that the porosity of the 1000-layer two-dimensional section of the tailings sand sample changes significantly, but the porosity shows an increasing trend, ranging from 7.01% to 12.03%, with an average value of 9.74%.

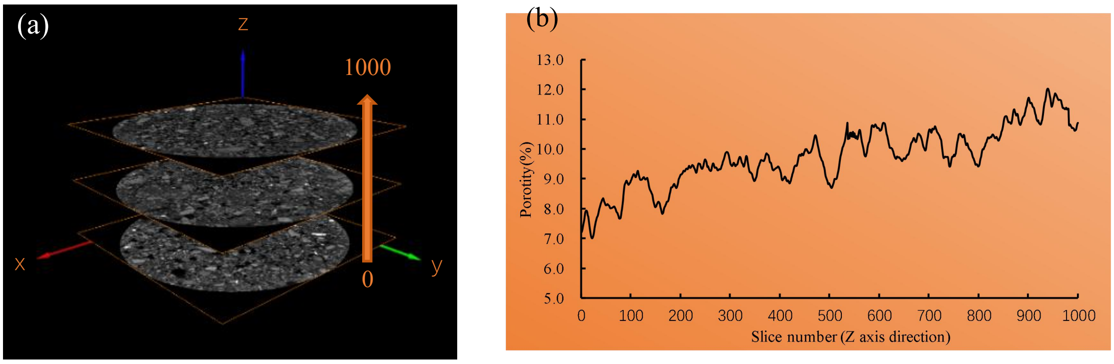

Figure 8: Porosity calculation from a series of 1000-layer in tailings sand sample (a, b).

In order to obtain the pore size distribution of the tailings sand sample, the Lable Analysis and Analysis Filter modules in the Avizo 3D visualization software were used. The threshold segmented pores are displayed through the Surface View, and the topological triangular patches are connected in the Generate Tetra Grid. Then Lable Analysis identifies the boundaries of the individual pores and marks them to generate the pore space marker image, as shown in Figure 9. The Lable Analysis module in Avizo, which has a unique label attached to each aperture, results in a parameter value for the pore size. Finally, the pore size is extracted and extracted by the Analysis Filter module. The relationship between pore size and quantity is obtained by statistical analysis, as shown in Figure 10.

Based on the statistical analysis of the interval and quantity relationship of pore size distribution, with the increase of the interval value of pore size distribution, the number of pores tends to decrease gradually. The decreasing trend of the number of pores in 0-20μm is the most obvious. The decreasing trend of the number of pores larger than 20μm is gradually slowed down, indicating that the pore distribution of the tailings sand sample is mainly small pores of 0-20μm, supplemented by 20-80μm pores, larger than 80μm. The number of pores is the least.

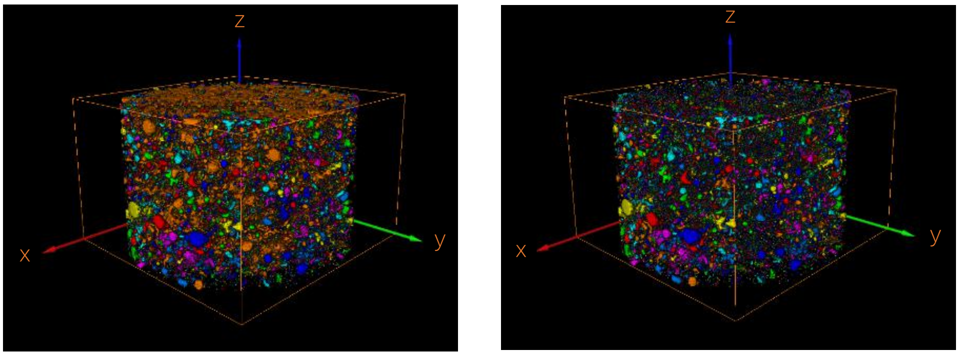

Figure 9: (a) Marked image of pores (b) Distribution of isolated pores.

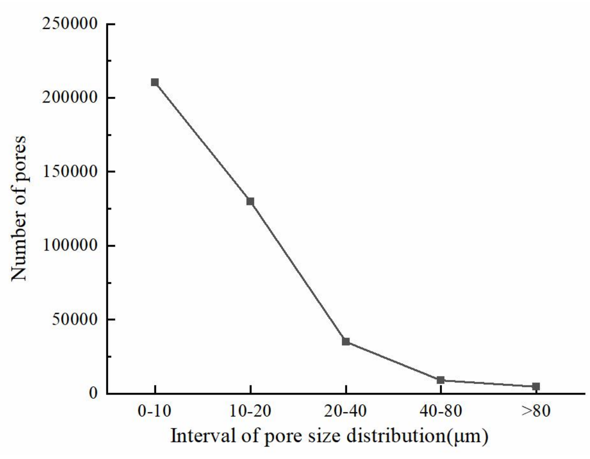

Figure 10: Pore size and its quantity.

7. Conclusions

3D volume rendering of 2D CT slices using the Volume Rending module of Avizo 3D visualization software. Based on the experimentally and theoretically calculated void ratio e, the optimal segmentation threshold is determined, and the pore structure of the tailings sample is extracted and quantitatively analyzed the result shows:

(1) The tailings sand sample has rich pore development and good pore connectivity.

(2) The porosity of the 1000-layer two-dimensional section of the tailings sand sample changed significantly, but the overall trend showed an increasing trend, ranging from 7.01% to 12.03%, with an average value of 9.74%.

(3) The pore distribution of tailings sand samples is mainly small pores of 0-20μm, supplemented by 20-80μm pores, and the smallest number of pores larger than 80μm.

Acknowledgments

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