Hindawi
Advances in Civil Engineering
Volume 2019, Article ID 9079754, 8 pages
https://doi.org/10.1155/2019/9079754

Research Article

Mechanical Properties of Tailings Sample with Different Moisture Contents under Dry and Wet Cycles

Ling-ling Wu,[1,2,3] Yao-hui Guo,[1] Kai-wen Tong,[1] Lin Hu,[1] Qing Yu ,[1,2,3] and Zhi-jun Zhang [1,2,3]

[1]*School of Resource & Environment and Safety Engineering, University of South China, 421001 Hengyang, China*
[2]*Key Discipline Laboratory for National Defense for Biotechnology in Uranium Mining and Hydrometallurgy, University of South China, 421001 Hengyang, China*
[3]*Hunan Province Key Laboratory of Green Development Technology for Extremely Low Grade Uranium Resources, 421001 Hengyang, China*

Correspondence should be addressed to Zhi-jun Zhang; zzj181@163.com

Received 20 January 2019; Revised 14 May 2019; Accepted 2 June 2019; Published 14 December 2019

Academic Editor: M. Shahria Alam

Due to precipitation infiltration, evaporation of water, and rising and falling of the wetting line, the tailings are in a cyclical moisture absorption-dehumidification state for a long time. The mechanism of change of physical and mechanical properties of tailings during the dry and wet cycle is related to the safe operation of the entire tailings dam. In order to explore the variation of the mechanical behavior of tailings in a tailings pond in Hunan Province with the number of dry and wet cycles under different initial water content conditions, the tailings sand samples with moisture content of 6.10%, 10.40%, 14.00%, 18.20%, and 21.00% were subjected to 0 to 6 times of moisture absorption and desorption cycles at natural dry density, and then, the stress-strain relationship curves, pore water pressure, failure mode, and shear dilatancy of these samples were tested by triaxial consolidation undrained shear test. The test results showed that when the number of moisture absorption and desorption cycles increases, the strength of the tailings sand sample was weakened, and the strength tended to be stable after 3~5 cycles. In addition, the stress-strain curve of the sample with lower water content dropped sharply. However, the pore pressure of tailings sand samples with different water contents under different wet and dry cycles all showed a phenomenon of increasing first and then decreasing in general.

1. Introduction

As a peripheral structure of the tailings pond, the safety and stability of the tailings dam is the most important prerequisite for the normal operation of the mining area. Under actual conditions, due to changes in the natural environment such as rain and snow, the position of the immersion line of the tailings dam body is repeatedly changed, causing some parts of the dam body to repeatedly be in the dry and wet alternate. Therefore, the settlement deformation and mechanical properties of the tailings dam will have some non-negligible changes [1]. Zhang and Chen [1] found that under the function of the moisture absorption and desorption cycle, the clay sample with the same water content has a smaller matrix suction as the number of cycles increases. Vaezi et al. [2, 3] studied the tailings sand in the tailings pond and found when the tailing sand is discharged, the consolidation process and the increased sediment density can enhance the stability of the dam. Huang and Cai [4] analyzed the underflow and overflow of tailings sand and found that under static conditions, the shear performance of the underflow tailings is better than that of the overflow tailings. Rico et al. [5] analyzed the function mechanism of flood on tailings dam by studying the phenomenon of dam failure caused by flooding in tailings dam. Tian [6] experienced a repeated dry and wet environment under the simulated natural conditions of the tailings dam and found that its safety factor is decreasing due to the effect of dry and wet. Liu et al. [7] found that the dry and wet cycles have a greater impact on low-density soils by studying the effects of different dry density soils on moisture absorption and dehumidification cycles. The above research mainly focuses on the cause of dam failure of tailings dam, the connection between consolidation process and dam stability, the influence of dry and wet circulation on dam body, and the relationship between moisture absorption-dehumidification cycle and matrix suction. Therefore, there is no quantitative study of water content, which is an influential factor for geotechnical research. In this paper, we explore the mechanical properties of tailings samples with different water contents under the natural dry density conditions of the wet and dry cycle, mainly including the failure mode, stress-strain relationship curve, pore water pressure, peak deviator stress, and shear dilatancy characteristics of the specimen under the triaxial consolidation undrained shear test. This has important theoretical and practical significance for enriching and perfecting the theory of unsaturated soil mechanics, innovating and developing the stability analysis method of tailings dam, and preventing the occurrence of tailings dam failure.

2. Sample Preparation and Experimental Scheme

2.1. Physical Properties of the Sample. Most of the tailings sand particle size is greater than 0.075 mm, so the particle size distribution and thickness of the sample obtained by sieve analysis method are reasonable. The tailings sand sample taken from the site was placed in a drying oven and dried to a constant weight at a temperature of 105 ± 5°C. After natural cooling to room temperature, a particle sieving test was performed. Three 500 g tailings samples were weighed for parallel screening test. The loss rate of each tailings sand sample before and after the experiment was less than 1%. The cumulative curve of the particles obtained by the three tests is shown in Figure 1. The particle grading parameters and basic physical properties of the samples are shown in Tables 1 and 2. According to Table 1, $C_u = 2.523 = C_c = 1.661$, cannot meet $C_u \geq 5$ and $C_c = 1 \sim 3$ at the same time, so the tailings sand sample is poorly graded.

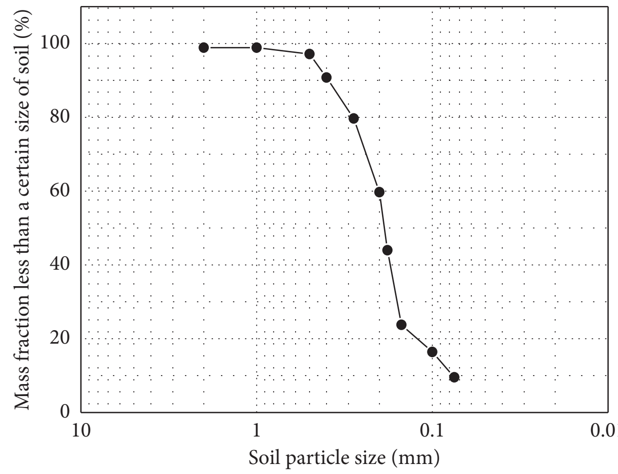


Figure 1: Grain grading accumulation curve.

2.2. Sample Preparation. This test sample uses a standard cylindrical tailings sand sample. In the specifications, the diameter is 39.1 mm and the height is 80 mm. The sample used a self-made device having an inner diameter of 39.1 mm and a height of 100 mm. In order to avoid microdeformation of the device at a higher temperature, the sample was dehumidified at 60°C and the natural density of the sample was taken as a test density study. According to the actual test results at the sampling site, as the burial depth of the dam increased, the water content increased gradually and the water content in the unsaturated region varied from 5.9% to 21.6%. The dam was divided into five layers according to the height, and the average moisture content of each layer was taken as the initial moisture content of the sample. So the initial moisture content of the samples were taken as 6.10%, 10.40%, 14.00%, 18.20%, and 21.00%. The tailings sand with a total mass of 152 g was poured into the apparatus four times, and the contact surface of the layer was compacted and shaved. When adding water, a filter paper was placed on the uppermost layer of the sample, and the sample was added with water to a desired water content using a syringe with a small outlet passage. The sample was sealed with a plastic wrap and allowed to stand for 24 hours and then dehumidified to the desired moisture content. The above was a dry and wet cycle process. The four tailings samples of the same type prepared are shown in Figure 2. Before the triaxial compression test, the top of the sample was smoothed to a height of about 8 mm, and the sample after demolding is shown in Figure 3.

2.3. Experimental Design. Oven-drying and artificially adding water were used to simulate the dry-wet cycle in the natural environment. The specific moisture content was obtained by measuring the quality of the dried sample and controlling the quality of the added water. After the sample was hygroscopic to the required moisture content, it was sealed with plastic wrap for 24 h to ensure uniform distribution of water in the sample. The sample was then placed in an oven and heated for dehumidification. The mass of the sample was monitored at specific intervals during dehumidification, and the moisture content at this time was calculated from the remaining mass. According to the natural environment of the sampling site, it is determined that the dry-wet cycle of the tailings sand sample is controlled to be between 1% and 23%, and the hygroscopic and dehumidification cycle is shown in Figure 4.

In this test, taking the dry density of the tailings sand sample as the natural dry density, the tailings sand samples with specific water content were subjected to 0, 1, 2, 3, 4, 5, and 6 times of moisture absorption and desorption cycles, respectively. Each group of tailings sand samples was subjected to 3 groups of controlled trials with a total of 140 groups. Under the hygroscopic dehumidification cycle, each sample with specific moisture content was subjected to

Table 1: Particle composition parameters of tailings.

Particle grading parameters				
Effective grain size, d_{10} (mm)	Median grain size, d_{30} (mm)	Constrained grain size, d_{60} (mm)	Nonuniform coefficient, C_u	Curvature coefficient, C_c
0.078	0.162	0.20	2.532	1.661

Table 2: Main physical property indexes of tailings.

Physical property index					
Natural moisture content, ω (%)	Natural dry density, ρ (g·cm^{-3})	Optimum moisture content, ω_{op} (%)	Maximum dry density, ρ_d (g·cm^{-3})	Relative density, G_s	Pore ratio, e
9.6	1.539	14.0	1.79	2.499	0.780

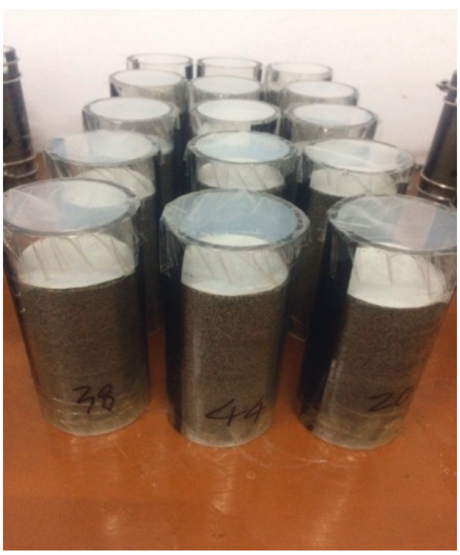


Figure 2: Prepared sample.

Figure 3: Sample of tailings sand after demolding.

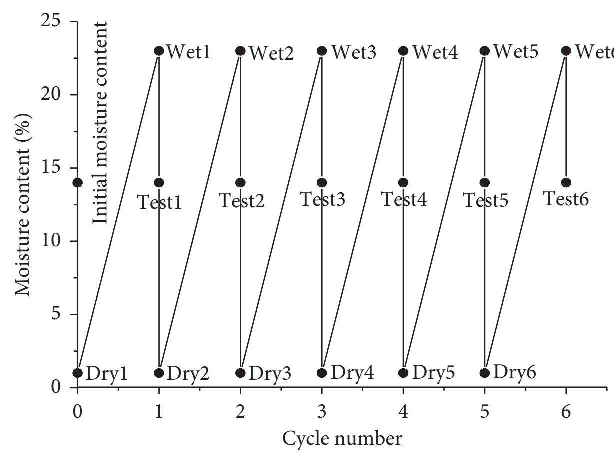
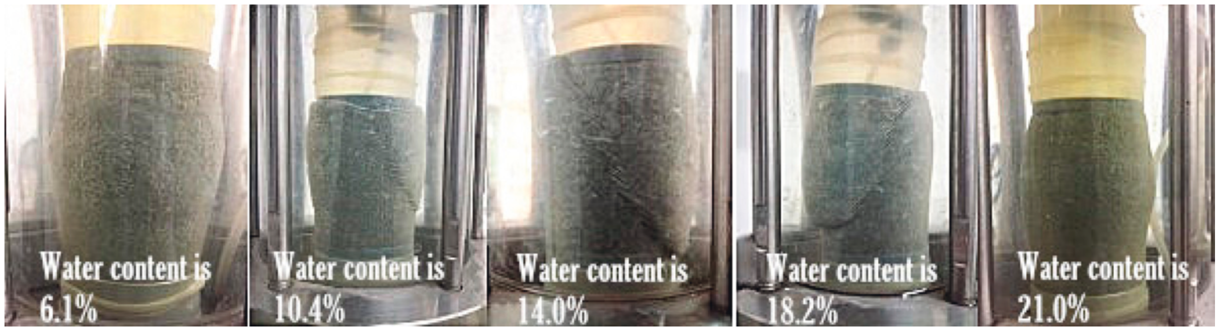


Figure 4: Schematic diagram of the dry and wet cycle.

triaxial consolidation undrained shear test at a confining pressure of 100 kPa. The test loading rate was 0.30 mm/min. The data was collected every 6 seconds and it was automatically processed and saved by the computer.

3. Test Results and Analysis

3.1. Failure Mode. By observing the failure shape of each specific tailings sample in the triaxial consolidation undrained shear test, the results show that the following: when the water content is 6.1% and 21.0%, the majority of the samples show dilatancy; when the water content is 10.4%, 14.0%, and 18.2%, most of the samples show splitting damage. The shape of each sample with different water contents after failure is shown in Figure 5. This is because when the water content is low, the force between the water molecules and the particles is small, and it is difficult to form a strong bond between the particles, and the particles are easily displaced, so that the dilating phenomenon occurs; as the water content gradually increases to a certain extent, the particle shift becomes more and more difficult, and thus the splitting damage occurs; however, when the water content continues to increase beyond a certain value, the water acts



(a) (b) (c) (d) (e)

Figure 5: The shape of the samples with different water contents after failure. Water content: (a) 6.1%, (b) 10.4%, (c)14.0%, (d) 18.2%, and (e) 21.0%.

as a lubricant on the surface of the particles, which will promote the occurrence of misalignment between the particles, and thus the dilatancy damage occurs.

3.2. Stress-Strain Relationship Curve. For the same soil, even if the same total stress is applied, if the drainage conditions for controlling the consolidation of the sample and the drainage conditions at the time of shearing are different, the obtained strength indexes are generally different. However, according to the principle of effective stress, the sum of the effective stress σ' at a certain point in the soil and the pore water pressure u is its total stress σ. During the test, if the pore water pressure of the sample can be obtained, the effective stress value in the soil can be calculated. Since the effective stress method of shear strength considers the existence of pore water pressure, regardless of the test method of UU (unconsolidated-undrained), CU (consolidated-undrained), and CD (consolidated-drainage) in the triaxial test, the shear strength has a one-to-one correspondence with the effective stress. In this test, the effective stress is actually the vertical compressive stress $\Delta\sigma_1$ ($\Delta\sigma_1 = \sigma_1 - \sigma_3$) loaded by the axial loading system on the specimen during shear failure, that is, the deviatoric stress. The test data were collected to obtain the stress-strain curves corresponding to different moisture absorption and dehumidification cycles of natural moisture density samples. The experimental curve is shown in Figure 6 (the stresses involved in this study refer to effective stresses).

When the tailings sand sample has not undergone the dry-wet cycle, it can be found from Figures 6(a)–6(e) that when the water content is 6.10%, the sample deviatoric stress peak exceeds 500 kPa. When the water content is 10.40%, 14.00%, 18.20%, and 21.00%, the peak value of the sample deviator is between 400 kPa and 420 kPa. The peak value of the deviator decreases as the water content increases, and it declines significantly between 6.10% and 10.40%, and then the peak value of the deviator stress tends to be stable with the increase of water content. When the water content is 6.10%, the peak value of the deviatoric stress of the sample is the largest, and the stress-strain curve shows a significant peak, and a sudden drop occurs after the peak value. Under the function of other water content, the curve develops gently, and there is no obvious peak and sudden drop.

According to the analysis, the strength of the tailings particles themselves is formed by the primary bond, and the attraction between the tailings particles and the particles, between the tailings particles and the water molecules, is formed by secondary bonds and hydrogen bonds. Since the bonding ability of the primary bond is much larger than the secondary bond, the bonding force between the particles is much smaller than the strength of the particle itself. Therefore, the overall strength of the tailings sample is primarily dependent on the bond between the particles. When the water content is low, the moisture in the sample is less, so under the action of the attraction between water molecules and particles, relatively strong clusters cannot be formed between the particles. When a large displacement between the particles causes the sample to break, the internal friction between the particles drops sharply and the corresponding stress-strain curve peaks then drop. When the water content reaches 10.40% or higher, due to the high water content, the sample particles are likely to form more clusters under the action of the attraction between water molecules and particles. However, as more water enters the soil, the undisturbed structure of the soil is destroyed. At the same time, more moisture acts as a lubricant on the surface of the particles, reducing the frictional resistance between the particles. Under the combined effect of these factors, when the sample shows a large water content, the peak value of the deviator is small. However, under the action of many powerful clusters, the particles are displaced, resulting in a peak of the deviator after the sample is destroyed.

After the sample has undergone different cycles of dry and wet cycles, it can be found from Figures 6(a)–6(e) that the peak value of the deviatoric stress of each tailings sample with different water content decreases under the function of dry and wet cycles. When the number of dry and wet cycles is small, the peak value of the stress-strain curve is significantly lower than that of the sample that has not undergone the moisture desorption and dehumidification cycle. When the number of dry and wet cycles reaches 3 to 4 times, the peak value of the stress-strain curve tends to be stable after falling. Compared with the sample without the dry-wet cycle, the sample after the moisture-absorbing dehumidification cycle

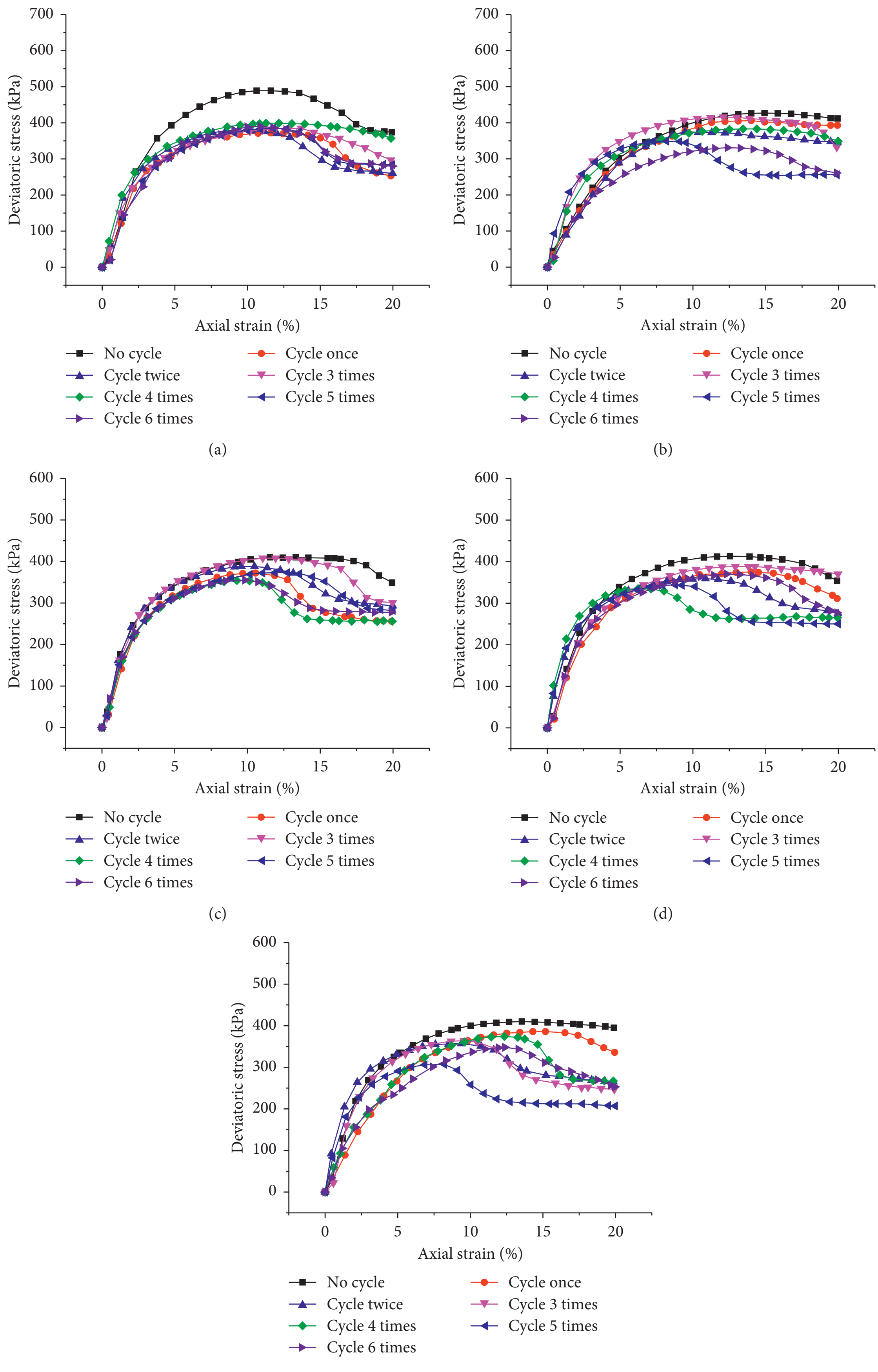


Figure 6: Stress-strain curves of samples with water content at natural dry density under different times of moisture absorption and desorption cycles. Water content: (a) 6.10%, (b) 10.40%, (c) 14.00%, (d) 18.20%, and (e) 21.00%.

has a large initial stiffness at the initial stage of loading. The tailings sand sample with a water content of 6.10% has a significant decrease in the peak value of the deviatoric stress compared with the uncirculated sample after undergoing a dry-wet cycle. For the tailings sand sample with a water content of 10.40% or more, the degree of decline in the peak value of the deviatoric stress is not as obvious as the former. During the dehumidification process, the pore water pressure inside the sample gradually decreases. According to the principle of effective stress of Terzaghi, when the effective stress of the sample increases, the tailings sand sample is more compact under the action of gravity, mainly showing the large initial stiffness at the initial stage of loading. In the process of moisture absorption, as the moisture of the tailings sample enters, the internal gas overflows and forms a path inside the sample. The inside of the sample will be hollowed out and the addition of water can destroy the original structure of the sample. Under the above factors, the compactness of the tailings sand sample decreases. Therefore, the peak value of the deviator tends to decrease after undergoing the dry-wet cycle. When the sample was subjected to several dry and wet cycles, flaky tailings appeared on the surface of the sample. This is because the discharge of gas in the sample during the addition of water causes a trace of gelatinous substance inside the tailings sand to be discharged and combined with the tailings sand on the surface of the sample to form a flaky substance. Moreover, the overflow of the gelling substance also reduces the strength of the tailings sand sample to some extent. As the number of dry and wet cycles increases, after 3 to 4 times, the path formed by the gas discharge tends to be stable inside the sample, that is, the internal pores of the sample are basically stable, and the bearing capacity of the sample tends to be stable. For the sample with a water content of 6.10%, the water content is low and there is much gas in the sample void. When the first humidification occurs, the gas inside the sample overflows a lot, and more internal voids are formed. Thus, the moisture content sample subjected to the first dry-wet cycle has a much lower strength than the uncirculated sample.

3.3. Development Characteristics of Pore Pressure. The pore water pressure includes the pore water pressure and the excess pore water pressure. The pore water pressure generally does not cause the instability of the soil, but when the excess pore water pressure increases, according to the principle of the effective stress of the Terzaghi base, the Mohr circle will appear to the left shift phenomenon, intersecting with the strength envelope to cause the destruction of the soil. When the dry density is $1.539\,g/cm^3$, the relationship between the pore water pressure and the axial strain of the samples subjected to different dry and wet cycles under different initial moisture contents is shown in Figure 7.

Generally speaking, after each tailings sample with different water contents experienced 0~6 dry and wet cycles, the uniaxial consolidation undrained shear test showed that the pore water pressure first increases to the peak and then begins to decrease. When the pore water pressure of the sample reaches a peak, the axial strain reaches 3% to 5%. As the load is further applied, the pore water pressure begins to decrease, exhibiting a negative value and tending to be stable. The intersection of the stress-strain curve before and after the moisture absorption and desorption cycle is basically consistent with the intersection of the pore pressure-strain curve. Indirectly, the pore water pressure is an important reason that affects the shear strength of the sample. At the same time, when the strain increases to a certain extent, the pore water pressure of the tailings sample of each moisture content under the dry and wet cycle conditions is larger than that of the uncirculated tailings sand sample. This is because the sample will produce microcracks during the drying process, and the micelles in contact with the particles of the tailings sand sample in the moisture-absorbing and dehumidifying cycle are more likely to be broken, and the broken particles are easily filled into the larger pores inside the sample. Therefore, the shearing performance of the sample is increased, which shows that the pore water pressure of the recycled tailings sample increases to the later stage of the test. When the pore water pressure of the tailings sand sample is 0, the axial strain becomes larger as the number of dry and wet cycles increases, that is, the axial strain at the critical point of sample shearing and dilatancy increases with increase in the number of cycles. After the dry and wet cycle, the shear dilatancy characteristics of the sample change. From Figures 7(a)–7(e), we can see that when the water content increases, the axial strain at the critical point of the sample shearing and dilatancy increases first and then decreases, and the maximum axial strain at the critical point corresponds to a moisture content of 10.40%. This is because when the water content is low, the attraction between the water molecules and the particles is small, relatively strong clusters cannot be formed between the particles, and the particles are likely to be relatively displaced, so that the dilatancy is likely to occur. As the water content increases, the bonding strength between the particles increases, so that dilatancy does not easily occur. When the water content continues to increase by 10.40% or more, although more clusters are formed under the attraction between the water molecules and the particles, more water destroys the original structure of the soil and the water lubricates the surface of the particles. The effect is that the friction between the particles is reduced. Under these factors, the sample particles are more likely to be displaced, so that dilatancy is prone to occur. After repeated dry and wet cycles, due to the overflow of gas in the pores, a path will be formed inside the tailings sand sample, thereby further enhancing the shearing characteristics of the sample. Specifically, as the number of dry and wet cycles increases, the pore water pressure of the sample increases, and the axial strain corresponding to the critical point of shearing and dilatancy increases.

4. Conclusions

(1) The results of consolidation and undrained shear test of tailings sand samples with different moisture absorption and dehumidification cycles under the

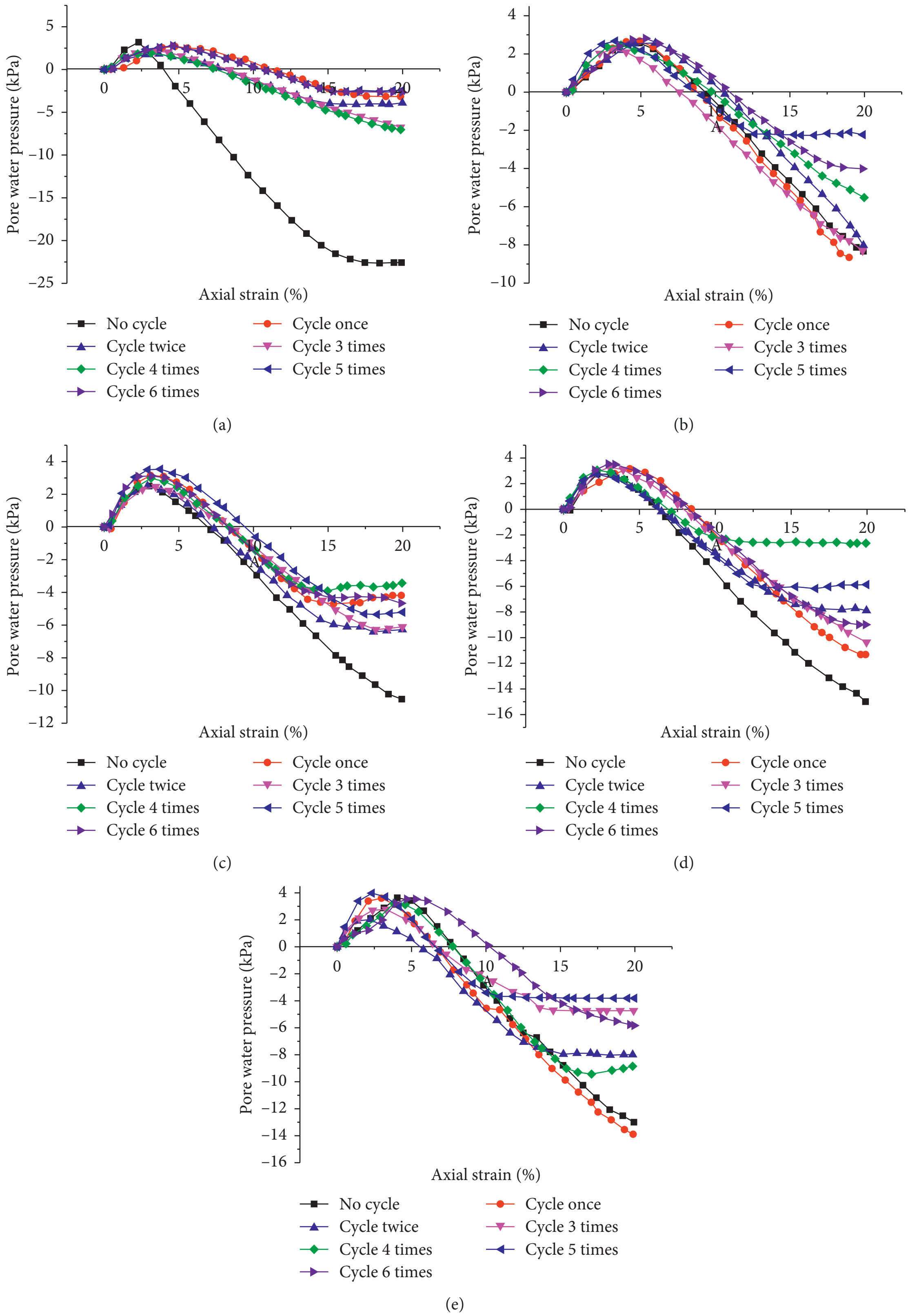


FIGURE 7: Changes in pore pressure of various moisture content samples at natural dry density under different times of moisture absorption and desorption cycles. Water content: (a) 6.10%, (b) 10.40%, (c) 14.00%, (d) 18.20%, and (e) 21.00%.

same water content show the following: as the number of hygroscopic and desorption cycles increases, the stress-strain curve undergoes an irreversible change. When the number of moisture absorption and desorption cycles increases, the strength of the tailings sand sample gradually decreases, and the strength tends to be stable after 3 to 5 cycles.

(2) The development of stress-strain curves for tailings sand samples varies with water content. When the water content is low, the stress-strain curve will drop suddenly after passing the peak. As the water content increases to a certain extent, the peak stress will increase. When the water content is large, the peak stress is reduced due to the lubrication of water.

(3) During the shearing process, the pore pressure of each tailings sample with different water contents shows a phenomenon of increasing first and then decreasing by experiencing different cycles of moisture absorption and desorption. The sample under moisture absorption and desorption will produce microcracks and the internal particles will be more likely to be broken. Therefore, after the sample is deformed to a certain extent, the recycled tailings sand sample has larger pore water pressure than the uncirculated sample. When the pore water pressure of the sample is 0, the axial strain becomes larger as the number of dry and wet cycles increases.

(4) When the water content increases, the axial strain at the critical point of the shearing and dilating characteristics of the sample increases first and then decreases. When the water content is relatively small and large, the particles are prone to dislocation and easy to undergo dilatancy, so the axial strain at the critical point of shear and dilatancy is also reduced.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (51804164 and 51774187), Natural Science Foundation of Hunan Province (2019JJ50498 and 2017JJ3274), and Research Foundation of Education Bureau of Hunan Province (18B276 and 17A184).

References

[1] F. Z. Zhang and X. P. Chen, "Influence of repeated drying and wetting cycles on mechanical behaviors of unsaturated soil," *Chinese Journal of Geotechnical Engineering*, vol. 32, no. 1, pp. 41–46, 2010.

[2] G. F. Vaezi, R. S. Sanders, and J. H. Masliyah, "Flocculation kinetics and aggregate structure of kaolinite mixtures in laminar tube flow," *Journal of Colloid and Interface Science*, vol. 355, no. 1, pp. 96–105, 2011.

[3] P. Ofori, A. V. Nguyen, B. Firth, C. McNally, and O. Ozdemir, "Shear-induced floc structure changes for enhanced dewatering of coal preparation plant tailings," *Chemical Engineering Journal*, vol. 172, no. 2-3, pp. 914–923, 2011.

[4] X. Huang and X. G. Cai, "Experimental study on physical and mechanical properties of central line tailings sands," *Journal of Disaster Prevention and Mitigation Engineering*, vol. 36, no. 2, pp. 220–224, 2016.

[5] M. Rico, G. Benito, and A. Díez-Herrero, "Floods from tailings dam failures," *Journal of Hazardous Materials*, vol. 154, no. 1–3, pp. 79–87, 2008.

[6] Y. K. Tian, "Study on the effect of moisture desorption-absorption cycie on the physical and mechaanical properties of tailings sand," Master's Degree thesis, University of South China, Hengyang, China, 2016.

[7] W. H. Liu, Q. Yang, X. W. Tang, and W. G. Ling, "Mechanical properties of different initial dry-density soils under dry-wet cycles," *Shuili Xuebao*, vol. 45, no. 3, pp. 261–268, 2014.