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Soil-Water Separation Property of Bauxite Mine Slime

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Abstract. Traditional disposal of the high-water content slime from the beneficiating and washing of the bauxite mine requires lots of land and a long time to consolidate, which has attracted a wide range of environmental and social concerns. High-speed centrifugal test was carried out to investigate the water property and composition of high-water content bauxite washing mud. Test results indicated that the bound water content ranged from 29.7% to 31.4%, free water content ranged from 250.6% to 252.3%. The bound water accounted for only 11%, while the free water accounted for about 89% of total water content. A series of model tests were conducted to study the slurry-water separation property of high-water content bauxite mine slime. Experiments showed that controlling the vacuum load application process can effectively inhibit the formation of low-permeability stratum around the drainage body. The final settlement increased by 31.5% and the amount of water discharge increased by 39.52% compared with the conventional vacuum preloading method. Moreover, the water content may decrease from 281.9% to 53.6% within 60 hours with the increase of density of drainage body under the controlled vacuum load application process.

Keywords. Bauxite, mine slime, soil-water separation, free water, bound water

1. Introduction

Alumina output of Guangxi Province ranks No.4 in China, with a huge amount of high-water content slime produced which requires lots of land and a long time to consolidate. About 0.8-1.0 tons of dry slime or 1.0 to 2.5 tons of wet slime will be discharged for each ton of alumina production according to statistics [1, 2], and there will be more and more mud dumps with the increase of alumina production capacity in the process of exploiting karst accumulative bauxite. The suspended solids with particle size less than 1 mm are mixed with water to form tailings slurry, which is sent to the thickener for concentration and then discharged into the sludge mud dump after the bauxite original ore washing treatment. The mud dump is a control project of the mine. In fact, in order to prevent pipeline blockage, the water content of newly dredged mud can reach more than 300% due to long distance and large span of pipeline transportation [3]. The consolidation degree of mud in the mud dump is affected by many factors, including mineral composition, initial water content, and whether the mud is in the state of

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flowing [4]. It is difficult to drain and consolidate high-water content mud under natural conditions [5]. The bearing capacity of surface layer in the dump will be extremely low after several or even more than ten years [6-8].

A large number of researches on the application of slime for preparation of cement materials have been carried out, but most of them stayed in the experimental stage due to economic reasons [9, 10]. Domestic scholars have carried out comprehensive experimental researches on the application of slime as new wall material [11], ceramic material, slime glass material, road building material and backfilling material, combined with the specific conditions of China [12]. However, the premise for further resource utilization is the effective separation of water and tailing particles in slime. Unfortunately, water characteristics of bauxite mine slime still needs to be further studied. In view of this, this study carried out the water property test and, analysed the water composition under different initial states. Small-scale slurry-water separation model tests were also carried out, with the surface settlement and, amount of water pumped from the slime under the controlled vacuum load application process recorded accurately. The research results can provide a reference to the dematerialization and recycling utilization.

2. Material and Test Method

2.1. Soil Specimen

The test specimen was a kind of mine slime from bauxite ore washing, collected from one of the mud dumps located in Debao County, Guangxi Province. The design mine slime storage capacity was 2848 × 10^4 m^3, and the rockfill dam was designed at 59.7 m. There were about 2500 × 10^4 m^3 high-water content bauxite mine slime in the dump. Slime was in the state of flowing after miles of pipeline transportation for, long years. The mine slime was composed of more than 12 minerals according to X-ray diffraction and electronic microprobe analysis. And the major mineral phases were gibbsite, goethite, kaolinite, diaspore, clinochlore, pyrophyllite, hematite, and quartz, which accounted for 93.4% of total minerals. Al_2O_3, SiO_2, and Fe_2O_3 accounts for 93.5% of all oxides according to the fluorescence spectrum. Detailed mineral type and content are shown in table 1.

Table 1. Mineral type and content of bauxite mine slime.

Mineral name	Chemical formula	Percentage
Quartz	SiO_2	3.6
Gibbsite	$Al(OH)_3$	32.2
Rutile	TiO_2	2.0
Hematite	Fe_2O_3	4.1
Diaspore	AlOOH	9.5
Portlandite	$Ca(OH)_2$	0.6
Goethite	FeOOH	19.8
Illite	$(K, H_3O)(Al, Mg, Fe)_2(Si, Al)_4O_{10}[(OH)_2, (H_2O)]$	2.1
Clinochlore	$(Mg, Fe)5Al(Si3Al)O10(OH)_8$	9.4
Vermiculite	$(Mg, Fe, Al)_3(Al, Si)_4O_{10}(OH)_2{\cdot}4H_2O$	0.2
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	4.9
Kaolinite	$Al_2Si_2O_5(OH)_4$	9.9

The soil specimen used in this test was collected from the surface layer without any impurities. According to automatic laser granularity analysis data, the high-water content mine slime was composed of 80.44% of clay particles, 19.37% of silt particles, and 0.19% of fine sand particles. The results showed that the mine slime was in liquid state with average water content of 281.9%. Wet density and specific gravity were about 1.184 g/cm^3 and 2.89 respectively. Main index of physical mechanics of the slime are shown in table 2.

Table 2. Main index of physical mechanics of the slime.

Parameters	Character value
Liquid limit, LL (%)	78.4
Plastic value, PL (%)	27.1
Liquidity index, LI	4.97
Clay particle (%)	80.44
Silt particle (%)	19.37
Sand particle (%)	0.19
Unit weight, γ_t (g/cm^3)	1.184
Water content, *w* (%)	281.9
State and color	Liquid state, yellow brown

2.2. Testing Devices and Methodology

2.2.1. Water Existing Form Test

Generally, water in bauxite mine slime can be divided into free water, bound water and hydration water. And the physical property is mainly affected by free water, bound water and their proportional relational relationship. The vapor pressure and density of bound water is different from free water due to its interaction with solid particles. Many methods can be used to test the bound water, including thermal drying method, dilatometric method, centrifugal separation method, and thermo-gravimetric-differential thermal analysis method, etc. Hitachi high speed centrifuge was employed in this study.

The procedure was as follows: first, set rational speed, temperature and, rotation time parameter, then weight up the centrifuge rotor used in this study, and fill the rotor with test slime in three layers brought back from the engineering site. The whole filling process should be rapid, and the rotor should be immediately covered after filled with slime to avoid water evaporation caused by sample loading. Put the rotor with soil into the centrifuge, and balance weight in the experiment to keep rotor balance during the test.

2.2.2. Soil-Water Separation Model Test

The model box shown in figure 1. adopted in this test was made of organic glass with a size of 400 × 180 × 400 mm. Three 400 mm long measuring tapes were pasted on the outside surface of the model box to measure the specimen settlement. The drainage used in this mode test was porous plastic tube with a diameter of 10 mm. And the drainage was wrapped with filtration cloth to prevent soil particles from entering the drainage during the test. One end of the drainage was embedded in the soil, while the other end was fixed in a water collecting bottle. Water drained from the slime would be collected to the bottle through pipeline. Water weight was weighted by the electronic scale at the bottom of the collecting bottle. Suitable vacuum pressure was controlled by the valve on the pipeline and vacuum pump.

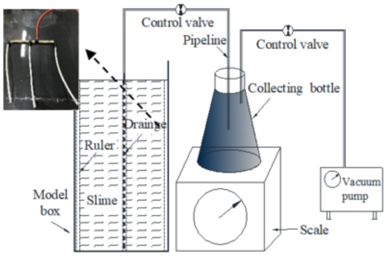


Figure 1. Centrifuge rotor and soil specimen.

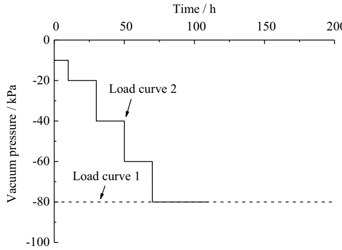


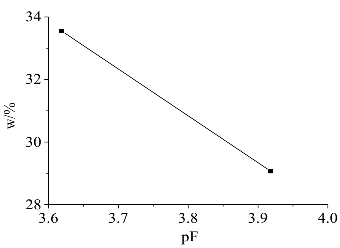
Figure 2. Vacuum loading Process.

Soil in the test was a kind of bauxite mine slime brought back from the field, and its main physical and mechanical parameters were listed in table 1. The slime was fully stirred and the initial water content was 281.9% before the model test. The drainage was placed in he designed position in advance and the slime was slowly poured into the model box until the height reached 380 mm. A plastic bag was bonded at the top mouse of the model box to ensure the vacuum in the process of vacuum loading. The loading process is shown in figure 2.

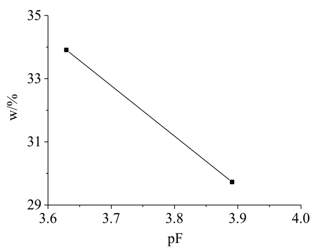
3. Test Results

3.1. Water Existing Form

The pF value, the soil-water suction potential index, was used to classify water as free water, bound water and hydration water. And it's widely accepted that there is a liner relationship between water content and pF when pF value ranges from 2 to 4. When pF value is lower than 3.8, the water is free water. When pF lies between 3.8 and 7.0, the water is bound water. When pF value is higher than 7.0, the water is hydration water, but it is not within the scope of this study. The test curves of water content and pF value are shown in figure 3 to figure 4.



(a)



(b)

Figure 3. Relationship between water content and pF of sample 1.

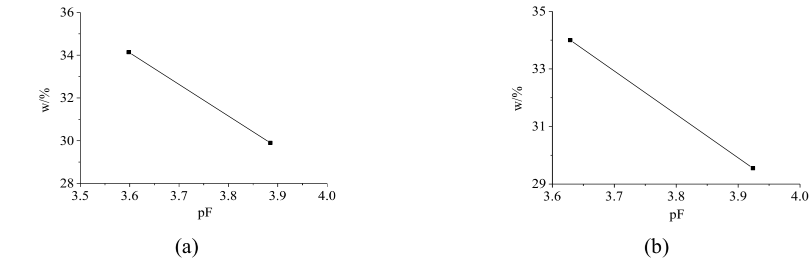


Figure 4. Relationship between water content and pF of sample 2.

The test curves demonstrated that the higher the pF value, the lower the water content. It can be seen that the water content was 33.35% when pF value was 3.619, and water content was 29.07% when pF value was 3.918 as shown in figure 3 (a). The water content was 33.91% when pF value was 3.629, and water content was 29.73% when pF value was 3.891 as shown in figure 3 (b). It can be seen that the water content was 34.14% when pF value was 3.598, and water content was 29.90% when pF value was 3.885 as shown in figure 4 (a). The water content was 34.00% when pF value was 3.629, and water content was 29.55% when pF value was 3.924 as shown in figure 4 (b).

3.2. Soil-Water Separation Test Results

3.2.1. Single Vertical Drainage Body

One porous plastic tube wrapped with filtration cloth with a diameter of 10 mm was positioned vertically in the model box, and it was used as drainage body in the experiment. The soil-water separation test results under load curve 1 (figure 2) are shown in figure 5. As it can be seen from the spot and line curve, the surface settlement and water drained from the slime through pipeline increased with the application of vacuum load. Further analysis showed that the increasing rate of the settlement and drained water was much higher within the initial 40 hours, but slowed down afterwards. And eventually the curve reached a plateau. The settlement was 112.9 mm, and the weight of the water pumped from the slime was 15.16 kg. The slime volume decreased by 29.7%, and the water content decreased from 281.9% to 103.2%.

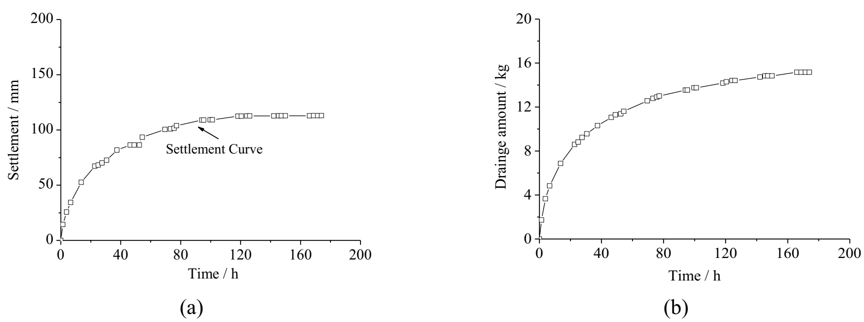


Figure 5. Settlement & Drainage amount with time under load curve 1.

The soil-water separation test results with one vertical drainage body under load curve 2 (figure 2) are shown in figure 6. The settlement first increased, then declined and kept stable finally, similar to changes of water pumped to the slime. Detailed analysis of experimental data indicated that water was drained rapidly from the slime in the initial 90 hours and then the increasing rate slowed down. The surface settlement was 232.6 mm, and the weight of the water pumped from the slime was 18.51 kg according to recorded experimental data. Compared with the initial state, the slime volume decreased by 61.2%, and the water content decreased from 281.9% to 63.2%.

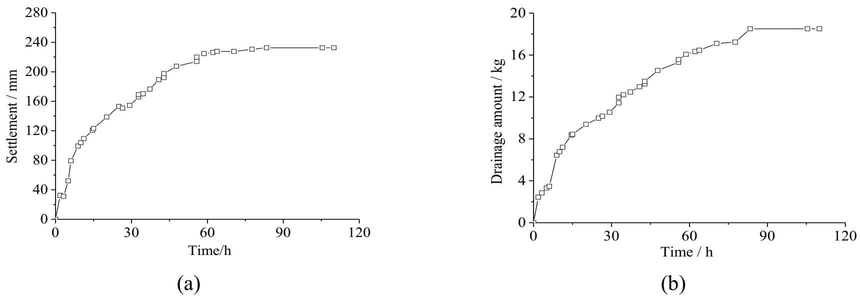


Figure 6. Settlement & Drainage amount with time under load curve 2.

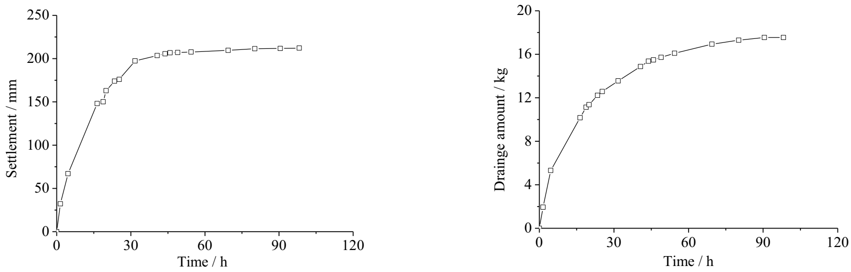
Comparison of the two groups of settlement and drained water amount data suggests that, the process of soil-water separation is strongly affected by vacuum loading process.

3.2.2. Three Vertical Drainage Bodies

Three porous plastic tubes were used as drainage body in the model test under two vacuum loading processes shown in the previous chapter in figure 2. Three tubes adopted in this test were parallel and equidistant from each other in the horizontal direction and they were vertically placed in the slime. The tubes were wrapped with filtration cloth and finally connected with the vacuum pipeline the same as in the previous experiment. Curves in figure 7 showed that high increasing rate in initial stage under load curve 1, to be more specific, within the first 45 hours, the settlement was 212.2 mm, and the pumped from the slime weighted 17.54 kg. The slime volume decreased by 55.8%, and the water content decreased from 281.9% to 75.1%.

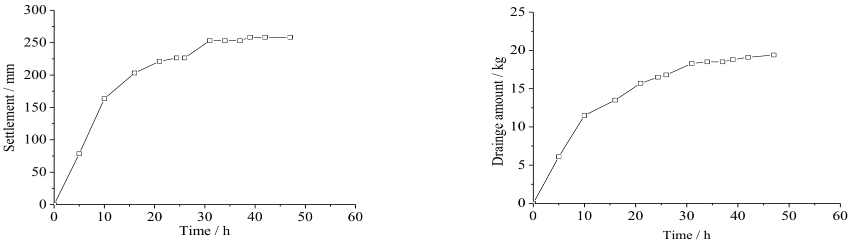
The final slime water content may decrease from 103.2% to 75.1% under the same loading pattern with the number of drainage body increased to three, when comparing figure 5 with figure 7. And the volume changes due to pumping rose from 29.7% to 55.8% at the same time.

Test results under load curve 2 in figure 2 are shown in figure 8. It can be concluded from figure 8 (a) that the surface settlement increased rapidly in the initial 30 to 40 hours, while the increasing trend slowed down until the end of the test. And the change regularities of drainage water amount share similar properties with surface settlement. The final amount of water pumped weighted 19.4 kg. By calculation, the volume decreased by 55.5%, and the water content decreased from 281.9% to 53.7%.



(a) (b)

Figure 7. Settlement & Drainage amount with time under load curve 1 (three drainage).



(a) (b)

Figure 8. Settlement & Drainage amount with time under load curve 2 (three drainage).

4. Discussion

Figure 5 to figure 8 give the soil-water separation test results under vacuum loading with different number of drainage bodies. It takes 180 hours to decrease the water content from 281.9% to 103.2% under common vacuum loading process, while it takes only about 120 hours for the slime to decrease to 61.2%. This means controlling the loading process can dramatically shorten the time needed to separate soil particles from water. With the increase of drainage paths, time required will be further shortened. It takes only about 50 hours for the water content decreased from 281.9% to 53.7%. It can be summarized as follows: 1) vacuum preloading can be used to accelerate the soil-water separation process; 2) water content can be decreased to less than 55% by increasing the drainage paths within 50 hours.

5. Conclusion

This study carried out laboratory and model test of bauxite mine slime collected from Debao County, Guangxi Province. The comprehensive characteristics, water existing form and soil-water separation property were studied in details. Based on this study, the following conclusions can be drawn:

(1) The soil-water suction potential pF can be used to classify bound water and free water. Indoor high-speed centrifuge was employed in this study at the

manufacturing centrifugal field. Free water accounted for 90%, while bound water accounted about only 10% of total water in the bauxite mine slime.

(2) Vacuum preloading can be used to accelerate the soil-water separation process. A transition from liquid state to plastic state takes only about 50 hours under the controlled vacuum loading process.

(3) The bauxite mine slime water content can be decreased to less than 55% by increasing the drainage paths. Model tests indicated that increasing the drainage path from one to three may make the water decreased from 281.9% to 53.2%.

Acknowledgments

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