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A new disposal method of ultra-fine tailings

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ABSTRACT
The ultra-fine tailings have the characteristics of poor water permeability, long consolidation time, low mechanical strength, and are difficult to dissipate excess pore water pressure. These characteristics lead to problems of dam construction difficulty, poor drainage of embankment, high water content of deposited tailings and low dam bearing capacity. This paper introduces a new method of chemical pretreatment combined with physical treatment of ultra-fine tailings. By adding flocculant, the fine particles in tailings can be combined into coarse particles to accelerate the setting speed and pre dehydrate the ultra-fine tailings. Fill the pre dehydrated tailings into different size geofabriform bag made of geotextile. Then apply low frequency load on the bag to accelerate dewatering and consolidation of ultra-fine tailings in the bag. The cost of this method is acceptable. Engineering application indicated that this method has easy site application and the ultra-fine tailings can be disposed in situ.

RÉSUMÉ
Les tailleurs ultra-fins ont les caractéristiques d'une faible résistance à l'eau, de longues périodes de concentration, une faible résistance mécanique, une faible résistance mécanique et une faible résistance mécanique. Il est difficile de dissiper l'excès de pression de l'eau. Ce papier possède une nouvelle méthode de traitement chimique combiné avec le traitement physique des taillis ultra-fins Flocculant, Les fines fines peuvent être combinées pour ajuster la vitesse de pose et prédéhydrer les fines fines Le coût de cette méthode est acceptable. Les applications de l'engineering indiquaient que cette méthode avait une application facile sur le site et que les tailleurs ultra-fins pouvaient être déposés dans le site.

1 GENERAL INSTRUCTION

At present, there is no general definition of fine tailings in China. There is a view that tailings with an average particle size of ≤ 0.03mm, in which the particle content of less than 0.019mm is generally > 50%, more than 0.074mm is < 10% and more than 0.037mm is ≤ 30% is fine tailings(*Tailings facility design reference*,1980) According to the technical bulletin T*ailings Dam Design Technology* (2019) of the International Commission on Large Dams (ICOLD), tailings types are classified into coarse tailings, hard rock tailings, altered rock tailings, fine tailings and ultra-fine tailings. No matter based on which classification method, fine tailings or ultra-fine tailings have the characteristics of high typical Atterberg limits, poor mechanical strength, low permeability coefficient, and are difficult to settling. These characteristics lead to the problems of dam construction difficulty, poor drainage, high water content of sedimentary tailings and poor bearing capacity of the dam.

The problem of fine tailings storage has been paid attention to for a long time, and has always been a research hotspot. J.L. Cheng et al. (2004) designed the combined drainage system of a gold mine tailings storage facility (TSF) in Anhui province of China which is built with upstream method. Z.Y. Zhao (2014) studied and discussed the technology of building a dam with waste rock in an iron ore TSF, obtained the method to solve the problem of large-scale fine tailings stacking, and put forward reasonable suggestions for its later stage stacking. The upstream method is rarely used in foreign countries. Even if used, the hydrocyclone coarse sand is used as the dam shell or the waste rock is directly used to build the upstream embankment. Albian Sand company uses a hydrocyclone to divide the ultra-fine tailings into fine tailings and coarse tailings. The fine tailings are added with flocculant and then pumped to the TSF, while the coarse tailings are directly pumped to the TSF. Cymerman, G. J. put forward the disposal method of solid tailings and sludge tailings as a whole.

The research on the disposal of ultra-fine tailings is mostly in the laboratory, and using the method of adding chemicals. L.Y. LIU et al. (2019) use two flocculants, cationic polyacrylamide (CPAM) and polymeric ferric sulfate (PFS) to treat the acid leaching pulp of laterite nickel ore. The results show that the combination of two flocculants can effectively improve the settling and filtration performance of pulp. The best combination ratio of the two flocculants was given. Suncor and Syncrude oil companies both use the composite tailings process, adding gypsum to the aged fine tailings, and coarse sand is added. Part of the coarse sand is used to fix the fine tailings to form a non segregated mixture, and the other part is used to build tailings dams. G.H. XUE (2019) and others developed a kind of degradable natural polymer flocculant which can be widely used in the flocculation and dehydration of fine tailings by analyzing the different properties of typical fine tailings. Aida Farkish and Mamadou Fall (2013) proposed to use super absorbent polymer (SAP) to rapidly dehydrate and densify mature fine tailings (MFT). The results show that SAP has the ability to significantly dewater, densify and increase the undrained shear strength of MFT. Shriful Islam and Julie Q.Shang (2019) use combined coagulation and electrokinetic treatment to enhance the settling effect. The results show the final solid content reaches 23.74% under the combined application of 350 mg/L ferric chloride and 218.75 V/m applied voltage gradient in the continuous mode.

These methods are currently in the laboratory research stage, and neither the in-situ solidification nor the engineering disposal of ultra-fine tailings has reached commercialization. At present, there is no fully applicable ultra-fine tailings disposal technology on the scale of engineering application. In recent years, in China, the introduction of geofabriform method (2011) has provided a new idea for the field of fine tailings dam construction, and has been applied to many TSFs. At present, the dam height has exceeded 30m. However, there are still some shortcomings in the geofabriform method for ultra-fine tailings. Therefore, the rapid disposal of ultra-fine tailings is still an urgent problem in engineering. This paper introduces a method of physical-chemical joint disposal method, which can greatly increase solids content by weight.

2 DISPOSAL METHOD OF FINE TAILINGS

At present, the main technologies to solve the problem of fine tailings storage are one-step constructed dam, paste or dry-stacking, and geofabriform method.

As early as 1995, S.Y. Chen (1995) proposed to avoid using fine tailings and reinforce the embankment built by fine tailings of different minerals. One-step constructed dam is in line with this idea. One-step constructed dam is a kind of damming method which uses the storage capacity formed by the primary dam built once or by stages to store the tailings without damming with tailings. In Bulletin 181 of ICOLD, modified upstream and modified downstream centerline dams methods have the same way, the waste rock is used to build a dam by stages to form a reservoir to pile up the tailings.

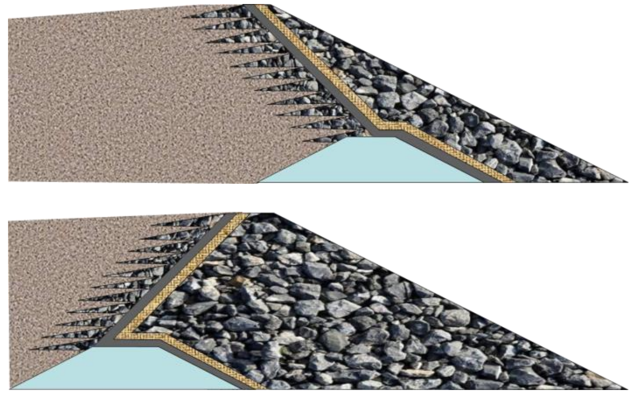


Fig. 1 Geometry of Modified Upstream and Modified Downstream Centerline Dams in Bulletin 181 of ICOLD

The principle of tailings paste storage and dry stacking of tailings is dehydration and concentration of tailings which can be divided into paste and dry-type tailings filter cake due to different moisture. Since 2008, the Chinese government has increasingly recognized the danger of TSF and wanted to promote the use of dry-stacking of tailings throughout the country. Through practice in recent years, it is found that the biggest problem of dry tailings stockpiling is rainfall and dust, and the equipment investment cost is high, the operation management is very complex, which makes this technologies only suitable for low-yield mines.

Most of the world's large-scale paste tailings storage projects are concentrated in Australia, and there are only few cases in China. It is mainly due to the lack of experience in tailings concentration and transportation equipment manufacturing, design and construction, and later management, as well as the different terrain characteristics and technical regulations in China. Paste and dry-stacking of tailings technologies are characterized by large investment in equipment and complex operation and management in the later stage.

In recent years, the geofabriform method was in introduced into the field of tailings dam by improving the technology of hydraulic geotube bag. This method is suitable for dam construction with fine tailings. This method is based on the characteristics of retaining sand and water permeability of the geofabriform cloth. Tailings were filled into the geofabriform bag, the bag is quickly drained and consolidated to form a bag body under the action of pressure, then construct embankment with staggered bag body. This is tailings damming with geofabriform method.

Fig.2 Schematic diagram of dam-forming by geofabriform method

The characteristics of the above methods are as follows.

Table 1. The characteristics of each fine grained tailings stacking method

Storage mode	Scope of application	Advantage	Shortcoming
One-step constructed dam	The tailings is too fine to be dammed, the reservoir depth is short or the freezing period is long	It does not involve the construction of dam with tailings in the later stage, so the dam has high safety.	Over investment in capital construction
Paste, dry-stacking	Areas with little rain and water shortage	High utilization rate of return water and tailings pond	High operating cost, not suitable for rainy areas
Geofabriform method	Tailings particle size is fine	Strong site adaptability, fast consolidation speed, high strength and strong anti earthquake liquefaction performance, can be produced while construction, low cost	Not suitable for tailings dam with high mud content. Not suitable for cold area.

The above methods have their own advantages and disadvantages for fine tailings. At present, in China, the geofabriform method solves the problem of fine tailings storage perfectly. Moreover, the method has strong site applicability, low investment, easy construction and good effect. However, new exploration is still needed if this technology is applied to the disposal of ultra-fine tailings. In this paper, the physical-chemical combined disposal method of ultra fine tailings is proposed based on development and application status of geofabriform method.

3 CHARACTERISTICS OF THE SLUDGES FROM A MINEWATER TREATMENT

The sludges from waste and mine water treatment plant of a copper mine is taken as the experimental research object. The source of the suldges is the sediment collected from the mine stope catchment to the water treatment. Due to the sulfur content of the ore, the water is acidic, and the sludges is also acidic, with a pH value of about 5 to 6. The results showed that the content of copper and zinc in the sludges is high. The concentration of the sludges on site is 10% to 15%.

The weight of particles with diameter less than 0.074mm is 99.21% of the total weight. According to the standard of classification of original tailings by particle size in *tailings facilities design*, the suldges particles group which can settle naturally (particle size above 0.037mm) accounts for 11.64% in solids content by weight, medium silt particles group (particle size below 0.037mm and above 0.019mm) accounts for 25.79% in solids content by weight, fine silt particles group (particle size below 0.019mm and above 0.005mm) accounts for 42.82%, and clay particle group (below 0.005mm) accounts for 19.75%. The weight content of particles which size are below 0.02mm in the whole sludges is 64.83%, and only 35% by weight of the sludges can be used to construct dam. So the sludges can be considered as ultra-fine tailings.

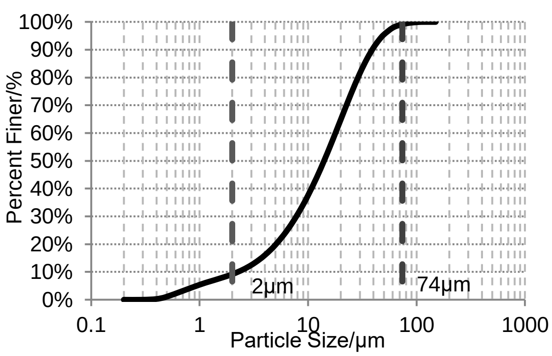


Fig. 3 Particle size distribution curve of the sludges

The coefficient of curvature of the sludges is 1.42 which is between 1 to 3, and the coefficient of unevenness is 7.2 which is greater than 5. So the sludges is well graded. The specific grading indexes are shown in Table 2.

Table 2. Grading index of the sludges

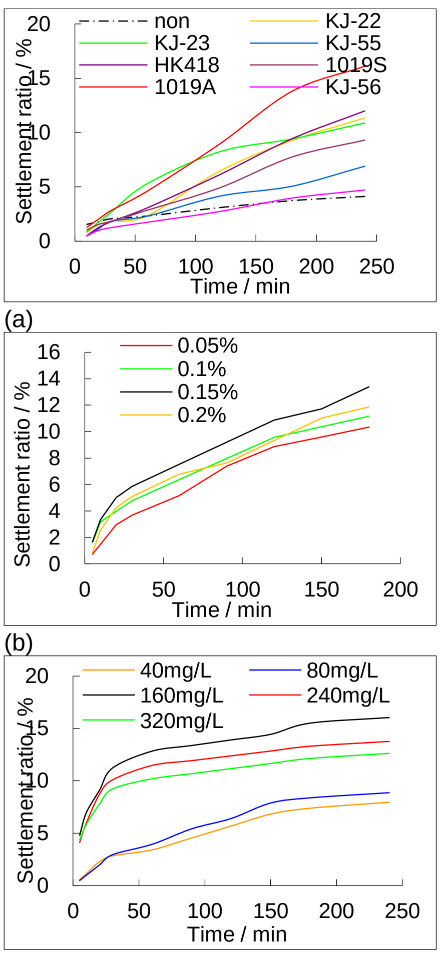
Sample	Effective particle size d_{10}/μm	d_{30}/μm	Median particle size d_{50}/μm	Controlled particle size d_{60}/μm	Curvature coefficient/C_c	Non-uniformity coefficient/C_u
sludges	2.5	8	14	18	1.42	7.2

4 A PHYSICAL-CHEMICAL COMBINED DISPOSAL EXPERIMENT OF ULTRA-FINE TAILINGS

4.1 Chemical treatment of the sludges

The weight of particles with diameter less than 0.074mm in the sludges is 99.21% of the total weight. It is a kind of ultra-fine tailings so sedimentation and dewatering are difficult with conventional disposal methods. In this paper, the physical-chemical combined disposal method is tested. First, the sludges is treated by chemical methods which flocculation and sedimentation experiments are performed under different flocculants under different usage modes and conditions.

The flocculants used are KJ-22, KJ-23, KJ-55, KJ-56, HK418, 1019S and 1019A. The flocculant concentration is 0.05%、0.1%、0.15% and 0.2%. The flocculant is added in an amount of 40mg, 80mg, 160mg, 240mg and 320mg per liter of sludges for testing. The experiment results are shown below.



(c)

Fig. 4 Test results. (a) different types of flocculants (b) different concentrations (c) different addition amount

According to the above test results, flocculant named 1019A is the best, and the optimal configuration concentration is 0.15%, the optimal addition amount of 160mg per liter of sludges.

4.2 Drainage experiment of geofabriform bag which filled with sludges in nature condition

The flocculant 1019A was prepared into a solution with a concentration of 0.15%. The amount of this flocculant added to each liter of sludge was 160mg. After full mixing, the sludge which has been treated by chemically method was filled into the small-size geofabriform bag for test. After filling, the change of water content of the sludge with time and the change of sludge concentration inside the bag were recorded.

Table 3. Data of geofabriform bag filling

Time/ min	Filling height/cm	Weight of spillages/g	Accumulated weight of spillages/g	Settlement ratio	Residue rate/%
0	14.5				
5	12.0	2209	2209	17.24	92.68
10	11.1	1129.5	3338.5	23.45	88.93
20	10.3	1014	4352.5	28.97	85.57
30	9.6	869.6	5222.1	33.79	82.69
60	8.8	1315.6	6537.7	39.31	78.33
120	7.6	765.6	7303.3	47.59	75.79
180	7.4	464.8	7768.1	48.97	74.25

The sludge concentration in the bag was 15.1% after one hour, 15.9% after two hours, 16.3% after three hours, and only 20.2% after 24 hours. It can be seen that the dewatering effect is limited when the sludge is filled in to geofabriform bag after adding flocculant without any measurements.

4.3 Drainage experiment of geofabriform bag which filled with sludges in applying low frequency disturbance load condition

From the above test results, it can be seen that in the nature state, the geofabriform bag filled with sludges added with flocculant has poor dewatering effect in the later stage, so the geofabriform bag body after filling is applied with low-frequency vertical motion. During this experiment, the geofabriform bag continues to dewatering with the application of low-frequency load. Under this experiment condition, the sludge concentration in the bag was measured regularly from 20.2% in the first day after filling to about 33% in the third day. 8 days later after filling, the sludge concentration in the bag reached about 37%. In the contrast group experiment, the geofabriform bag drained in the natural and without any disturbance, the sludge concentration in the bag could only reach about 26% after 8 days of filling.

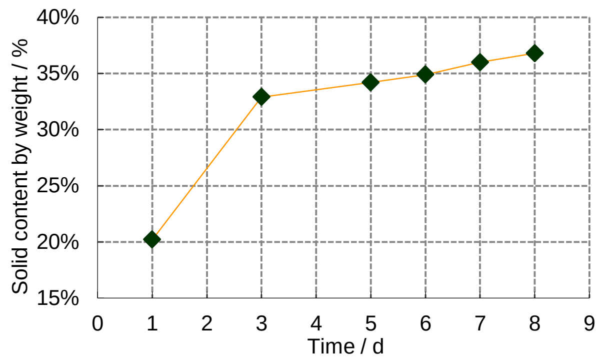


Fig. 5 Change of sludge concentration inside the geofabriform bag

It can be seen that after the low-frequency load is applied to the bag body, the dewatering effect is obvious, and the sludge concentration is greatly increased compared with that before the pressure is applied.

Fig. 6 State diagram of the sludges beform treatment and after physical-chemical combined disposal method

In this paper, the research results of ultra-fine tailings are used for reference. So chemical agents are added to the ultra-fine tailings first to combine the fine particles in the tailings into coarse particles and accelerate the settling speed to pre dewatering the ultra-fine tailings. For ultra-fine tailings, it is difficult to achieve high solid concentration only by chemical treatment. In this paper, the pretreated sludge is filled into the geofabriform bag. In order to achieve its rapid settling rate, the low-frequency load is applied to the bag after filling, and the test effect is good.

5 Conclusions and prospects

5.1 Conclusions

At present, the main technologies to solve the problem of fine tailings storage are one-step constructed dam, paste or dry-stacking, and geofabriform method. Among these methods, the geofabriform method has good applicability for fine tailings damming, and the construction is convenient and the project investment is small.

The results of various experiments showed that flocculant 1019A had the best effect on sludge sedimentation and dewatering. The best concentration is 0.15%, and the best adding amount was 160mg per liter sludge.

When low frequency load is applied to the filled geofabriform bag, the dewatering effect of the bag is obviously improved.

The solid content of ultra-fine sludges by weight rises from 15% up to 37%. The physical-chemical combined disposal method for ultra-fine tailings is an effective new idea.

5.2 Prospects

For oil sand tailings or sludges from waste and minewater treatment with different chemical composition, the chemical agent added in the pre dewatering treatment still needs further experimental research.

The loading mode of the geofabriform bag after filling should be further studied, so that the solid content by weight of ultra-fine tailings inside the bag can reach more than 40%.

The method discussed in this paper has controllable cost, good engineering applicability and strong site applicability, and can solve the ultra-fine tailings storage in situ. However, before the application of engineering projects, it is necessary to carry out in-situ experiment of damming with geofabriform method.

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