Hindawi
Advances in Civil Engineering
Volume 2022, Article ID 6067529, 6 pages
https://doi.org/10.1155/2022/6067529

Research Article

Study and Application of Full Tailing Deep Concentration and Rapid Dewatering Technology

Liang Peng,[1,2,3] Bokun Zheng,[2,3] TengLong Huang,[2,3] Xin Zhu ,[2,3] Yang Liu,[2,3] and Fan Hu[2,3]

[1]*School of Resources and Safety Engineering, Central South University, Changsha, Hunan 410083, China*
[2]*Changsha Institute of Mining Research Co., Ltd, Changsha, Hunan 410012, China*
[3]*National Engineering Research Center for Metal Mining, Changsha, Hunan 410012, China*

Correspondence should be addressed to Xin Zhu; 1056986271@qq.com

Received 7 April 2022; Revised 8 June 2022; Accepted 27 June 2022; Published 12 July 2022

Academic Editor: Qianqian Wang

The problem of unstable full tailing sand concentration and dewatering in some mine filling systems has led to substandard bottom flow concentration of tailing sand concentration equipment, wide fluctuation ranges of filling concentration, substandard return water concentration at filling stations, and high flocculant addition cost. Through flocculation and sedimentation tests, the effect of the flocculant and sedimentation law and the effect of slurry concentration on sedimentation rate were studied, and the field application of the flocculant addition point model was verified. The results showed that (1) when the dose of the flocculant was added, the $F1$-type polyacrylamide as the flocculant made the best settling effect of the whole tailing sand in the test, as judged by comparing the falling rate of the clarified layer and the clarification degree of the supernatant. (2) With the increasing flocculant concentration, the settling speed of tailing sand gradually becomes slower; the range of the best settling concentration was 8%–18% of tailing sand concentration; and the concentration of tailing sand corresponding to the maximum solid flux was 10%–14%. (3) Relying on the site conditions of a domestic copper mine, the feed concentration was diluted from 20%–25% to 10%–12%, and the overflow water clarification test was less than 300 ppm, which verified the flocculant test and the correctness of the flocculant addition point model. The type and dosage of the flocculant as well as the feed concentration of the tailing slurry all have an effect on the flocculation and settling effect. The results of the study can provide some implications for the efficient flocculation and settlement of tailings in other mines.

1. Introduction

In recent years, due to the gradual emphasis on environmental protection and safety in production, more and more metal mines have sought the transformation of mining methods in response to the national call to improve the safety of underground mining. Filling mining method has unique advantages such as protecting the surface environment, reducing the impact of goaf collapse, and improving the recovery rate of ore. It has been widely promoted and applied [1–8].

In the field of mine filling, most metal mines or some nonmetallic mines have started to use whole tailing sand from mine processing plants for filling underground mining areas, and many scholars have conducted indepth studies on tailing sand filling [9–11]. Wang et al. [12] conducted a study on the uniaxial compressive strength of the tailing sand filler specimens at low temperature and explored the strength evolution and consolidation mechanism of the tailing sand cemented fillers at low temperature. Hou et al. [13] studied the effect of maintenance age on the basic mechanical properties of tailing sand cemented fillers and established a segmental damage intrinsic model based on the damage mechanics theory considering the maintenance age. Zhao et al. [14] investigated the early mechanical properties and damage characteristics of the tailing sand cemented fillers with different fibers and obtained a damage intrinsic model under the action of different fibers. The early mechanical properties and damage characteristics of the tailing sand cemented fill with different fibers were investigated, and a damage instantiation model was obtained for the filler under the action of different fibers. Wu et al. [15] studied the proportioning parameters of different filling materials in the Fankou Pb-Zn mine and analyzed the variation pattern of the tailing sand slurry fluidity and pipeline conveying resistance characteristics under different conditions. In order to improve the dewatering efficiency of the tailing sand and to increase the bottom flow concentration of the slurry, flocculant was added to the thickener. Adding flocculant to the thickener can significantly improve the settling efficiency of the tailing sand slurry and can increase the bottom flow concentration at the same time [16–22]. Li et al. [23] made technical changes to the sand bin and added a flocculant dosing device, which effectively solved the problems of unclear overflow water and low filling concentration and achieved high-quality filling of the whole tailing sand. Based on FBRM (focused beam reflectance measurement) and PVM (particle video microscope) research means, Li et al. [24] studied the distribution of floc chord length, the change of floc number, and the dynamic evolution of average floc chord length and then analyzed the fragmentation mechanism of the floc structure. Wang et al. [25] carried out a measuring cylinder settling experiment, small land semi-industrial deep cone dynamic dense test, and concluded that the nonionic flocculant with a molecular weight of 12 million was most favorable for tailing sand settling.

Flocculants can solve the problems of low concentration of tailing sand slurry and nonclarification of overflow water to a certain extent, but the problems of unstable dewatering of full tailing sand concentration and the consequent substandard bottom flow concentration, the wide fluctuation range of filling concentration, and the high cost of flocculant addition in tailing sand concentration equipment are still difficult to solve, and few relevant research results have been reported. In this context, this study aimed to investigate the effect of flocculant and settling law, the effect of slurry concentration on settling rate, and the field application of the flocculant addition point model by conducting flocculation and settling test to obtain the optimal flocculant type, the best flocculation slurry concentration, and successful practice experience, which provide a reference basis for high-quality mine tailing sand filling.

2. Study on the Role of Flocculants and the Optimal Flocculant Preference

2.1. Density and Grain Size Determination of Whole Tailing Sand. The flocculation and sedimentation test study were carried out with the whole tailing sand of a domestic production copper mine, and the solid density was first determined. The solid density of the whole tailing sand was tested at a temperature of 20°C, and the solid density of the tailing sand sample was 2.805 g/cm^3. The results are presented in Table 1.

Malvin MS3000 laser diffraction particle size analyzer was used to analyze the particle size of the whole tailing sand, and the test results are shown in Figure 1.

Table 1: Determination of density of the sample at 20°C.

Sample	Density (g/cm^3)
1	2.801
2	2.806
3	2.808

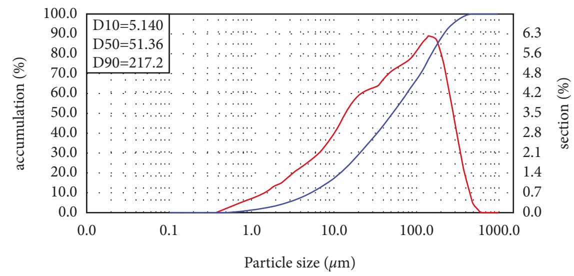

Figure 1: Differential and cumulative distribution curves of whole tail sand particle size.

Compared with the total tailings in the references [16–23], the density of the total tailings in this copper mine and the particle size of the total tailings was smaller, as a result of which there may be differences in the flocculation settlement effect.

2.2. Flocculant Preference Test. The settlement effect of the tailings is embodied in the speed of settlement. The settlement speed of tailings was calculated by observing the height of the clarification layer changing with time, and then the settlement effect of each type, different concentration, and flocculant ratio of tailings mortar were compared. The most suitable flocculant type, the best settlement concentration, and the corresponding flocculant addition were selected.

In order to select the most suitable flocculant for tailing sand, it is necessary to observe and study the settling effect of each type of polyacrylamide flocculant on the test tailing sand through selection tests to determine the flocculant type to be selected for subsequent tests and actual projects. The flocculation and sedimentation effect of the tailing sand is mainly judged by comparing the rate of fall of the clarified layer and the degree of clarification of the supernatant.

Eight different types of flocculants from a flocculant manufacturer, *F*1, *F*2, *F*3, *F*4, *F*5, *F*6, *F*7, and *F*8, were selected for this test, of which *F*1, *F*2, *F*3, and *F*4 were cationic type and *F*5, *F*6, *F*7, and *F*8 were anionic type, as shown in Figure 2. The flocculants were prepared into 1000 ppm concentration.

The tailing slurry with 15% mass concentration was prepared in 1 L cylinder as a control group to observe natural settling. Eight groups of tailing sand slurry with 15% mass concentration were prepared, and different types of flocculant solutions were added to each group of tailing sand slurry at 15 g/t. The hole stirrer was placed at the bottom of the measuring cylinder and was lifted twice quickly and then once slowly to ensure that the settling conditions of each group of tailing sand were the same except for the different types of flocculants. While the stirrer left the liquid surface, the timing was started, and the heights of the clarified layers at 30 s, 60 s, 120 s, and 180 s were recorded as shown in Table 2, and the effect of settling of tailing sand was observed.

According to the test observation, the tailing sand was fine, and the natural settling speed was slow; therefore, it was not possible to observe an obvious clarification layer, but the effect was significant after adding the flocculant. It can be determined that it is feasible and effective to improve the settling effect of the tailing sand by adding flocculant.

The settling of tailing sand is divided into two stages,fast settling and compression settling. When the tailing slurry starts to settle down, it enters the fast settling stage, and the duration is generally 30 s to 2 min. With the same dosage of flocculant added, the higher the concentration, the slower the settling speed of the fast settling stage, and the longer the duration of the fast settling stage. In the fast settling stage, the sediment layer and the liquid surface of the clarified layer can be observed at the bottom. When the liquid surface of the clarified layer coincides with the liquid surface of the sediment layer and the settling speed is lower than 30 mm/min, it enters the compression settling stage.

In this test, the rapid settling phase was completed within 60 s, so the settling speed within 60 scan reflects the superiority of its settling effect. The bar graph of flocculation and sedimentation for each group is shown in Figure 3.

It can be seen in Figure 4 that, in the $F1$, $F8$, $F2$, and $F4$ flocculant group ,the settling speed is faster than in other groups, and it is observed that the clarification of the supernatant is best in the $F1$ group, slightly worse in $F2$ and $F4$ groups, and the worst in the $F8$ group; therefore, when the added flocculant dose is certain, $F1$-type polyacrylamide as flocculant makes the best settling effect of test full tailing sand.

Compared with the flocculation effect in [16–23], the flocculation sedimentation effect of the cationic flocculant was better than that of the anionic flocculant, indicating that the properties of the tailings were more suitable for the cationic flocculant. The flocculation settling velocity was slower than the tailings in the references [16–23], which was related to the smaller density of the total tailings.

3. Study on the Effect of Slurry Concentration on Flocculation and Sedimentation Rate

The concentration of tailings produced by the concentrator and the amount of flocculant added also have an important impact on the settlement of tailings. In general, the lower the concentration of tailings produced by the concentrator, the faster the settling velocity after entering the sand bin. Within a certain range, the larger the flocculant dosage is, the faster the sedimentation rate is. The concentration of the tailing sand output of the processing plant is generally determined according to the beneficiation process, and the tailing sand treatment as a downstream process does not require the beneficiation process to change to achieve the best results for itself, especially when such changes require a certain cost. Flocculation does not get better with increasing amounts

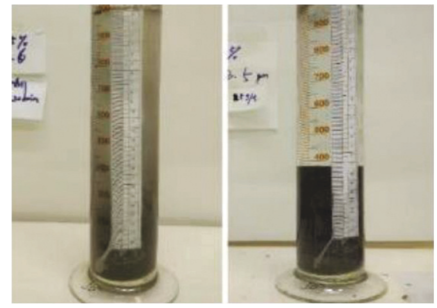

Figure 2: Comparison of natural settling and flocculation settling.

of flocculant. On the one hand, the increase of flocculant addition means the increase of cost. On the other hand, the study also found that, after an increase of the flocculant amount, the settlement of tailings would not change significantly or may even become worse.

The laboratory test aims to study the effect of flocculant settling when different concentrations of tailing slurry are added with different amounts of flocculant and to determine the best amount of flocculant to be added for each concentration of tailing sand to provide a basis for the modification of the filling system.

According to the results of the flocculant selection test, weigh the corresponding tailing sand and water volume and prepare 8%, 10%, 12%, 15%, 20%, and 25% tailing sand slurry, respectively. The total volume should be ensured to be 1 L after the completion of the preparation, and the flocculant addition amounts are 5 g/t, 10 g/t, 15 g/t, 20 g/t, and 25 g/t, respectively. The corresponding flocculant solution amounts are added into the tailing sand slurry with a pipette. The hole stirrer was put to the bottom of the measuring cylinder and lifted twice quickly and then once slowly to ensure that the settling conditions of each group of tailing sand were the same except for the different amounts of flocculants added.

While the stirrer was left on the liquid surface, the time was started, the height of the clarified layer at 10 s, 20 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, and 240 s was recorded, and the clarity of the supernatant during settling was observed and judged qualitatively.

For example, at 8% tailing sand concentration, the settling effect is already obvious at 5 g/t flocculant, so there is no need to test the settling effect at a higher flocculant addition for this concentration of tailing sand; for example, at 12% tailing sand with 5 g/t flocculant, the settling effect is not good, so there is no need to test the settling effect at a higher flocculant addition. Therefore, there was no need to test 5 g/t of flocculant when the concentration of tailing sand was higher. In the end, 19 sets of tests were conducted, and 18 sets of data were measured, among which the clarified layer was not observed for the tailing sand slurry with a concentration of 15% and a flocculant addition of 10 g/t.

The best settling effect of 8% tailing slurry was achieved at 5 g/t flocculant addition, 10% tailing slurry at 10 g/t flocculant addition, 12%, 15%, and 20% tailing slurry at 15 g/t flocculant

Table 2: Recording the height of the clarification layer for the flocculant test (unit: mm).

Type / Time (s)	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*
30	70	42	71	50	70	60	68	74
60	121	83	119	95	110	107	120	117
120	150	139	148	143	154	156	164	163
180	170	153	171	163	170	172	178	173
Degree of clarification	Good	Average	Good	Poor	Poor	Average	Poor	Average

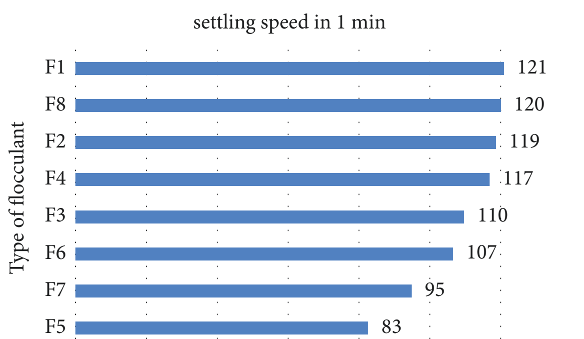

Figure 3: Comparison of flocculation and sedimentation speed (unit: mm/min).

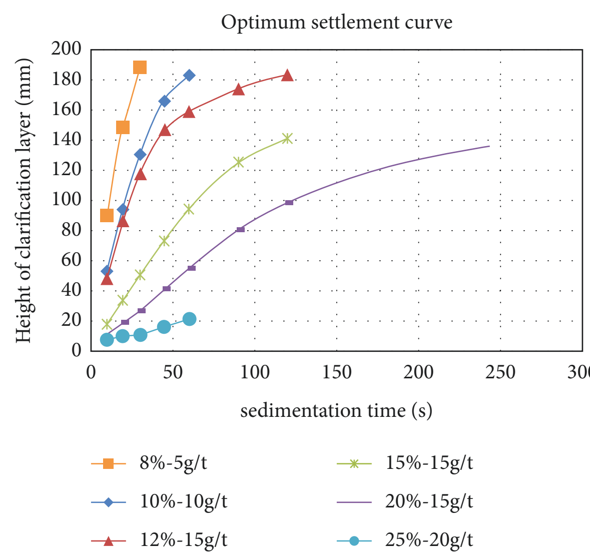

Figure 4: Settlement curve.

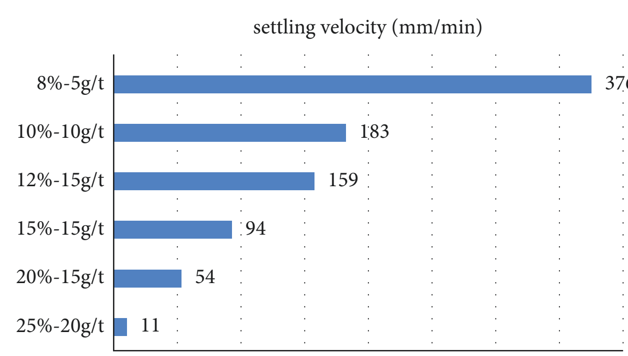

Figure 5: Settlement curve.

addition, and 25% tailing slurry at 20 g/t flocculant addition. The best settling data for different concentrations were compared, and the curves shown in Figure 4 were obtained.

Its settling velocity was obtained by calculation as shown in Figure 5.

Through the test data, it can be intuitively seen that, with the increasing concentration, the settling speed of each group of tailing sand gradually becomes slower, when the concentration is 8%, and only 5 g/t of flocculant is added. The settling height is 188 mm in 30 s, which completes the process of rapid settling and turns into compression settling, and its settling speed is 376 mm/min; while when the concentration of tailing sand is 25% and the amount of flocculant added is 20 g/t, the settling speed is only 11 mm/min, which is 1/34 of the settling speed of 8% tailing sand slurry, so it can be seen that the size of the initial concentration has a great influence on the speed of settling. On the other hand, the amount of flocculant consumed during the settling of low concentration tailing slurry is also less, and the cost is lower. Therefore, according to the test results, the secondary dilution of the tailing sand of the processing plant can be designed to reduce its concentration to a reasonable range during the use of the subsequent filling system.

Compared with the tailings in the references [16–23], the initial concentration of tailings slurry in this copper mine was higher, and the maximum concentration was about 25%. At the same time, the optimal flocculant dosage was 20 g/t, and the dosage was large. In references [16–23], the tailing slurry concentration was about 5%~18%, the flocculant dosage was about 7~16 g/t, the the dosage was small, and the flocculant cost was low. Therefore, the dilution of tailing slurry can improve the flocculation effect and reduce the dosage of flocculant and can reduce the cost.

4. Coagulant Addition Point Model and Application Validation

4.1. Optimal Dilution Concentration and Solid Flux of the Concentrator. Secondary dilution concentration is the key research direction of flocculation and sedimentation, and many studies mainly focus on the optimal dilution concentration of the study target mines, lacking general and generic studies of similar mines. The design tailing concentration, experimental optimum dilution concentration, and actual postdilution concentration vary from mine to mine.

According to the definition of solid flux, the physical amount of a certain solid passed vertically through a unit

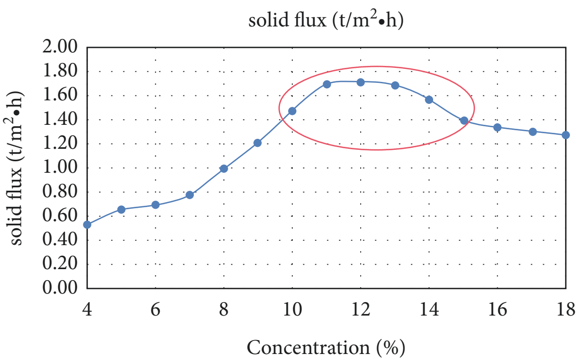

Figure 6: Solid flux-feed concentration curve.

area per unit time. A maximum value exists because the lower the concentration of the slurry, the faster the settling speed, but, at the same time, the lower the mass per unit volume of the slurry. The larger the solid flux, the greater the concentration processing efficiency and the faster the concentration rate.

Combining the relationship between the feed concentration and settling velocity mentioned in Section 3, the solid flux of the slurry at different feed concentrations was calculated and the variation curve of solid flux vs. feed concentration was plotted as shown in Figure 6.

Since the settling rate of full tailings is affected by the mass concentration of tailings slurry, regarding tailing settling experiments and related flocculation and settling studies, the range of optimal settling concentration is generally 8% to 18% of tailings concentration. It can be seen from Figure 7 that the maximum solid flux corresponds to 10% to 14% of tailings concentration. Therefore, to take into account the treatment efficiency and dilution cost,based on the study of the rapid dewatering flocculant addition system of the thickener, the mathematical model of solid flux and the best dilution concentration of incoming tailings from common nonferrous metal ores are suggested to be 10%–16%.

4.2. Center Feed Barrel Flocculant Addition Point Model and Application Validation. Based on the site conditions of a domestic copper mine, a small feed bucket device was designed to flocculate and settle the tailing sand slurry for secondary dilution according to the feed concentration range. The mine tailing sand solid density is 2.8 t/m^3, about 20%–25% mass concentration of low concentration tailing sand slurry into the top center of the thickener small feed bucket device, to seek the best performance of flocculant concentration and secondary dilution concentration, to develop a highly efficient dynamic concentration and dewatering test program suitable for the site concentration device, and to optimize the location and number of flocculant addition point.

A model of the center feed bucket flocculant addition point is shown schematically in Figure 7.

The flocculant preparation concentration was diluted to about 0.1% in the central feed barrel for multipoint addition, and the location and depth of the addition point were

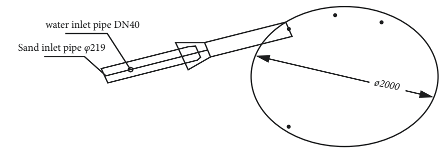

Figure 7: Schematic diagram of the flocculant addition point model for the central feed drum.

Figure 8: Overflow effect diagram.

optimized and adjusted according to the site conditions. The feed was diluted from 20%–25% to 10%–12% based on the self-dilution and the appropriate addition of external water according to the fluctuation of the feed volume to achieve the best flocculation and sedimentation effect and also to ensure a large solid flux site The results show that the overflow water clarification test is less than 300 ppm, and the overflow effect graph is shown in Figure 8.

5. Conclusion

By carrying out flocculation and settlement tests on filled tailings, the effect of flocculants and settlement laws and the effect of concentration on settlement rate and field application verification were studied, and the following conclusions were obtained:

(1) When a certain dose of flocculant was added, it was judged that *F*1-type polyacrylamide as a flocculant made the best settling effect of the whole tailing sand in the test by observing and comparing the falling rate of the clarified layer and the clarification degree of the supernatant.

(2) With the increasing concentration, the settling speed of the tailing sand gradually becomes slower, and the optimal settling concentration ranges from 8% to 18% for the tailing sand and 10% to 14% for the maximum solid flux. Subsequent secondary dilution of the tailings sand is required to improve the settling speed and solid flux.

(3) Relying on the site conditions of a domestic copper mine, the feed concentration was diluted from 20%–25% to 10%–12%, and the overflow water clarification test was less than 300 ppm, which verified the correctness of the flocculant test and the addition point model.

The type and dosage of flocculant as well as the feed concentration of the tailings slurry all have an effect on the flocculation and settling effect. The results of the study can provide some implications for the efficient flocculation and settlement of tailings in other mines.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported and financed by the National Key Research and Development Program of the 13th Five-Year Plan (nos. 2018YFC0604603 and 2018YFC0604606), all of which are greatly appreciated.

References

[1] W. Zhiyuan, Z. Wenru, and L. Qianyong, "Research and practice on safe and efficient mining of ore bodies under complex conditions," *Mining Research and Development*, vol. 38, no. 5, pp. 10–12, 2018.

[2] Z. Yongfeng, Z. Xuongtian, and M. Hongfu, "Research on efficient mining methods for slowly inclined medium-thick ore bodies," *Metal Mining*, vol. 6, pp. 19–23, 2016.

[3] Z. Tongtong, W. Yongyan, and Y. Zhuoqun, "Effect of loading rate on the strength characteristics of layered fillers," *Science Technology and Engineering*, vol. 21, no. 34, pp. 14535–14541, 2021.

[4] X. Wenbin, L. Bin, and W. Yubin, "Experimental design and analysis of permeability characteristics of all-tailed sand colluvial fill," *Mining Research and Development*, vol. 41, no. 12, pp. 99–103, 2021.

[5] C. Jie, C. Yunkai, and H. Qingheng, "Study on the rheological properties of high sand filling materials[J]," *Mining Research and Development*, vol. 41, no. 12, pp. 109–113, 2021.

[6] Z. Aiqing, L. Jinyun, W. Aixiang, and Z. Y. Wang, "Experimental study on the mechanism of whole tailing sand vibratory dewatering based on bulk dynamics," *Mining Research and Development*, vol. 41, no. 12, pp. 119–123, 2021.

[7] W. Fan, H. Bin, and H. Yafei, "Calculation and application study of friction loss of paste-filled slurry pipe transport," *Journal of Mining and Safety Engineering*, vol. 38, no. 6, pp. 1158–1106, 2021.

[8] Z. Meidao, R. Yunzhang, and X. Wenfeng, "Orthogonal test for optimization of all-tailed sand paste filling ratio," *Gold Science and Technology*, vol. 29, no. 5, pp. 740–748, 2021.

[9] R. Zhuen, W. Aixiang, and W. Yiming, "Multi-objective optimization of key performance indicators for all-solid waste paste," *Journal of Engineering Science*, pp. 1–9, 2020.

[10] C. Gezhong, L. Cuiping, and R. Zhuen, "Effect of flocculation conditions on floc structure and solid-liquid separation efficiency in paste filling," *Chinese Journal of Nonferrous Metals*, pp. 1–20, 2020.

[11] C. Chong, L. Wu, and Z. Yalei, "Research and application of upward-downward nested paste-filled mining technology," *Mining Research and Development*, vol. 39, no. 7, pp. 24–27, 2019.

[12] W. Binwen, G. Su, and D. Pingbo, "Experimental study on consolidation characteristics of tailing sand colluvial fillings in alpine regions," *Chinese Journal of Nonferrous Metals*, pp. 1–12, 2014.

[13] H. Yongqaing, Y. Shenghua, and C. Yong, "Uniaxial compressive stress-strain relationship and its damage intrinsic model for tailing sand cemented fillers," *Materials Guide*, no. 7, pp. 1–15, 2022.

[14] Z. Kang, S. Yufeng, and Y. Xiang, "Early mechanical properties and damage intrinsic modeling of tailing sand colluvial fill under the action of different fibers," *Journal of Rock Mechanics and Engineering*, vol. 41, no. 2, pp. 282–291, 2022.

[15] W. Junhui, X. Youwei, and L. Xiaojing, "Experimental study on the characteristics of high-concentration tailing sand filling materials in Van Kou lead-zinc mine," *Mining Research and Development*, vol. 41, no. 7, pp. 135–139, 2021.

[16] J. Xiaodong, Z. Gengjie, and S. Laifa, "Effect of flocculants on the performance of colloidal filler of ultrafine tailings," *Metal Mining*, vol. 10, pp. 61–66, 2021.

[17] S. Can, W. Xiaojun, and W. Xinmin, "Study on the law and mechanism of APAM single consumption on flocculation of particles of different grain size in full tailing sand flocculation and sedimentation," *Mining Research and Development*, vol. 40, no. 5, pp. 67–74, 2020.

[18] Z. Liyi, Y. Peng, and L. Wensheng, "Experimental study on the influencing factors of flocculation and sedimentation and densities of all-tailed sand," *Mining Research and Development*, vol. 41, no. 8, pp. 59–64, 2021.

[19] L. Qi, C. Youhua, and L. Dongrui, "Prediction of technical parameters of full tailing sand densities based on static settlement test," *Gold Science and Technology*, vol. 29, no. 2, pp. 266–274, 2021.

[20] Y. Zilong, T. Yuye, and F. Jianxin, "Optimal flocculant selection and floc NMR analysis of all-tailed sand," *Mining Research and Development*, vol. 41, no. 4, pp. 136–140, 2021.

[21] Z. Gengjie, Z. Wangcheng, and H. cheng, "Study on the application of flocculants in vacuum filtration and dewatering of gold tailings," *Metal Mining*, vol. 4, pp. 45–52, 2021.

[22] W. Zhenjiang, Y. Xiaobing, and L. Litao, "Selection and optimization of flocculation and settling parameters for all-tailed mortar based on RSM-BBD," *Chinese Journal of Nonferrous Metals*, vol. 30, no. 6, pp. 1437–1445, 2020.

[23] L. Chengwei, Z. Xin, and P. Liang, "Design and application study of a full tailing sand filling system technology for an iron ore mine," *Mining Research and Development*, vol. 42, no. 3, pp. 158–142, 2022.

[24] L. Cuiping, C. Zhongge, and R. Zhuen, "Dynamic evolution law of floc structure during the whole process of tailing sand densification," *Chinese Journal of Nonferrous Metals*, pp. 1–18, 2022.

[25] W. Hongjiang, W. Xiaolin, and Z. Xi, "Dynamic flocculation concentration test of ultrafine whole tailing sand with deep cone," *Journal of Engineering Science*, vol. 44, no. 2, pp. 163–169, 2022.