Industrial Practice on Optimizing Tailings Composition Combined with Ore Concentration Processes

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ABSTRACT

Cemented paste backfill (CPB) is increasingly applied in underground mines world-wide and has a broad prospect considering its benefits in environmental protection and ground control. During the paste production, a well-graded aggregate is critical for the achievement of CPB. Mine tailings from the outcome of ore-dressing plant are commonly used as the fill aggregate. However, it is difficult to obtain an ideal particle size distribution for the mine tailings which are roughly mixed with final residuum in ore concentration processes. In this study, a novel industrial method is proposed to select fill aggregates from different parts of ore-dressing processes. With combined design of concentration plant and backfill plant, the tailings with desired particle sizes and proportions during the mineral processing are chosen to produce CPB without disturbing the regular ore concentration. The problem of passively accepting final tailings from ore-dressing plant has been improved.

INTRODUCTION

Paste backfill technology is the development direction of backfill technology in our country. It maintains stability of surrounding rock, decreases surface subsidence and improves recovery rate of mineral resources [1]. High strength can be reached by adding small amount of cementing agent producing a good roof contact performance and overall performance, thus reducing filling cost of mining. It has broad prospects for development with advantages in economy, environmental protection, safety and high efficiency [2]. However there are some defects in paste backfill technology which hinders its use in practice. One of the problems to be urgently resolved is selection and optimization of filling aggregate. The mine enterprises often can't implement paste backfill due to lack of proper filling aggregate. Filling aggregate is the key factor to decide the filling scheme and quality. Especially for paste backfill, the property of aggregate decides whether or not the paste backfill scheme can be used. Moreover, tailings gradation has crucial influence on the filling quality. Therefore, studies of filling aggregate gradation are significant.

At present, filling system and mineral processing plant are considered separately for most of mines during their design and construction of filling system. The tailings used by filling system are mixed tailings produced at the final procedure of mineral processing. Yet it is often too different from the ideal graduation as filling aggregate. To solve this problem, based on status of mineral processing technology that tailings are produced at multiple sub-processes, we put forward optimized combination tailings paste backfill technology based on mineral processing. This technology makes full use of tailings produced during mineral processing, mixes the tailings produced at different sub-processes of mining processing technology in different proportions. It produces filling aggregate with relatively ideal particle size, thus providing technical support for preparation of paste backfill slurry.

IDEAL FILLING AGGREGATE

The ideal filling aggregate should be continuous gradation. The fine grains fill in the pores between coarse particles acting as 'lubricant 'and thus reducing resistance loss of pipeline transportation. Also the fine grained material has large surface area which can produce high water absorbing capacity guaranteeing sufficient water-retaining property. They are evenly distributed among the coarse particles when thoroughly mixed with water making paste backfill slurry highly workable. At the same time it produces a stable structure guaranteeing a certain plasticity of paste backfill slurry at rest [3-4]. On the other hand chemical composition of filling aggregate must also be taken into consideration. Nonferrous metallic mines mainly consist of SiO_2 and CaO, accompanied with partial metallic oxide which is oxidized crude ore ungraded in mineral processing. Some of the mine tailings contain remaining mineral monomer [5]. Chemical composition of tailings directly affects performance of backfill. For example, when the content of CuO is greater than 3%, it has a great effect on setting time of paste. For backfill which uses cement as cementing material, if there are pyrite minerals in the filling materials, sulfate radical (SO_4^{2-}) ions would be generated when in contact with air and water. The ions would erode cement and generate insoluble sulphoaluminate crystals and dihydrate gypsum. As a result the volume of the fill body would expand more than two times, which generates internal stress in the backfill causing damage to the backfill [6]. Therefore, the ideal filling aggregate shall have two characteristics, namely, optimal gradation and optimum chemical composition, so as to form dense structure.

Application range of filling aggregate of mines is very extensive, and it has gradually shifted from the traditional mountain sand, sea sand, river sand, fine stone, etc. to industrial waste such as fly ash, tailings, slag, etc. Classified tailings have been main sources of filling aggregate for long time. Finer materials are eliminated from them, so that the backfill slurry can be dehydrated quickly after entering stope, and strength of backfill is raised obviously [7]. But at the same time, classification of tailings will inevitably lead to insufficient sources of filling aggregate, and inlet of plenty of overflow tailings increases difficulty in dam stack of tailings dam, and enhances the risk of dam failure.

At present, most of the nonferrous metallic mines in our country cannot apply paste backfill due to nonexistence of fly ash, slag and other aggregates or high cost. Limited by different mining aggregate sources, it can be difficult to get most ideal aggregate considering the filling scheme, filling cost and other factors. Moreover, at present, filling system and mineral processing plant fail to be taken into overall consideration for most of mines in our country during the design and construction, which causes the fact that the tailings used by filling system are mixed tailings produced at the final procedure of mineral processing. Those tailings are often uneven graded, which can cause segregation phenomenon or difficulty in dehydration and other problems.

To resolve this problem, we put forward optimized combination tailings paste backfill technology based on mineral processing, with regard to mines where tailings of mineral processing plant are produced at multiple sub-processes. Core of this technology is to mix the tailings with different gradation in a certain proportion to form an optimized particle size, thus laying the foundation for preparation of paste backfill slurry.

OPTIMIZED COMBINATION METHOD OF TAILINGS BASED ON MINERAL PROCESSING

Proportioning of filling materials is crucial for filling quality. By choosing proper material, adjusting content of coarse and fine tailings, an optimum filling performance could be reached. Proportioning of backfill after optimization can not only guarantee stability and flowability of backfill, but also meet requirements of mining process, and minimize filling cost.

A qualified backfill slurry shall not be segregated during transportation, which requires a certain fine particle content in the filling aggregate. In general, a minimum of 15% fines (<20μm) must be fulfilled. The fines has a strong water retention capacity, and enables the water to fill the pores among micro-fine particles, thus guaranteeing that there are sufficient cement water to form fluidity of the backfill slurry. On the other hand too high content of fines (<20μm) would reduce strength of backfill and increase pipeline transportation resistance.

To apply optimized combination tailings paste backfill technology, particle size distribution of tailings from different sub-processes must be determined and then optimized mixing ratio is theoretically calculated. Several lab tests shall be carried out to confirm the calculated optimized mixing ratio. Those tests include: water segregation test, permeation test, flowability test, etc. There are three kinds of means to combine tailings from different mineral processes. They are flexible, variable, and should be selected according to specific field production technique.

The first kind of combination way is to firstly mix different tailings and then concentrate it. The tailings produced from the gravity process is mixed with the classified tailings and overflowed tailings produced from the flotation process with a certain proportion according to the filling needs. It is then concentrated in a sand silo or other dehydrating device. The concentrated tailings is blended with cementitious material and water to form the paste filling slurry. The process is shown in figure1.

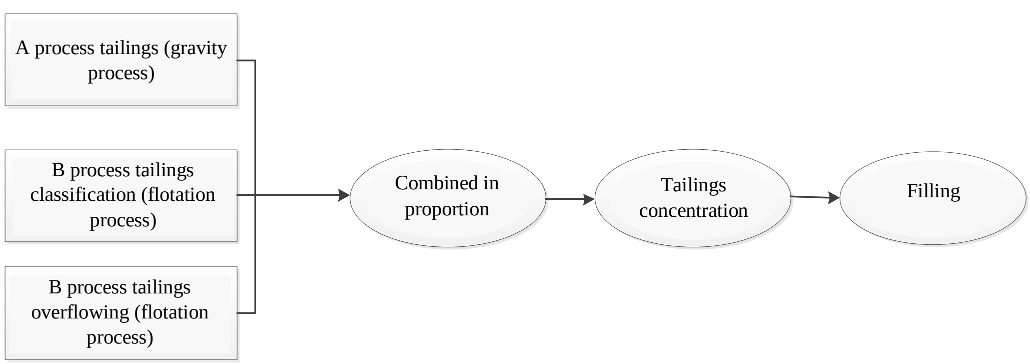


Figure 1. Combination way of firstly mixing and then concentration of different tailings

The second kind of combination way is to firstly concentrate different tailings and then mix concentrated tailings with a certain proportion. As it is shown in figure 2, the tailings produced from the gravity process, classified tailings and overflowed tailings produced from the flotation process are concentrated respectively according to the filling needs. Concentrated tailings are mixed with a certain proportion to achieve a relatively ideal gradation. It is finally blended with the cementitious material, water to prepare the paste filling slurry.

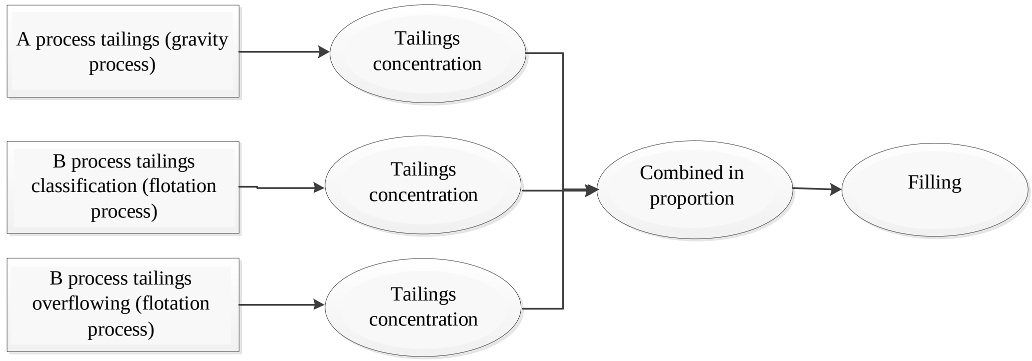


Figure 2. Combination way of firstly respective concentration and then proportional mixing of different tailings

The third kind of combination way is incorporated way of the previous two ways. The first combination way is applied to some of the tailings, and the second combination way is applied the other tailings. Tailings produced by two combination ways are then blended with a certain proportion and then mixed with cementitious agent and water to prepare the paste filling slurry. All three kinds of combination ways have pros and cons. The first kind of combination way does not require much the concentration facilities and equipment, and thus has low relatively low cost. It might however cause the stratification phenomenon at the concentration stage, thus unable to achieve the optimal gradation. The second kind of combination way demands highly on concentration facilities and equipment which needs relatively high cost. But it can ensure the even mixing of filling aggregates according to the designed proportion. The third kind of combination way has both advantages and disadvantages of the first two kinds.

APPLICATION OF FILLING PROCESS OPTIMIZATION TECHNOLOGY BASED ON THE MINERAL PROCESSING

The design of Anqing Copper Mine, Anhui, China adopts the method open stope mining followed by backfilling periodically. The filling way is the classified tailings filling. The filling station contains 3 sets of independent filling system, and each set of system contains 1 sand silo, 1 cement silo, 1 mixer as well as the supporting measurement equipment and automation management system. The tailings in the originally designed dressing plant flotation workshop will be classified through 4 swirlers. After classification, the overflowing fine-grained tailings and the underflow coarse-grained tailings will be respectively delivered to the heavy media factory for the secondary mineral processing of tailings, then the fine-grained tailings after the secondary mineral processing will be discharged to the tailings pond. The coarse-grain classified tailings will be pumped to the vertical sand silo in the filling station for filling. The mineral processing flow of this Mine is shown in Figure 3.

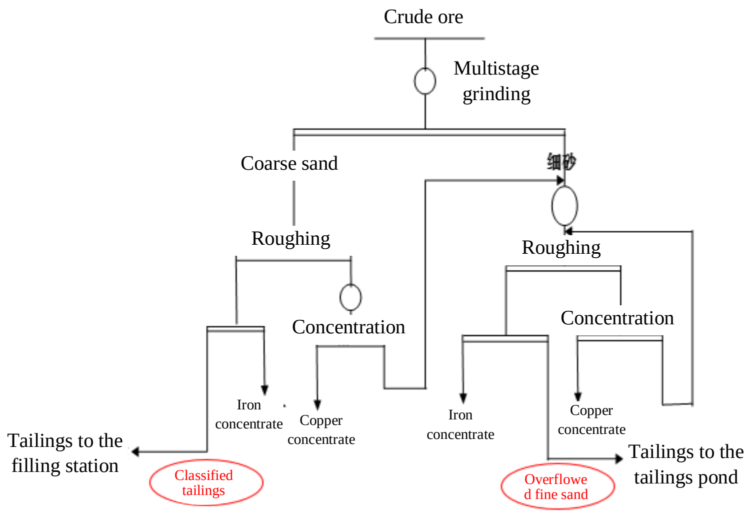


Figure 3. Mineral process flow diagram of Anqing Copper Mine, Anhui, China

There are several problems during filling process with classified tailings, such as low filling concentration, filling slurry segregation, high filling cost and insufficiency in filling of classified tailings in the future, etc. In order to solve the problems at present, based on the comprehensive consideration of mineral processing, a scheme to optimally combine some of the overflowed fine sand with the classified tailings pumped to the tailings pond, optimize the filling aggregate gradation, and prepare the filling slurry of no segregation is put forward. The test analysis on basic parameters of tailings, sedimentation test, water segregation test, flowability test and proportioning test have been carried out, which provides the basis for technological transformation of the filling system.

Test Analysis on Basic Parameters of Tailings

Tailings particle size distribution

A laser particle size analyzer was used to determine the tailings particle size distribution(PSD). The PSD curves of the classified tailings and overflowed tailing are shown in figure 4. 10%-20% fines (<20μm) was added to the mixture of classified tailings and the overflowed tailings. The resulted fines content was between 15%-20% and the PSD curves are shown in figure 4. The coefficient of uniformity and coefficient of curvature of the tailings are listed in table 1.

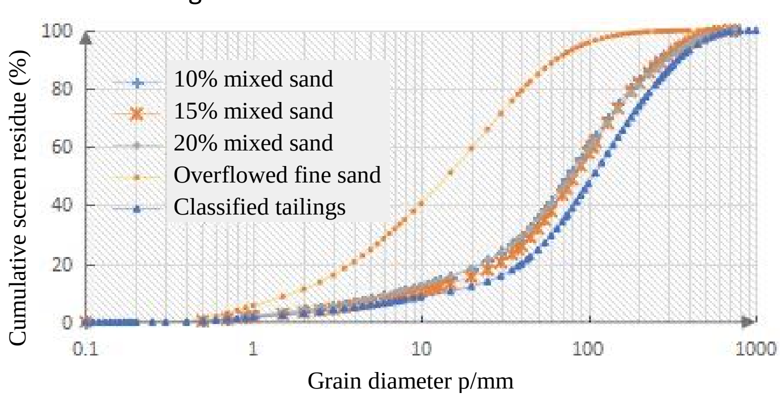


Figure 4. Particle size distribution curve

Table 1. Result of particle size analysis results for the tailings

Type	-20μm content	d10	d30	d60	Coefficient of uniformity Cu	Coefficient of curvature Cc
Overflowed fine sand	59.43%	1.78	6.41	20.74	11.625	1.112
10% mixed sand	15.54%	9.31	46.57	105.45	11.329	2.209
15% mixed sand	18.26%	7.24	40.4	99.78	13.784	2.26
20% mixed sand	18.56%	6.93	40.99	103.72	14.967	2.338
Classified tailings	12.21%	13.86	60.83	137.97	9.952	1.934

The coefficient of uniformity and coefficient of curvature of different tailings were calculated. The gradation of classified tailings, overflowed tailings and mixed tailings of the Mine was good in the perspective of compactness. However, as the tailings of the Mine will be finally prepared into slurry for pipeline transportation, the emphasis should be put on analyzing its gradation based on the experience in slurry pipeline transportation. According to the analysis, -38μm in the classified tailings of the Mine occupied 19.13%; -74μm occupied 36.29%; the particles of 38-74μm in size was in a low content; the coarse particle with the size of +74μm occupied 63.71%. With the high content in coarse particles, it is classified to be coarse tailings type, and the filling slurry prepared from this can easily cause segregation. By adding the fine tailings of different proportions in the classified tailings, the PSD of mixed tailings was improved obviously. The content of -20μm after adding the fines was within 15%-20%which is the precondition to produce the high concentration structural flow. However the rheological test must be carried out to assure that the tailings fulfill the requirement for flowability.4.1.2 Tailings chemical composition

A spectrum generator was used to test the chemical composition in tailings. The results are shown in Table 2, Table 3.

Table 2. Table of results for quantitative analysis of classified tailings element

Element	SiO_2	Al_2O_3	TFe	FeO	MgO	CaO	Na_2O
Content / %	46.52	6.2	7.86	5.44	8.99	19.2	1.64
Element	K_2O	TiO_2	P_2O_5	MnO	S	Cu	Loss on Ignition
Content / %	0.25	0.27	0.18	0.21	0.61	0.11	5.08

Table 3. Table of results for quantitative analysis of overflowed tailings element

Element	SiO_2	Al_2O_3	TFe	FeO	MgO	CaO	Na_2O
Content / %	43.4	5.67	8.56	7.43	10.65	18.89	1.44
Element	K_2O	TiO_2	P_2O_5	MnO	S	Cu	Loss on Ignition
Content / %	0.31	0.25	0.25	0.19	0.94	0.2	6.14

It can be known from the test results that there are a great amount of CaO and a certain amount of MgO, FeO in this Mine, which is conducive to cementing and filling in the future. The harmful composition, such as S, etc., has a low content. Therefore, both classified tailings and overflowed tailings meet the filling requirements.

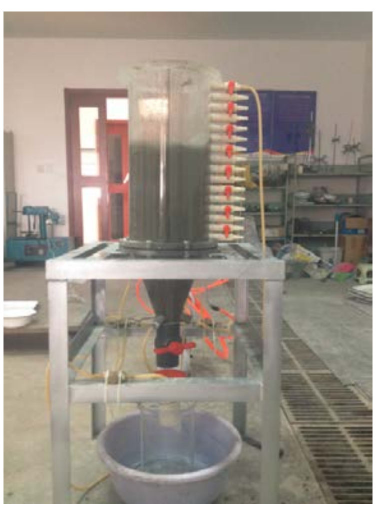
Sedimentation Test

The sedimentation test was carried on according to the concentration of classified tailings and overflowed tailings produced from the mineral processing. The result shows fast sedimentation of classified tailings and slow sedimentation of overflowed tailings. Meanwhile, the sedimentation test of mixed tailings was carried on, with the results data shown in Table 4.

Table 4. Tailings sedimentation test data results

Designation	Concentration	Stability time min	Average sedimentation velocity cm/min
Classified tailings	40%	30	0.60
10% mixed sand	40%	40	0.40
15% mixed sand	40%	60	0.30
20% mixed sand	40%	80	0.22
Overflowed tailings	20%	100	0.22

The sedimentation velocity of classified tailings is about 3 times of the sedimentation velocity of overflowed tailings. If the first kind of optimized combination way is adopted, namely the method of firstly mixing and then concentration, it may lead to the stratification of classified tailings with the overflowed fine sand in the mixing process due to its fast sedimentation, thus causing the uneven particle size distribution of mixed tailings. In order to verify this conclusion, the relevant test was carried on: Firstly the classified tailings and overflowed tailings were mixed in the simulation container according to a certain flow ratio, and after the sand surface was stable, the sand was put in the test mold, then the sampling was made at different heights in the test mold to make the particle size test. The result shows a big difference of tailings particle size composition at the upper, middle and lower parts (figure 5). Therefore, the second kind of optimized combination way is to be adopted, namely the method of firstly respective concentration, then mixing proportionally.



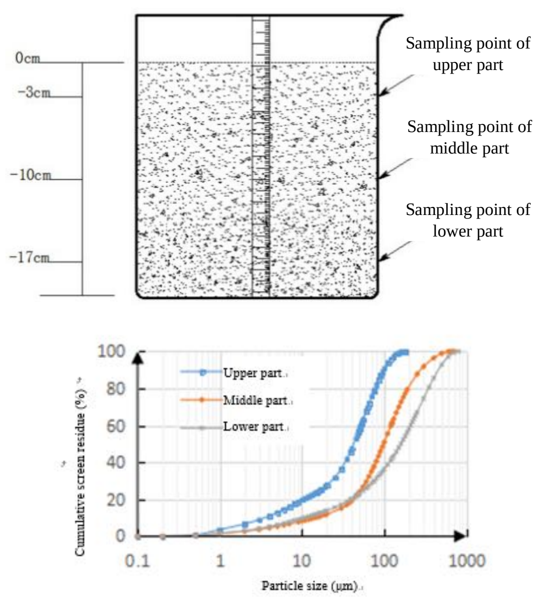


Figure 5. Verification test on the mixed tailings sedimentation stratification of the first kind of combination way

Water Segregation Test

The bleeding rate is a key indicator for the optimal filling concentration with less bleeding in the filling stope, and at the same time, it is an important index to measure the dehydration amount of filling slurry after entering the stope. To realize the paste filling, it is necessary to ensure the bleeding rate of filling slurry is below 5%. Therefore, the water segregation test for different tailings filling slurry was carried on, with the test results shown in Figure 6.

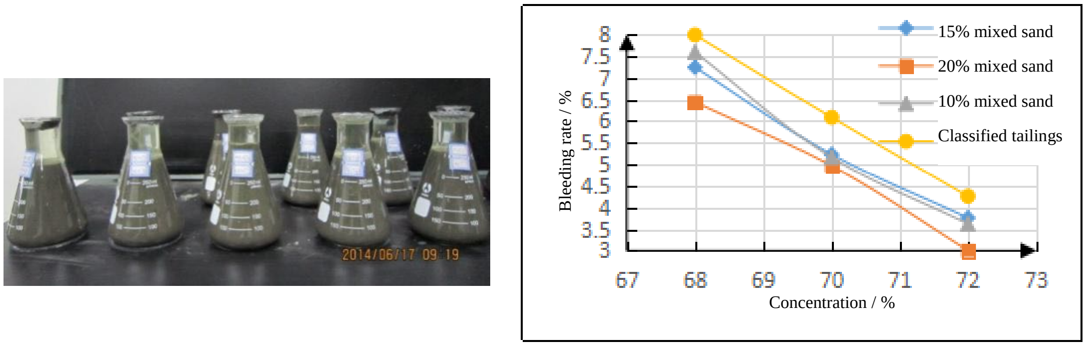


Figure 6. Results of water segregation test for different tailings

When the slurry concentration is 70%, and the fine sand content is 15%-20%, the average bleeding rate is 4.8%; when the slurry concentration is 72%, and the fine sand content is 15%-20%, the average bleeding rate is 3.5%. Based on experience, when the bleeding rate of filling slurry is less than 5%, the filling slurry meets the paste bleeding requirements. Therefore, this can confirm that the concentration of filling slurry needs to be greater than 70%, and the content of overflowed tailings needs to be within 15%-20% to reach the optimum.

Slump Test

Under the condition of ensuring a certain water retention capacity of mixed tailings, it is also necessary to ensure the filling slurry has a certain flowability. Therefore, the test and analysis on the flow property of classified tailings and mixed tailings were carried on. A diffusance bucket was adopted for the flowability test, and a small slump cone was used to test on a piece of glass marked with scale. The upper and lower diameter is respectively 3.5cm, 6.0cm, and the cone height is 6.0cm. The test procedure is firstly use a cloth to clean the slump cone, and put it on a horizontal glass panel, then pour the well mixed filling slurry from the upper mouth of slump cone. Use a steel ruler to scrape away the extra slurry from the upper mouth, and then quickly lift up the slump cone vertically. The filling slurry will form a circle on the glass panel. Through the measurement of circle diameter in two vertical directions, the average value will be diffusance of this slurry. The test process and result are shown in Figure 7.

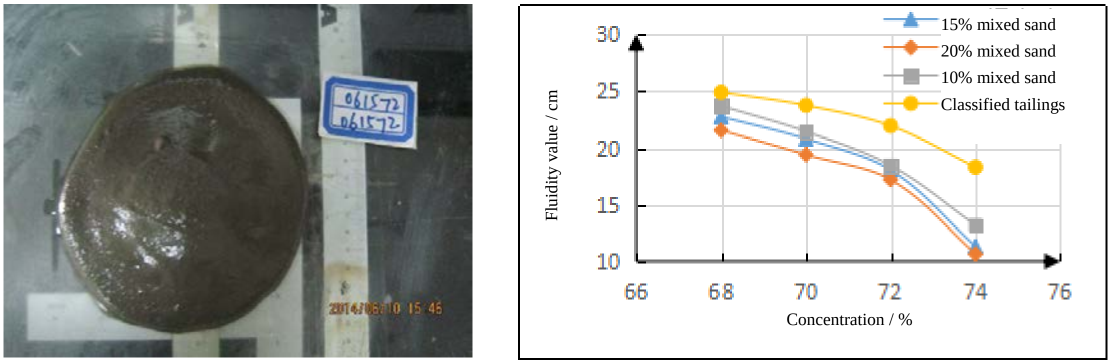


Figure 7. Slump test process and results

It can be known from test results that the diffusion diameter of filling slurry decreases with the increase of fines content on the whole. With the increase of concentration, the flow property becomes poor, showing that adding the overflowed tailings and too high concentration are adverse to slurry transportation. Therefore, it is necessary to control the amount of overflowed tailings and the concentration of filling slurry.

Scheme of Optimizing the Filling Technology Based on the Mineral Processing

Through the preliminary theoretical analysis and the test data analysis, the second kind of combination optimizing way is finally determined to be adopted, specifically as follows: The coarse tailings and fine tailings produced from dressing plant will be respectively pumped to the filling station by two pipelines. The classified coarse tailings will be pumped to the classified tailings silo for natural sedimentation and concentration, and the overflowed fine sand will be pumped to the fine sand silo for flocculating sedimentation and concentration. During filling, the concentrated coarse and fine tailings will be mixed according to the mass ratio of overflowed tailings / (overflowed tailings plus classified tailings) of 15%. The aggregates will then be mixed with cement, water into the paste filling slurry with the solid content of 70%-72%. Th slurry shall be mixed thoroughly and filled into the underground stope by selffolwing in the filling borehole. The process is shown in Figure 8.

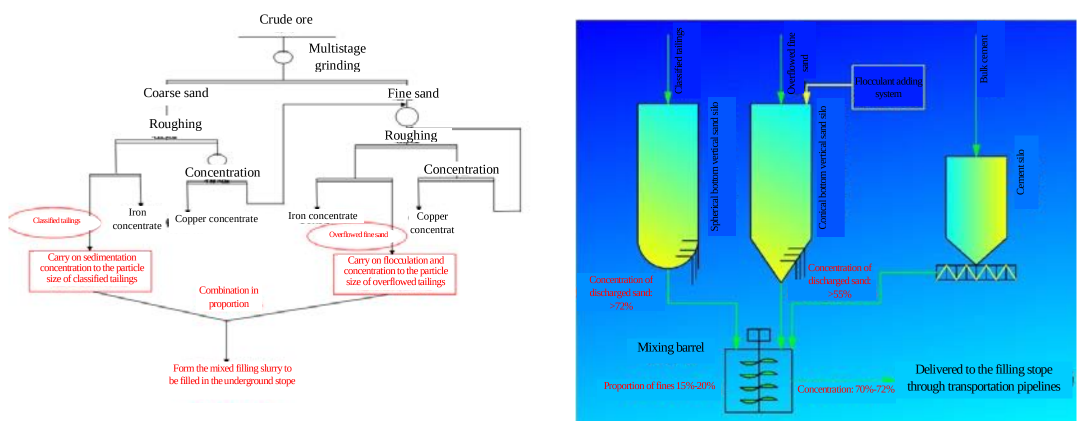


Figure 8. Filling technology flow chart of Anqing Copper Mine, Anhui, China based on the mineral processing

Application Effects of Filling Process Optimization Technology Based on the Mineral Processing

After the transformation of filling system according to the design scheme is completed, the sampling test was carried on at the sampling mouth of filling pipeline. The test results reached the expectations, namely having improved the filling quality, solved the problems of segregation, stratification of filling slurry for classified tailings, and realized the stable, efficient paste filling. The sand discharging effect drawing of filling slurry for mixed tailings at the filling pipeline sampling mouth is shown in Figure 9.

Figure 9. Sand discharging effect drawing of filling slurry for mixed tailings at the filling pipeline sampling mouth

In order to verify the superiority of the filling process optimization technology based on mineral processing, especially the wholeness reflected in the uniformity of fillings, the underground fillings sampling test has been carried out. Two test stopes were chosen, namely 2P stope and 10R stope. Among them, 2P is the stope after the transformation of filling system technology, and 10R stope is the stope before the transformation of filling system technology. The sampling position for both stopes was filling of the first layer. The cement-sand ratio is 1:4, and the sampling height, angle were consistent. The comparison of sampling results are shown in Figure 10.

2P stope sampling results 10R stope sampling results

Figure 10. Comparison of sampling results of underground fillings

The sampling results showed that the fillings of 2P stope ensured good integrity, but the sampling effect of 10R stope was very poor and the fillings were relatively broken. Thus it can be proved that the filling technology scheme based on mineral processing is feasible, reliable, and it can solve the problems of segregation and stratification of filling slurry, uniformity of fillings strength. Meanwhile, adding some of the overflowed fine sand in the classified tailings not only solves the problem of classified tailings insufficiency, but also can reduce the stress of tailings pond, and prolong the service life of tailings pond.

CONCLUSIONS

Based on the tailings production characteristics of the mineral processing for non-ferrous metal mines, the tailings optimized and combined filling technology based on mineral processing is put forward. The core of this technology is to comprehensively consider the filling scheme, filling cost, etc., and to mix the tailings with different gradations, chemical compositions according to a certain proportion based on the conditions of tailings production from mineral processing multilink so as to prepare the mixed tailings of continuous gradation. It combines the design, building of filling system for the mine with the plant dressing process scheme for overall consideration and integrated design, which provides a new idea for optimizing aggregates in the paste filling technology.

By carrying on the test on basic parameters of tailings, sedimentation test, water segregation test and fluidity test, this paper confirms the scheme of optimizing the filling technology based on mineral processing, and implements practical applications. Through the filling slurry sampling and the underground stope fillings sampling, it can be proved that the filling technology scheme based on mineral processing is feasible, reliable, and it can solve the problems of segregation and stratification of filling slurry, uniformity of fillings strength.

The filling process optimization technology based on mineral processing can not only solve the problem of tailings insufficiency due to single tailings, but also can consume more tailings, reduce the stress of tailings pond, and prolong the service life of tailings pond.

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REFERENCES

Liu Tongyou and Cai Sijing. 1998. Application and Research Situation of Paste Backfill Technology at Home and Abroad. China Mining Magazine.

Wu Aixiang and Wang Hongjiang. 2015.Theory and Technology of Paste Filling for Metal Mines. Beijing: Science Press.

Wang Hongjiang, Li Hui, Wu Aixiang et al. 2014. New Definition of Paste Based on Full Tailings Gradation. Journal of Central South University of Technology: Natural Science Edition.

Gan Fengwei.2009. Study on Tailings Composition and Pollution Transfer of Gejiu Stannum Polymetallic Mining Area. China University of Geosciences (Beijing).

Wang Fazhi, Zhu Yingsheng and Hui Lin. 2006. Discussion on Factors Affecting the Filling Quality of Dongguashan Copper Mine. Mining Technology.

Wang Xinmin, Xiao Weiguo and Zhang Qinli. 2005. Theory and Technology of Filling for Deep Mines [M]. Changsha: Central South University Press.