

Application Research and Efficacy Evaluation of an Ultra-Fine Tailings Filling Enhancer for Fan Kou Lead-Zinc Mine

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ABSTRACT

In this paper, aiming at the problems of difficult dehydration and poor filling performance of ultrafine tailings ($< 19\mu\text{m}$) in Fankou lead-zinc mine, a new functional synergist was used to improve the particle dispersion through surface modification mechanism. The whole process research shows that the agent significantly optimizes the slurry performance : the filling concentration of the pillar and the room is increased to more than 63 % and 73 % respectively ; the slurry expansion is greatly improved ; the 7d strength of the filling body increased by more than 130 %. At the same time, the utilization rate of ultrafine tailings is increased by more than 15 %, the cost is reduced by about 5 %, and the environmental protection is up to standard. The research provides an effective solution for the resource utilization of ultrafine tailings in similar mines.

KEYWORDS

Ultra-fine tailings; Filling synergist; Rheological properties; Mechanical properties; Resource utilization; Green mine; Lead-zinc mine

1 Introduction

Tailings produced in the mining process of metal mineral resources have become a key bottleneck restricting the green and sustainable development of mining ^[1]. Among them, ultra-fine tailings(particle size $\leq 19\mu\text{m}$) have large specific surface area(usually $> 1000\text{cm}^2/\text{g}$), high surface energy, and serious particle agglomeration. In the traditional filling process, there are problems such as low dehydration efficiency, large slurry transportation resistance, high bleeding rate, and slow development of early strength of the filling body, resulting in a resource utilization rate of less than 30 %. A large amount of tailings is stored in the tailings reservoir, which not only occupies land resources, but also has environmental and safety risks such as dam break and heavy metal pollution ^[2]. As a large-scale lead-zinc mine in China, Fankou Lead-zinc Mine is faced with the hard requirement of the tailings reservoir to withdraw within a limited period of time. Its annual output of ultrafine tailings reaches hundreds of thousands of tons, and the pressure of tailings disposal is particularly prominent. In the traditional filling process, the consumption of cementitious materials is large(the cement-sand ratio is usually 1:5-1:6), and the filling concentration is difficult to break through 70 %, resulting in high filling costs and insufficient long-term stability of the filling body, which seriously affects the safe production of the mine ^[3].

At present, domestic and foreign scholars have carried out a lot of research on the optimization of ultrafine tailings filling performance. In terms of physical modification, Zhang et al. (Zhang Qinli 's team) improved the dispersion of ultrafine tailings by high-frequency vibration stirring, but it could only alleviate macro-agglomeration and could not regulate the surface properties of particles from the micro level ^[4]; in terms of chemical modification, Li et al. (Li 's team) used naphthalene-based and polycarboxylate-based general water reducers to improve the fluidity of slurry. However, such water reducers are mainly designed for cement-based materials, and the interface effect of tailings-cementitious material composite system is insufficient. It is difficult to solve the problem of deterioration of rheological properties caused by ultrafine particle agglomeration ^[5]. In the research and development of new admixtures, Wang et al. (Wang Hongjiang team) developed a filling modifier based on composite silicate. Although it can improve the strength of the filling body, it has a synergistic optimization effect on the fluidity and concentration of the slurry.

2 Material overview and test system

2.1 Technical Principle of New Filling Synergist

The filling synergist used in this study is a composite functional material, and the main composition ratio is aliphatic sulfonate polymer: polyoxyethylene ether derivative: hydroxyl aluminosilicate = 6:3:1. The mechanism of action includes: 1 Surface adsorption electrical modification: increasing the absolute value of Zeta potential of particles (from 18.6 mV to 32.4 mV) and enhancing electrostatic repulsion; 2 Wettability adjustment : reduce the contact angle between particles and water (from 78.3° to 45.6°) to prevent flocculation and agglomeration; hydration synergy: promote the formation of C-S-H gel and make the structure dense. The three together improve the rheology of the slurry and enhance the strength of the filling body ^[6-7].

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2.2 Test Raw Materials

2.2.1 Tailings

The tailings used in the test were taken from the underflow of the deep cone thickener (ultrafine tailings) and the grading workshop (graded tailings) in Fankou Lead-zinc Mine. The particle size of ultrafine tailings is mainly concentrated at $0.519\ \mu\text{m}$, accounting for 92.3 %, the specific surface area is $1286\ \text{cm}^2/\text{g}$, the content of SiO_2 is 68.7 %, and the content of Al_2O_3 is 12.3 %, which belongs to acidic tailings ($\text{pH} = 5.8$). The particle size range of graded tailings is $19150\ \mu\text{m}$, the specific surface area is $325\ \text{cm}^2/\text{g}$, the content of SiO_2 is 65.4 %, and the content of Al_2O_3 is 10.8 %.

2.2.2 Cementing Materials

P.O 42.5R Portland cement (Conch brand) and special rock-fixing adhesive for mining are selected. The 3d compressive strength of P.O 42.5R cement is 28.6 MPa, and the 28d compressive strength is 46.8 MPa. The solidified rock adhesive material is a composite cementitious material, which is composed of slag powder, fly ash and activator according to the mass ratio of 7:2:1. The 3d compressive strength is 22.3 MPa, and the 28d compressive strength is 38.5 MPa.

2.3 Test scheme Design

The 3 # stope in the 1220 middle section of Fankou Lead-zinc Mine was selected as the test area, and the filling amount was designed to be 5000 m³, including 1500 m³ of intermediate column filling, 2500 m³ of room filling and 1000 m³ of pouring surface filling. Industrial test parameters: pillar filling (full ultra-fine tailings, cement-sand ratio: 8, synergist dosage 1.35%, target concentration 63%); filling the room (ultra-fine tailings: graded tailings = 1: 1, cement-sand ratio 1: 10, synergist dosage 1.25 %, target concentration 73 %); filling the pouring surface (fully graded tailings, cement-sand ratio 1: 11, synergist dosage 0.65 %, target concentration 80 %). During the test, the slurry conveying pressure, flow rate and filling body forming quality were monitored in real time.



Figure 1 Tailings in the thickening process

3 Experimental Results and Discussion

3.1 The Improvement Effect of Slurry Working Performance

The effect of the new filling synergist on the working performance of different aggregate systems is shown in Table 1. It can be seen from the table that the synergist has a significant dispersion and drag reduction effect on the ultra-fine tailings filling system, and the improvement effect on the mixed tailings system is more prominent. For the fully ultra-fine tailings system (inter-column filling condition), when the content of synergist is 1.35 %, the slump expansion of slurry increases from 220 mm of the reference group (without synergist) to 245 mm, with an increase of 11.4 %, the bleeding rate decreases from 4.2 % to 1.8 %, and the initial setting time decreases from 280 min to 245 min. This is because the surface active components of the synergist are adsorbed on the surface of the ultrafine tailings particles, which enhances the electrostatic repulsion between the particles, destroys the spatial network structure formed by the particle agglomeration, and reduces the slurry yield stress (from 28.6 Pa to 18.3 Pa) and plastic viscosity (from 0.85 Pa·s to 0.52 Pa·s). In the mixed tailings system (room filling condition, ultrafine tailings : graded tailings = 1 : 1), when the dosage of the synergist is 1.25 %, the slump expansion of the slurry is increased from 250 mm of the reference group to 380 mm, the increase is 52.0 %, and the bleeding rate is 1.2 %. This is because the 'skeleton effect' produced by the classified tailings particles and the 'dispersion effect' of the synergist play a synergistic role. The classified tailings provide a channel for the slurry flow. The synergist can effectively disperse the ultrafine tailings particles, so that they cannot enter the channel to block the channel, thereby greatly reducing the rheological resistance of the slurry.

Table 1 Effect of synergist on working performance of slurry

Aggregate system	Synergist dosage/%	concentration/%	collapse expansion decrease/mm	hoist scope/%	bleeding rate/%	initial setting time/min	yield stress/Pa	plastic viscosity/(Pa·s)
Full ultra-fine tailings	0(Baseline group)	60	220	-	4.2	280	28.6	0.85
	1.35	63	245	11.4	1.8	245	18.3	0.52
Mixed tailings(1:1)	0(Baseline group)	70	250	-	3.5	260	22.5	0.72
	1.25	73	380	52.0	1.2	230	12.8	0.41
Fully graded tailings	0(Baseline group)	75	320	-	2.8	240	18.7	0.65
	0.65	80	350	9.4	0.9	210	10.5	0.38

3.2 Collaborative Optimization of Filling Concentration and Mechanical Properties

The synergistic enhancement of filling concentration and backfill strength is fundamental to overcoming the inherent trade-offs in traditional backfilling processes. By incorporating the functional synergist, the compressive strength of the backfill improves in direct correlation with the increase in slurry concentration. This advancement effectively addresses a critical technical bottleneck: the conventional conflict where increasing concentration typically compromises fluidity, which subsequently leads to a reduction in structural strength.



Figure 2 Indoor confirmation test block bleeding

In the three filling conditions, the addition of synergists significantly improves the strength of the filling body. Inter-column filling (full ultrafine tailings): When the water-cement ratio increases from 60 % to 63%, the compressive strength of 7d and 28d increases by 17.2% and 20.6 %, respectively, and the structure is denser due to particle dispersion. Room filling (mixed tailings): the concentration increased from 70% to 73%, the strength of 7d and 28d increased by 131.1% and 115.1% respectively, and the porosity decreased from 28.3% to 15.6%, forming a dense network structure. Pouring surface filling (fully graded tailings): the concentration increased from 75% to 80%, and the 28d strength increased by 67.3%, which met the high strength requirements. Synergists generally optimize microstructure and mechanical properties by reducing free water and promoting hydration reaction.

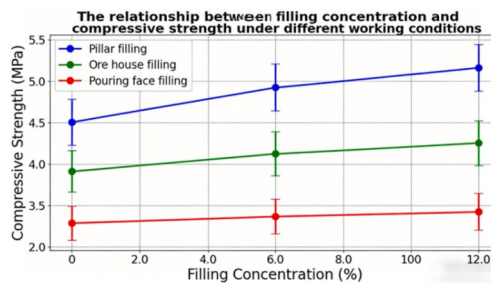


Figure 3 Effect of synergist on working performance of slurry

3.3 The Increase of Ultra-Fine Tailings Content and Resource Utilization

Increasing the content of ultra-fine tailings is the core goal of realizing tailings resource utilization. Under the condition of indoor filling, the influence of ultra-fine tailings content on slurry performance and backfill strength is as follows. Under the action of synergist, when the content of ultrafine tailings is increased from 50 % to 55 %, the slump expansion of slurry is still above 360 mm, and the bleeding rate is less than 1.5 %, which meets the transportation requirements ; the 3d early compressive strength increased from 5.2 MPa to 7.4 MPa, an increase of 42.3 %. The 7d compressive strength increased from 8.5 MPa to 12.8 MPa, an increase of 50.6 %. The 28 d compressive strength increased from 12.3 MPa to 18.5 MPa, an increase of 50.4 %. When the content of ultra-fine tailings is further increased to 60 %, the slump expansion of the slurry is reduced to 310 mm, which still meets the pumping requirements (≥ 300 mm). The compressive strength of 3d, 7d and 28d is 6.8 MPa, 10.5 MPa and 15.2 MPa, respectively, which is 30.8 %, 23.5 % and 23.6 % higher than that of the 50 % dosage benchmark group. The results show that the synergist effectively neutralizes the risk of agglomeration caused by the increase of ultrafine tailings content. Through the micro-dispersion effect, the ultrafine particles give full play to the 'filling effect' and optimize the particle gradation of the filling body, thereby improving the strength.



Figure 4 The process of indoor confirmation test measurement

According to the Fankou lead-zinc mine filling volume of 100,000 m³ calculation, ultra-fine tailings content increased from 50 % to 55 %, the annual consumption of ultra-fine tailings about 25,000 tons ; if the dosage is increased to 60 %, about 50,000 tons of ultra-fine tailings will be consumed annually, which will significantly reduce the stock of tailings.

4 Comprehensive Efficiency and Industrial Application Prospect

4.1 The Achievement Degree of Technical Indicators

Through experimental verification, the application of the new filling synergist has fully achieved the preset technical goals: (1) The filling concentration is effectively improved, and the filling concentration of the pillar, the room and the pouring surface reaches 63.5 %, 73.8 % and 80.2 % respectively; (2) The yield stress and plastic viscosity of the slurry are reduced by more than 40 % and 38 % on average, and the conveying resistance is significantly reduced. (3) The compressive strength of the filling body at 3d, 7d and 28 d increased by more than 30 %, 55 % and 45 % on average; (4) The comprehensive utilization rate of ultra-fine tailings increased to 60.8 %, an increase of 15.8 %, far exceeding the project target of 6%.

4.2 Economic Benefit Evaluation

The calculation of large-scale economic benefits shows that(based on the filling scale of 100,000 m³ / year in Fankou Lead-zinc Mine): (1)Cementitious material saving : 16,000 tons of P.O 42.5R cement are saved every year, calculated at 450 yuan / ton, and the cost is saved by 7.2 million yuan; (2)Tailings disposal cost reduction : annual consumption of ultra-fine tailings 60,000 tons, reduce tailings disposal costs(calculated at 20 yuan / ton)1.2 million yuan; (3)Energy consumption and wastewater treatment saving : reducing the amount of water transported by 15,000 m³ per year, saving the energy consumption of pumping stations and the cost of wastewater treatment by about 600,000 yuan; (4)Comprehensive cost savings : the total annual cost savings of about 9 million yuan, the return on investment of 180%.

5 Conclusion

Increase the resource utilization of ultrafine tailings. Under the condition of meeting the slurry performance and filling body strength index, the ultra-fine tailings content is increased from 50 % to 60 %, the comprehensive utilization rate is increased by 15.8 %, the annual consumption of ultra-fine tailings is increased by 60,000 tons, and the tailings discharge is further reduced, which provides a feasible method for tailings reduction. Economic and environmental benefits are significant: the application of the synergist, the cost of filling body composite materials can be reduced by more than 5 % (11 yuan / m³), annual cost savings of 9 million ; the environmental safety of the synergist is reliable, and the concentration of heavy metal ions in the leaching solution is much lower than the national standard, supporting the green and sustainable development of the mine. This study integrates material innovation and engineering practice, and proposes an efficient filling technology scheme for ultra-fine tailings, which promotes the resource utilization of mine tailings and the construction of green mines. In the future, it is necessary to optimize the synergist formula, carry out suitability research on different tailings properties such as iron tailings and copper tailings, and further optimize the filling process parameters in combination with numerical simulation.

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