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Co-disposal of waste rock with unclassified tailings as cemented paste backfill at Jinchuan Nickel Mine

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Abstract

Jinchuan Nickel Mine (JNM) is the first mine to adopt cemented paste backfill (CPB) in China. It has a mechanised downward backfilling mining method with the world's largest continuous stoping area. There are three mining areas at JNM. The second mining area of JNM has experienced three generations of CPB systems, the biggest difference among which is dewatering equipment. This paper mainly introduces the third-generation CPB system, which was established in 2021. Through this system, the waste rock and unclassified tailings are co-disposed. To achieve a stable paste concentration and desirable strength of CPB body, a deep cone thickener (DCT) is applied and waste rock is used as coarse aggregates. The DCT with a diameter of 16 m can achieve a capacity of 104 t/h and an underflow concentration of 60% solids concentration by mass (wt%). A two-stage, double-shaft, horizontal mixer with a capacity of 100–120 m³/h is used to mix the thickened tailings, waste rock, and cement homogeneously to prepare the paste, and then the paste is transported to the underground stope by a piston-type positive displacement pump. The paste concentration is 77–79 wt%, the cement dosage is 25 wt%, and the tailings–waste rock ratio is 4:6. As a result, the paste is non-stratification, non-segregation, and non-bleeding. The slump is more than 23 cm. The uniaxial compressive strengths of the CPB body after curing for seven days and 28 days are more than 3 MPa and 5 MPa, respectively. The third-generation CPB system contributes greatly to the mechanised downward backfilling mining method at JNM.

Keywords*: cemented paste backfill, co-disposal, waste rock, unclassified tailings, deep cone thickener*

1 Introduction

Jinchuan Nickel Mine (JNM) is located in Jinchang City, Gansu Province, China. The orebody is distributed within an area 6.5 km long and 500 m wide at the foot of Longshou Mountain. It is the world's third-largest nickel-copper sulphide deposit. With a history of more than six decades, it has established an annual capacity of producing 200,000 t of nickel, 1 million t of copper, and 15,000 t of cobalt.

JNM is the first mine to adopt cemented paste backfill (CPB) in China. It uses a mechanised downward backfilling mining method with the world's largest continuous stoping area, which is more than 100,000 m^2 (Yang. 2017). There are three mining areas at JNM: the Longshou mining area, the second mining area, and the third mining area. Currently, there are 16 backfill systems at JNM and six backfill systems at the second mining area. The capacity of each backfill system is 100–150 m^3/h and the total annual backfill capacity at

JNM is about 4 million m^3. This paper mainly focuses on the backfill system, especially the CPB system at the second mining area.

The second mining area has experienced three generations of CPB systems, the biggest difference among which is the dewatering equipment. In 1987, CPB pilot-scale tests using classified and rod-mill tailings were carried out successfully. Thereafter, first-generation CPB system comprising a vacuum belt filter, active mix, and a two-stage pump station underground was built in 1999. However, discontinuous tailings feeding and cement transport blockages seriously decreased the CPB system's stability and reliability. In 2009, the second generation CPB, comprising a vertical tailings tank thickener to replace the belt filter, was introduced and the pipeline transport system of cement slurry was cancelled. Because of the complex pipe distribution layout and unstable underflow concentration, the system was out of service in 2014. Three years later, the University of Science and Technology Beijing and JNM launched research on the co-disposal of waste rock with unclassified tailings. In 2021, the third-generation CPB system was established.

2 Materials and experimental study for third-generation system

2.1 Materials

The materials in the third-generation CPB system include waste rock, unclassified tailings, and cement.

2.1.1 Waste rock

The waste rock comes from underground tunnelling and is crushed to less than 16 mm. The specific gravity of the waste rock was 2.69 and the particle size distribution (PSD) meets the requirements in Table 1.

Table 1 Particle size distribution requirement of waste rock

Particle size/millimetre	The upper limit of cumulative distribution/wt%	The lower limit of cumulative distribution/wt%
16.00	>98.0	>98.0
9.50	60.0	45.0
4.75	35.0	20.0
2.36	15.0	10.0
0.30	12.0	1.0
0.15	8.5	0.5
0.075	5.0	0

2.1.2 Unclassified tailings

The unclassified tailings with a specific gravity of 2.785 comes from the mineral processing plant. The PSD is shown in Figure 1. The content of particles below 20 and 74 µm are 55 and 88 wt%, respectively.

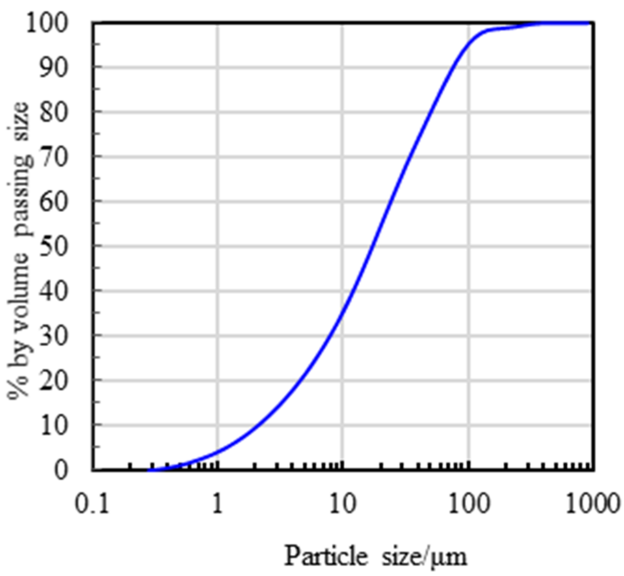

Figure 1 Particle size distribution of the unclassified tailings

2.1.3 Cement

The cement used is Portland fly ash cement, which has been successfully applied at JNM.

2.2 Flocculation and sedimentation characteristics of unclassified tailings

A cylinder and a pilot-scale deep cone thickener (DCT) were used to conduct the flocculation and sedimentation experiments.

According to the cylinder settling experiments, the optimal diluted feeding concentration and flocculant dosage were 10 wt% and 25 g/t, respectively (Wu et al. 2020). Under such conditions, the maximum static sedimentation concentration was 46.6 wt%.

As shown in Figure 2a, the pilot-scale DCT has a diameter of 1 m and a height of 6 m. The experiment conditions were:

- Feed concentration of 20 wt% (before dilution).
- Flocculant dosage of 25 g/t.
- Flocculant concentration of 0.1 wt%.
- Feed rate of 5 m^3/h.
- Rotation rate of the rake 1 rpm.

As shown in Figure 2c, the underflow concentration reached 63.9 wt% after eight hours, which was more than 17 percentage points higher than the maximum static sedimentation concentration. At the same time, the turbidity of the overflow was lower than 100 ppm, as shown in Figure 2b.

Figure 2 Flocculation and sedimentation experiment. (a) Pilot-scale deep cone thickener; (b) Overflow; (c) Underflow

2.3 Slump and uniaxial compressive strength of cemented paste backfill

To control the broken expanded rock under high ground stress, a cemented undercut-and-fill mining method was adopted at JNM. The required strength of the fill is higher than most underground mines worldwide, being three day, seven day, and 28 day uniaxial compressive strength (UCS) of ≥ 1.5 MPa, ≥ 2.5 MPa, and ≥ 5.0 MPa, respectively (Yang 2017). The cement dosage is 310 kg/m^3, representing approximately 25% of the total mass of tailings and waste rock. The tailings–waste rock mass ratio is 4:6.

When the paste concentration is 77–79 wt%, the cement dosage is 25 wt%, and the tailings–waste rock ratio is 4:6, the slump and UCS of the fill are shown in Figure 3. The three day UCS, seven day UCS, and 28 day UCS is in the range of 2.71–3.10 MPa, 3.72–4.05 MPa, and 5.72–7.18 MPa, respectively. The slump decreases from 25.0 to 23.1 cm, with the solids concentration increasing from 77 to 79%. Therefore, the recommended mix proportion of CPB is satisfactory.

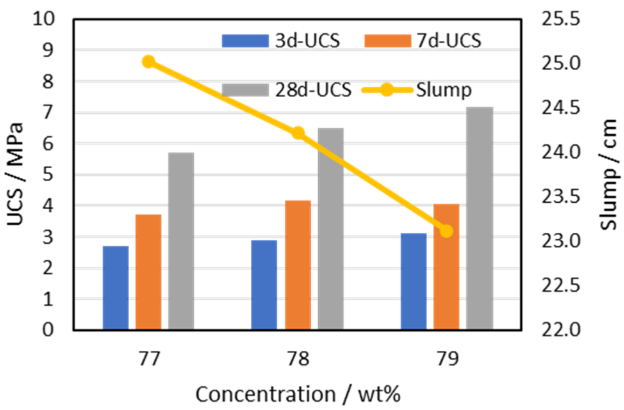

Figure 3 The uniaxial compressive strength (UCS) and slump of the cemented paste backfill under different recommended concentrations

3 Co-disposal cemented paste backfill system

The co-disposal CPB system includes a DCT, two double-shaft horizontal mixers, and a piston-type positive displacement pump. The sketch of the system is shown in Figure 4. The capacity is 100–120 m^3/h with a paste concentration of 77–79 wt%.

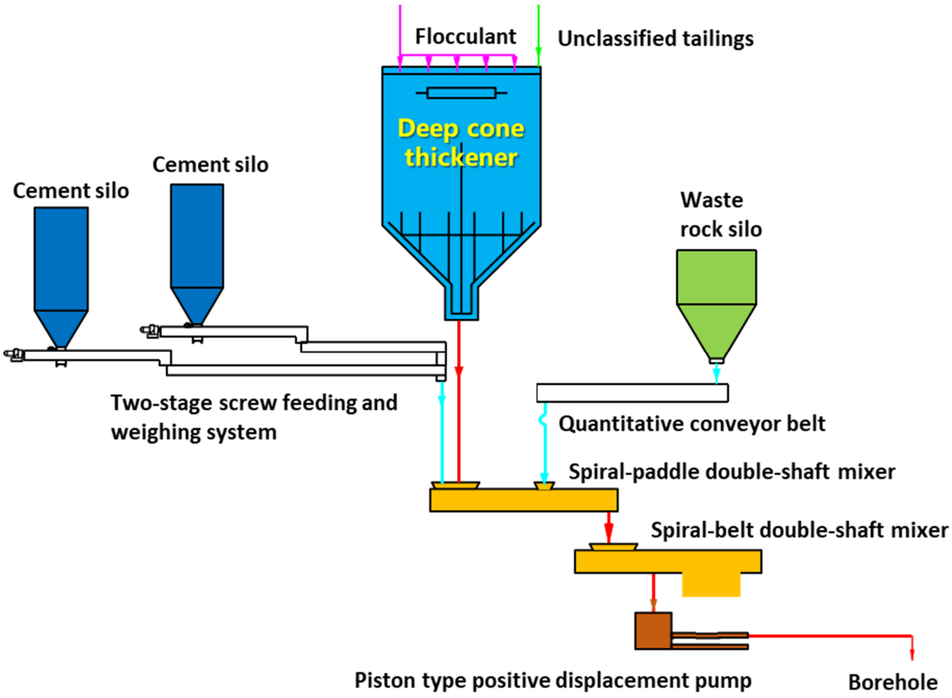

Figure 4 Co-disposal cemented paste backfill system

3.1 Thickening subsystem

The thickening subsystem comprises a 16 m diameter DCT from FENY, a flocculant preparation and dosing system, and other auxiliary equipment. The nominal volume of the DCT is 2720 m^3, and the rotation rate of the rake in the DCT is 0.199 rpm. The capacity of the DCT is 104 t dry tailings/hour. The underflow concentration of the DCT is 55–60 wt%, and the overflow turbidity is below 200 ppm, as shown in Figure 5.

Figure 5 The overflow of the deep cone thickener

3.2 Mixing subsystem

The mixing subsystem comprises a two-stage, double-shaft, horizontal mixer (as shown in Figure 6a) from FENY, two cement silos, a waste rock silo, two two-stage screw feeding and weighing systems for adding cement, and a weighing belt conveyor (as shown in Figure 6b) for adding waste rock. The first-stage mixer is a spiral-paddle, double-shaft mixer, and the second-stage mixer is a spiral-belt double-shaft mixer. The volume and capacity for each mixer are 6 m^3 and 100–120 m^3/h, respectively.

Figure 6 Mixing subsystem. (a) Two-stage double-shaft horizontal mixers; (b) Weighing belt conveyor

3.3 Pipeline and delivery subsystem

The pipeline and delivery subsystem includes a pipeline reticulation subsystem and a piston-type positive displacement pump. The reticulation subsystem is shown in Figure 7. This illustrates the CPB mainly delivers to the stope at level 1038 and level 934 through the pipeline. For the reticulation to level 1038, the pipeline length is 2,305 m, of which the vertical height difference is about 642 m. For the reticulation to level 934, the pipeline length is 2,559 m, of which the vertical height difference is about 746 m.

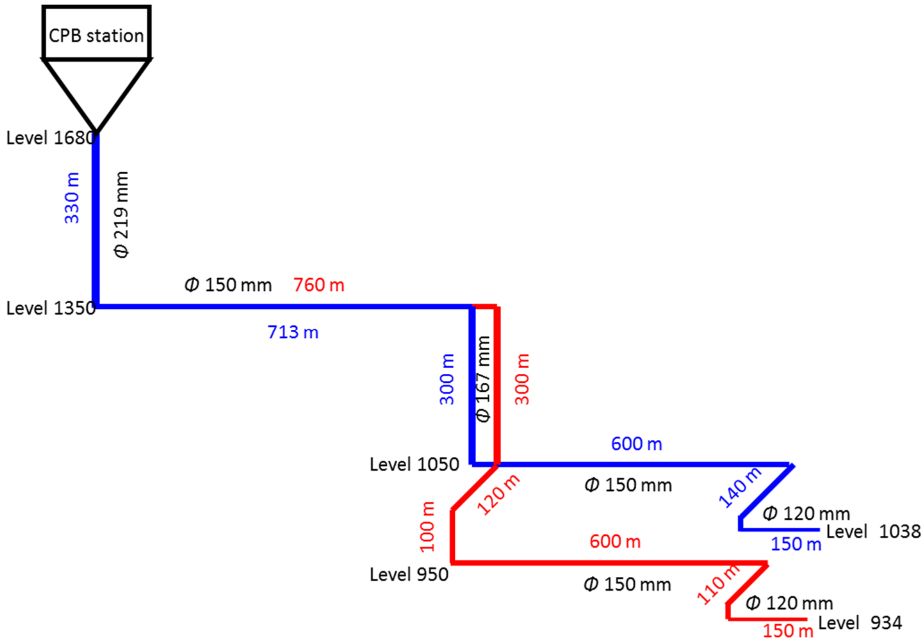

Figure 7 Reticulation subsystem for cemented paste backfill

The boreholes in the reticulation subsystem were drilled for the high-concentration backfill before the CPB system was established. To save construction costs, they were adopted in the new CPB system. The inner diameter of the borehole from level 1680 to 1350 is 219 mm, while that from level 1350 to 1050 and from level 1050 to 950 is 167 mm. According to the capacity of 100–120 m^3/h, the inner diameter of the other main pipelines is 150 mm, resulting in a flow velocity of 1.57–1.89 m/s. At the same time, the inner diameter of the pipeline in the stope is 120 mm. Figure 8b illustrates the main horizontal pipeline.

Based on the Buckingham rheological equation, the total friction loss for the stope at level 1038 is 18.55 MPa. The safety factor is set as 1.2, increasing maximum friction losses to 22.26 MPa. The outlet pressure is set as 0.5 MPa, and the gravity pressure due to the vertical height difference is 12.46 MPa. Accordingly, pumping is required since the static head is insufficient. An S-valve piston-type positive displacement pump from FENY was selected, as shown in Figure 8a. The nominal pressure and capacity of the pump are 12 MPa and 120 m^3/h, respectively.

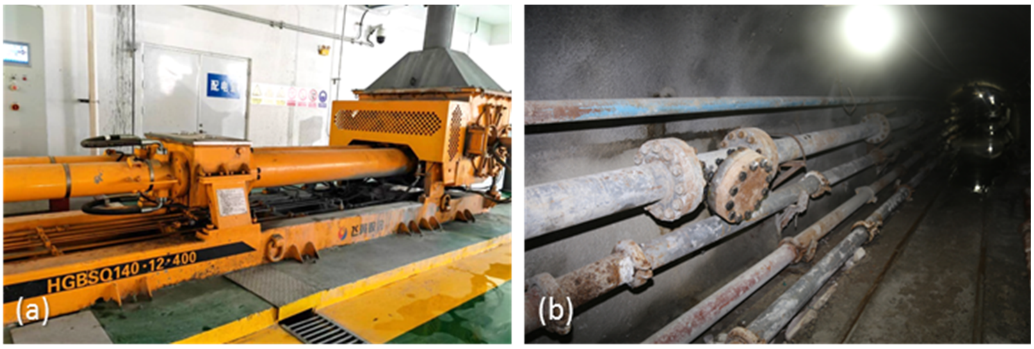

Figure 8 Pipeline and delivery subsystem. (a) Piston-type positive displacement pump; (b) Backfill pipeline

3.4 Automatic control subsystem

An automatic control subsystem was established to ensure system stability, as shown in Figure 9. To measure the paste concentration, an Ecophyspribor Na-22 densitometer was used, as shown in Figure 9b. The densitometer is environmentally friendly and more accurate than an ultrasonic densitometer for paste. At the same time, an underflow circulation unit was installed in the DCT to prevent rake blockage. Since pipeline blockage and leakage occurred in the previous backfill systems, several pressure sensors were installed on the main horizontal pipelines to avoid pipeline blockage and leakage, as illustrated in Figure 9c.

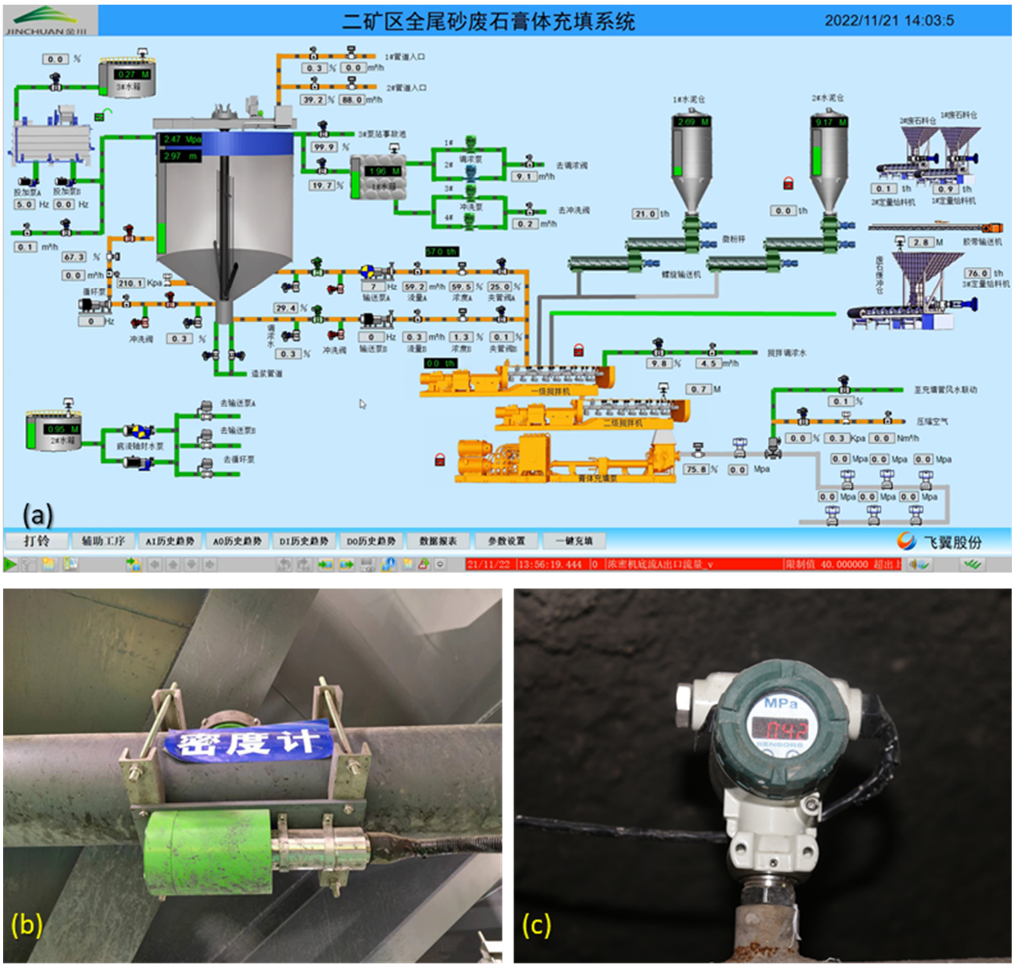

Figure 9 Automatic control subsystem. (a) Control and operator interface; (b) Densitometer; (c) Pressure sensor

4 Construction achievements

A stable paste concentration and desirable strength of the CPB body have been achieved. The paste concentration is controlled in the range of 77–79 wt%. The slump is more than 23 cm. The UCS of the CPB mass after 28 days is more than 5 MPa. As shown in Figure 10a, the paste is non-stratification, non-segregation, and non-bleeding (Wu et al. 2022).

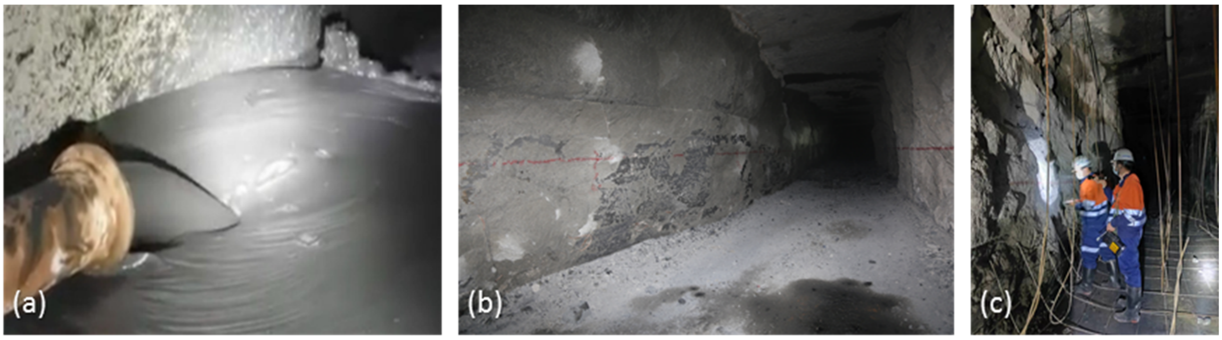

Figure 10 (a) Paste in the stope; (b) CPB body; (c) Field strength inspection

5 Conclusion

A co-disposal CPB system comprising waste rock, unclassified tailings and cement was established at JNM. The characteristics of the criteria system are as follows:

- The capacity of CPB is 100–120 m^3/h with a paste concentration of 77–79 wt%. The slump is more than 23 cm. The UCS of the CPB body after 28 days is more than 5 MPa.
- A 16 m diameter DCT with a capacity of 104 t dry tailings/h was installed. The underflow concentration is 55–60 wt%.
- A two-stage, double-shaft, horizontal mixer was used to mix thickened tailings, waste rock, and cement. The tailings–waste rock mass ratio is 4:6. The cement dosage is 25 wt%.
- An S-valve piston-type positive displacement pump with a nominal pressure of 12 MPa is used for paste delivery.
- An automatic control subsystem is deployed to ensure system stability.

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