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Study on the strength property and ratio parameter selection of waste rock cemented backfill

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ABSTRACT: When tailings are used for cemented backfill preparation, the extremely fine unclassified tailings may lead to slow consolidation and low strength of backfill material. Wasted rock as an additional filling aggregated was suggested to optimize the gradation composition of aggregate by scholars over the world. In this paper, the effect of waste rock addition, cement-tailing ratio and slurry concentration on strength and flow properties of waste rock cemented backfill were studied. The results indicate the strength of waste rock cemented backfill was significantly higher than that of unclassified tailings cemented backfill under same cement consumption, which the average strength improvements were 2.02MPa, 0.98MPa and 0.46MPa under cement-tailing ratio of 1:4, 1:8 and 1:10. With the increase of waste rock addition, the strength change of waste rock cemented backfill was less obvious, but the flow property (yield stress) of filling slurry was improved. Further analysis of the slurry stability illustrates that, with the increase of waste rock addition, the bleeding rate demonstrated a trend similar to that observed for the flow property, however, in an adverse manner. Overall, the optimal slurry concentration of 80% and waste rock addition of 40%～50% were determined. Based on the strength requirement, cement dosage was selected, which the cement-tailing ratio of top 10m and the bottom 10m was 1:8, the cement-tailing ratio of the centre stope was 1:10. The research findings can provide a reference for the ratio parameter determination of extremely fine unclassified tailings backfill of similar mines.

KEYWORDS: Waste rock cemented backfill, Strength property, Ratio parameter selection, Coupling analysis.

1 INTRODUCTION

Cemented backfill methods has been increasingly used to fill the mined cavities in underground mine operations compare to other mining methods, with associated economic and environmental advantages, such as higher recovery rate, lower dilution rate, controlled ground pressure by providing underground support systems and mitigation of potential environmental impacts by reducing surface-disposed tailings emissions. (Klein and Simon, 2006; Abdul and Fall, 2012). With the improvement of mineral processing technology, the particle size of unclassified tailings was even finer, which made the sedimentation and concentration of tailings more difficult (Chen *et al.*, 2019; Fu *et al.*, 2014). When extremely fine unclassified tailings were used as a single aggregate of cemented backfill, its mechanical properties were often greatly affected by the particle gradation. Hence the strength of cemented backfill may not meet the mining requirements. In order to increase the backfill strength, the gradation composition of aggregate can be improved by adding waste rock (He *et al.*, 2013; Hassani *et al.*, 2008; Hassani *et al.*, 2007).

The waste rock filling technology not only reuses waste rock on the ground hence protect the environment but also improve the strength and stiffness of backfill and reduce mining costs. In this context, several studies have examined the slurry flowability and backfill strength of waste rock cemented backfill by various domestic and foreign scholars. Han et al., reported a case study in Jinfeng Gold Mine for strength and fluidity indices, which indicated that when the slurry concentration was 75%, and cement dosage was 12%～20%, the requirements of gravity transportation of slurry can be fulfilled. To fulfill gravity pumping requirements, the cement backfill slurry concentration and cement dosage should be 75% and 12%～20% respectively. In order to improve the strength of unclassified tailings cemented backfill, an experiment using crushed waste rock in the Jingying Gold Mine, with waste rock particle of 5mm, slurry concentration of 75% and cement dosage of 11% were conducted (Han *et al.*, 2012). The laboratory results showed the addition of waste rock could significantly increase the backfill strength, and the optimal slurry concentration of 65%～70% and waste rock addition of 50% were selected. (Deng *et al.*, 2017; Cheng, 2016).

In Jinchanghe polymetallic mine, which located on the plateau, while the fine unclassified tailings were used as the filling aggregate, the cement consumption was extremely high. In order to reduce the filling cost, the waste rock was considered as a coarse aggregate for filling, which could not only eliminate the ground storage of waste rock in the mine but also reduce the risk of safety and environmental. As thus, this paper aimed to detect the appropriate ratio parameter of waste rock cemented backfill by analyzing the effect of waste rock addition, cement-tailing ratio and slurry concentration on the backfill strength and flow property.

2 BACKFILL MATERIALS

2.1 Unclassified tailings

The unclassified tailings were sourced from the discharge outlet of the tailings pond when the dressing plant kept running normally. The CILAS 1064 Laser Particle Size Analyzer was employed to measure the particle size distribution of unclassified tailings, as shown in Figure 1. The tailings particle of 200 mesh (≤0.074mm) and 400 mesh (≤0.038mm) were 83.70% and 65.94% respectively. Compared with similar mines in China, the particle size of unclassified tailings was even finer.

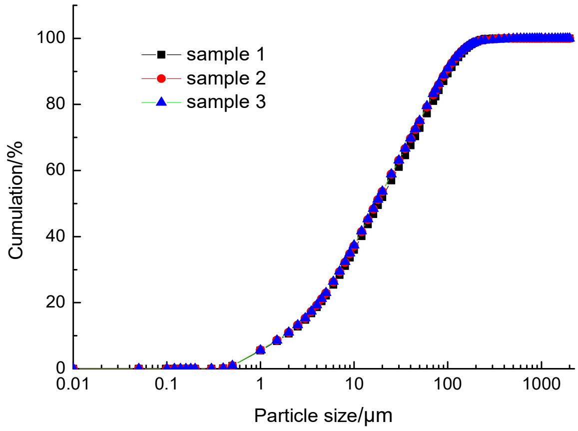


Figure 1. Particle size distribution of unclassified tailings

The physical properties and chemical composition of unclassified tailings were shown in Table 1 and Table 2, respectively.

Table 1. The physical properties of unclassified tailings

Moisture content/%	Specific gravity	Density/ (g/cm^3)	Porosity /%
0.52	3.20	1.14	64.54

Table 2. The chemical composition of unclassified tailings

Element	Ca	Si	Al	Mg	Fe
Concent/%	15.59	16.34	0.94	1.49	17.72
Element	P	K	Na	S	LOI
Concent/%	0.024	0.31	0.18	0.2	10.53

2.2 Waste rock

Waste rock from underground excavation and surface storage, were aimed to crushe into 5mm particles. The actual particle size distribution of crushed waste rock was shown in Figure 2. The physical properties of waste rock were shown in Table 3.

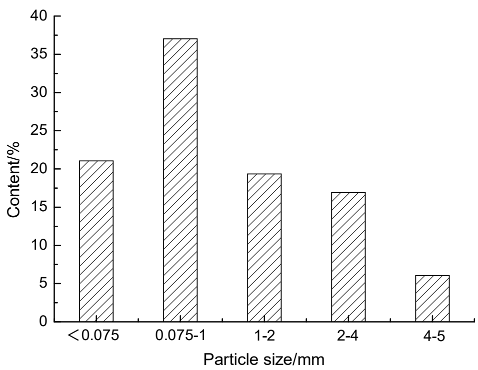


Figure 2. Particle size distribution of waste rock

Table 3. The physical properties of waste rock

Water absorption/%	Mud content/%	Density/ (g/cm^3)	Porosity /%
1.03	0.77	1.74	49.20

3 TEST SCHEME

3.1 Test design of unclassified tailings cemented backfill

According to the main factors influencing the backfill strength and slurry flowability, 12 groups of mix designs consisting of four cement-tailing ratios (1: 4, 1: 6, 1: 8, and 1: 10) and three slurry concentrations (68%, 70% and 72%.) were examined.

3.2 Test design of waste rock cemented backfill

As the particle size of waste rock was much larger than that of the unclassified tailings, the specific surface area of the solid particles in the filling slurry after adding waste rock was greatly reduced, and the water required to reach a better flowing state was also drastically reduced. Based on the relevant research results, the test scheme of waste rock cemented backfill was designed as follows: the slurry concentrations were 76%, 78% and 80% respectively; the cement-tailing ratios were 1:4, 1:8, 1:10 and 1:15 respectively; the waste rock additions were 30%, 40%, 50% and 60% respectively.

4 TEST RESULTS AND ANALYSIS

4.1 Test results

In the backfill tests, the blocks were placed in a curing chamber for 28d age. The temperature was controlled at (23 ± 3) ℃ and relative humidity was controlled in 96% (to simulate humidity and temperature of underground stopes). To ensure sufficient accuracy, three samples were tested for each block and the mean value was taken as the strength value for the test blocks. The strength results of unclassified cemented backfill and waste rock cemented backfill were shown in Table 4 and Table 5, respectively.

Table 4. The strength of unclassified tailings cemented backfill/MPa

Slurry concentrations	Cement-tailing ratio			
	1:4	1:6	1:8	1:10
68%	2.17	1.20	0.86	0.67
70%	2.52	1.36	0.91	0.77
72%	3.31	1.93	1.28	0.98

Table 5. The strength of waste rock cemented backfill/MPa

Slurry concentration	Cement-tailing ratio	Waste rock addition			
		30%	40%	50%	60%
76%	1:4	3.64	4.30	3.57	3.54
	1:8	1.39	1.79	1.79	1.57
	1:10	0.97	1.26	1.18	0.81
	1:15	0.48	0.86	0.73	0.82
78%	1:4	4.59	5.60	5.34	5.14
	1:8	1.88	2.46	2.27	2.16
	1:10	1.19	1.41	1.51	1.37
	1:15	0.88	0.98	0.95	0.91
80%	1:4	6.76	7.28	7.01	7.18
	1:8	2.27	3.30	3.08	3.16
	1:10	1.76	1.93	2.01	1.83
	1:15	0.99	1.13	1.14	1.15

4.2 Strength analysis

As shown in Figure 3, the strength of waste rock cemented backfill was significantly higher than that of unclassified tailings cemented backfill under the same cement consumption. The strength improvement between the waste rock cemented backfill and unclassified tailings cemented backfill with a cement-tailing ratio of 1:4 was 0.45MPa~3.75MPa, average of 2.02MPa; the strength improvement with a cement-tailing ratio of 1:8 was 0.36MPa~1.67MPa, average 0.98MPa; the strength improvement with a cement-tailing ratio of 1:10 was 0.08MPa~0.90MPa, average 0.46MPa. In general, the use of waste rock in cemented backfill improved the strengths performance of cured blocks, therefor reduced the cement consumption and filling cost during underground ore extraction. In terms of strength improvement between the waste rock cemented backfill and unclassified tailings cemented backfill, the higher the cement-tailing ratio, the greater the strength improvement (Helinski et al., 2007).

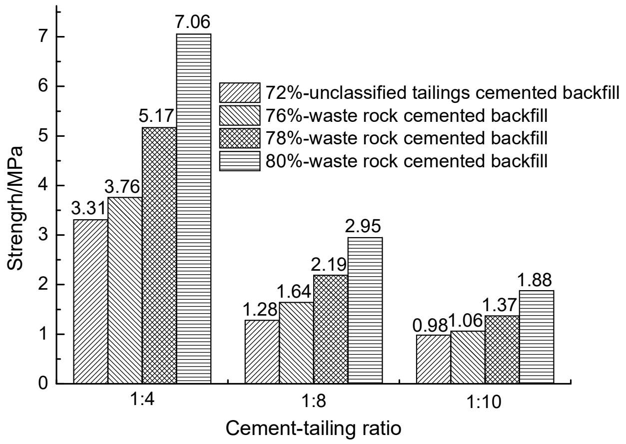
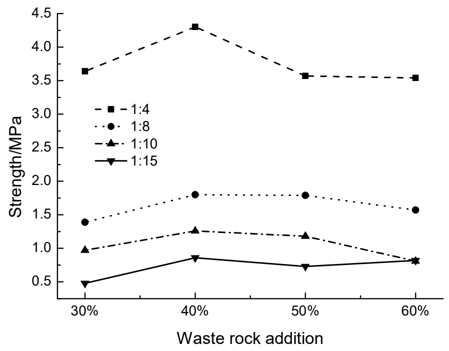


Figure 3. Strength comparison of same cement consumption

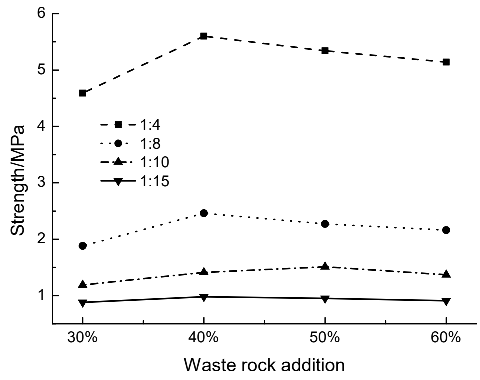
Figure 4 illustrates the variations of backfill strength against waste rock addition for various cement and slurry content.

For the samples contain 76%～78% slurry concentration, the strength of waste rock cemented backfill initially increased with the addition of waste rock and reached peak strength at 40% waste rock addition, then decreased slowly for more waste rock addition. The strength analysis showed that with the increase of the waste rock aggregate, the particle gradation of filling aggregate was optimized. However, with further addition of waste rock aggregate, the compactness of the cemented backfill reduced, which lead to the decrease of backfill strength.

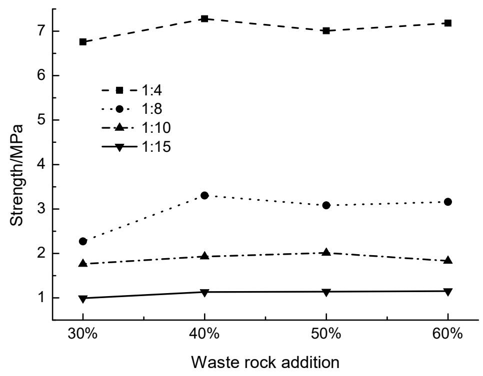
For the samples contain 80% slurry concentration, the strength of waste rock cemented backfill did not show significant change with the rise of waste rock addition as no visible segregation effect occurred in the filling slurry. Therefore, the fluidity performance of the filling slurry was changed more by the addition of waste rock aggregate.



(a) 76%



(b) 78%



(c) 80%

Figure 4. The strength curve of waste rock cemented backfill with different slurry concentration

5 RATIO PARAMETER SELECTION

5.1 Strength requirement

Jinchanghe polymetallic mine used high stage delayed cemented filling method for its mine excavation, where the ore body was separated into rooms and pillars. The stope was arranged vertically to the orebody and each level was 50m in height; the stope pillar width was 18m and the length was the horizontal thickness of the orebody (100m on average).

Due to the different mining conditions and filling materials, different mines selected different cement-tailing ratios, ranging from 1:4~1:15. The backfill strength ranged from 0.63~3.94MPa for tailings cement backfill to 4.0~7.0MPa for waste rock cement backfill. These strengths could meet the sufficient lateral areas of adjacent pillars, with the exposure areas from 3000m^2~6000m^2, the exposure heights from 50m~100m. With the current cement dosage for cement backfill, the cured backfill result in good stability and no collapse has taken place.

The stress state of cemented backfill was governed by many factors, e.g. the physical and mechanical parameters of the backfill itself, its geometrical shape, the interaction between the backfill and the surrounding walls, and stoping operations. Considering the influences of partial stress transfer and blasting in the surrounding environment, the first-step strength requirement in different segments of 1500m stage was shown in Figure 5. According to the strength results in Table 4, one mix-proportion of waste rock cement backfill was adopted and listed below: the cement-tailing ratio of top 10m and the bottom 10m in the stope was 1:8, and the slurry concentrations were 78%～80%; the cement-tailing ratio of centre stope was 1:10, and the slurry concentration was 80%.

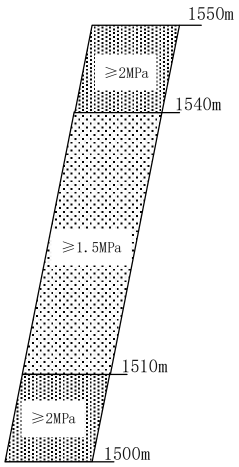


Figure 5. The first-step strength requirement of cemented backfill

5.2 Flow property

The RST-SST Rheometer was employed to measure the flow property of filling slurry. For high concentration filling slurry, the Bingham model is one of the most common models, and its expression is given below:

$$\tau=\tau_0+\eta_p\gamma \quad , \tag{1}$$

where τ_0 was the yield stress(Pa), η_p was viscosity coefficient(Pa•s).

The rheological curves of each group of waste rock filling slurry were tested by rheometer, and the rheological parameters were regressed by the Bingham model. The yield stress and viscosity coefficient were shown in Table 6 and Table 7, respectively. At the same cement-tailing ratio and slurry concentration, the yield stress and viscosity coefficient decreased quickly with the increase of waste rock addition; At the cement-tailing ratio of 1:8, the yield stress and the viscosity coefficient increased rapidly with the rise of slurry concentration from 78% to 80%; At the slurry concentration of 80%, the yield stress and viscosity coefficient decreased slowly with the reduction of cement-tailing ratio from 1: 8 to 1:10. The yield stress range of paste backfill was 50Pa～200Pa, at the slurry concentration of 78%, cement-tailing ratio of 1:8, when waste rock addition below 50% the yield stress of slurry meets the requirement.

Table 6. The yield stress of waste rock filling slurry/Pa

Slurry concentration	Cement-tailing ratio	Waste rock addition			
		30%	40%	50%	60%
78%	1:8	126.2	83.6	37.7	27.3
80%	1:8	171.6	147.8	92.9	74.5
	1:10	162.6	139.9	86.3	52.8

Table 7. The viscosity coefficient of waste rock filling slurry/(Pa•s).

Slurry concentration	Cement-tailing ratio	Waste rock addition			
		30%	40%	50%	60%
78%	1:8	0.54	0.63	0.45	0.34
80%	1:8	1.44	0.95	0.76	0.71
	1:10	1.38	0.82	0.72	0.56

5.3 Bleeding property

The bleeding property was an essential factor affecting the slurry stability during the pumping process. In the process of preparing the waste rock filling slurry, the bleeding rate was a characteristic index of the slurry stability. The bleeding rates of each group of waste rock filling slurry were determined and shown in Table 8. The bleeding rate of filling slurry increased rapidly with the rise of waste rock addition. Under the slurry concentration of 78%, cement-tailing ratio of 1:8 and waste rock addition of 60%, the bleeding rate of filling slurry was 4.22%, and the slurry was segregated, which didn't meet the transportation requirement. When the slurry concentration was 80% and cement-tailing ratio was 1:8, the bleeding rates of different waste rock addition were lower than the bleeding rates measure from other two groups, which proved that the waste rock filling slurries of slurry concentration 80% and cement-tailing ratio 1:8 had better stability than other two groups.

Figures 6 illustrate the coupled analysis of bleeding rate and yield stress against waste rock addition for cement backfill under the slurry concentration of 80%, cement-tailing ratio of 1:8. The bleeding rate demonstrated a trend similar to that observed for the yield stress, however, in an adverse manner. However, the potential of causing pipe plugging will increase when either of the bleeding rate and yield stress of waste rock filling slurry increased. In order to ensure the stability of filling slurry in the transportation process, the selected range of waste rock addition was 40%～50% to keep both bleeding rate and yield rate in a relatively low level.

Table 8. The bleeding ratio of waste rock filling slurry/%

Slurry concentration	Cement-tailing ratio	Waste rock addition			
		30%	40%	50%	60%
78%	1:8	1.65	1.96	2.22	4.22
80%	1:8	0.58	0.75	0.96	2.23
	1:10	0.76	1.06	1.85	2.81

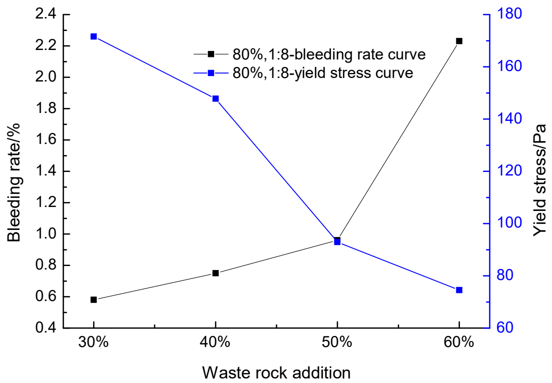


Figure 6. The coupling analysis of bleeding ratio and yield stress

5.4 Comprehensive analysis

According to the first-step strength requirement and strength results of waste rock cemented backfill, the adopted mix-proportions for various stope position in the waste rock cemented backfill are listed below:

the cement-tailing ratio of top 10m and the bottom 10m in the stope was 1:8, and the slurry concentrations were 78%～80%; the cement-tailing ratio of centre stope was 1:10, and the slurry concentration was 80%. Through the comprehensive analysis of the flow property and bleeding property of waste rock filling slurry, the stability and transportation performance became better under the slurry concentration of 80% and waste rock addition of 40%～50%. Therefore the ratio parameter selection of waste rock cemented backfill as follow: slurry concentration of 80%, and the waste rock addition of 40%～50%, where cement-tailing ratio for top and bottom 10m of the backfill stope of 1:8 and the cement-tailing ratio for the centre stope of 1:10.

6 CONCLUSION

According to strength analysis of ratio tests, the strength of waste rock cemented backfill was significantly higher than that of unclassified tailings cemented backfill under same cement consumption, where the average strength improvements were 2.02MPa, 0.98MPa and 0.46MPa under cement-tailing ratio of 1:4, 1:8 and 1:10, respectively. At the slurry concentration of 76%～78%, waste rock cemented backfill reached peak strength at 40% waste rock addition. However, at the slurry concentration of 80%, the strength variation of waste rock cemented backfill was not noticeable.

Through the coupling analysis of the flow property and bleeding property of waste rock filling slurry, the bleeding rate was negatively correlated with yield stress and the optimal slurry concentration and waste rock addition were determined. Based on the first-step strength requirement and strength results, the ratio parameter selection of waste rock cemented backfill as follow: the slurry concentration of 80%, the waste rock addition of 40%～50%, the cement-tailing ratio of 1:8 and 1:10 for top and bottom 10m in the stope and centre stope, respectively.

Aiming at the low strength of extremely fine unclassified tailings backfill, the addition of waste rock aggregate had a significant effect on improving the mechanical strength of cemented backfill. This study provided a basis for the selection of filling scheme. Furthermore, the overall technical and economic benefits of waste rock cemented backfill should be comprehensive analyzed combined with the investment of filling system, the preparation cost of waste rock aggregate, and the operation cost of the filling system.

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