An Experimental Study on the Strength Distribution of Cemented Tailings Backfill

Chen Xinzheng[1,2], Yang Xiaocong[1,2], Peng Xiaopeng[1,2] and **G Lijie[1,2*]**

1. *Beijing General Research Institute of Mining and Metallurgy, China*
2. *National Centre for International Joint Research on Green Metal Mining, China*

ABSTRACT

To explore the spatial strength distribution of backfill in the stope, a group of experiments in a large similar stope model was designed for simulating the consolidation of cemented tailings backfill (CTB) in a stope. The height of CTB in similar stope model was measured to analyse the flow and sedimentation characteristics. The unconfined compressive strength (UCS) test on specimens cored in the different position of CTB sample in similar stope model was conducted. Moreover, the particle size and cement content of CTB sample were tested to help to explain the mechanism. The results show that during the flow and sedimentation of filling slurry in the model, inconsistency of the particle size and cement content leads to the inconsistency of strength. In the flow direction (horizontal direction), the median particle size of CTB first increases and then decreases, the cement content of CTB decreases slowly and then increases sharply, and the strength of CTB first decreases and then rises. In the sedimentation direction (vertical direction), the cement content of CTB decreases with the increase of depth, while the strength of CTB increases with the increase of depth. The strength is affected by the interaction between particle size and cement content, and the higher cement content of CTB does not translate into higher strength. The results provide a theoretical basis for improving the quality of CTB and optimizing the design.

INTRODUCTION

With the concern of environmental protection and the promotion of green mining, backfilling of underground voids as part of mining method is widely used in the world. Usually, filling slurry is mainly composed of filling aggregate, cementing material and water, and is conveyed to the stope through a pipe, which then hydrates and sets to form the backfill (Yang, X.C 2018). During the flow sedimentation process, the various materials constituting the filling slurry have different trajectories due to their different properties, which leads to inconsistency of the backfill. The inconsistency of the filling body has an important impact on the quality of backfill. Many studies have researched the fluidity and intensity distribution of backfill. Through studying the flow and sedimentation law of the filling slurry, researchers found the filling slurry in the infinite horizontal plane is normally distributed (Xiao, L 2015; Xu, W.Y et al. 2011; Lu, H.J et al.2016). The non-uniformity of the backfill strength in the height direction was studied in an experiment in the laboratory (Gan, D.Q et al.2016; Lu, H.J et al. 2017). Shi C.X et al studied the non-uniformity of the in-situ backfill strength in an underground stope. Previous studies mainly focused on the non-uniformity of the backfill strength, but few studied the intrinsic mechanism of the inhomogeneity of the backfill strength. Due to the limited number of samples, previous studies are not enough to obtain the spatial distribution law of the backfill strength. This paper carried out a group of experiments in a large similar stope model and through testing strength, particle size and cement content of CTB sample in the similar stope model, the spatial strength distribution of CTB and its internal mechanism are explored.

METHODOLOGY

2.1 Test platform construction

In order to explore the strength distribution of backfill and obtain the flow and sedimentation law of filling slurry, a group of experiments in a similar stope model was carried out. The focus was on measuring the particle size and the cement content distribution within the filling body. According to the actual situation of a copper mine in south China, a stope with the parameters of 50 m × 15 m × 60 m (length × width × height) was selected as the basis for the model. The ratio of the model to the actual stope was 1:15, so the length of the model was 3300mm, the width was 1000mm, and the height was 800mm. The test platform and the similar stope model are shown in Figure 1.

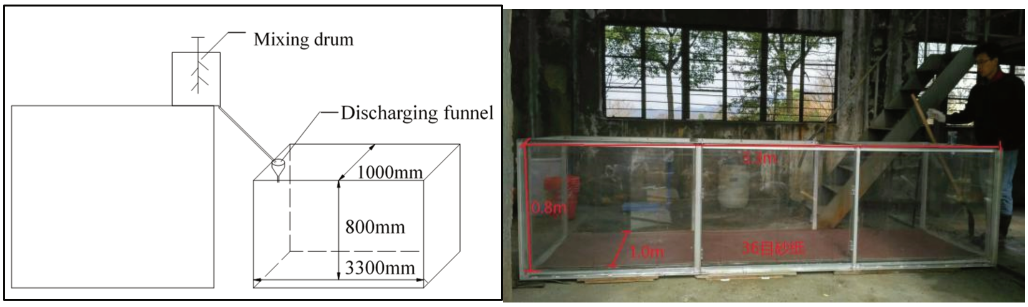


Figure 1 Testing platform and similar stope model

Based on the similarity theory, a similar ratio is obtained according to the Froude similarity criterion:

$$\lambda_v = \frac{v_p}{v_m} = \sqrt{\frac{L_p}{L_m}} = \lambda_l^{0.5}, \lambda_Q = \frac{Q_p}{Q_m} = \frac{A_p v_p}{A_m v_m} = \lambda_A \lambda_V = \lambda_l^{2} \lambda_l^{0.5} = \lambda_l^{2.5} \quad (1)$$

Where:

λ_v = similar ratio of flow rate =actual flow rate/similar flow rate.

λ_Q = similar ratio of flow quantity =actual flow quantity/similar flow quantity.

λ_l = actual goaf size/the test model size=15.

According to the formula (1) and the actual filling slurry parameters of the mine, the model test parameter values were determined: the similar ratios of flow rate and flow quantity were 3.87 and 871.4, respectively, and the experimental values of flow velocity and flow quantity were 0.91 m/s and 1.91 L/min, respectively.

2.2 Test materials and filling proportion

Testing materials included filling aggregates, cementitious materials and water. The filling aggregate that selected was coarse tailings with a density of 3.04 g/cm^3, and the cementitious material was P.C 32.5 grade composite Portland cement with a density of 3.02 g/cm^3, and the filling water was the recycled water of the mineral processing plant. According to the actual filling operation of the copper mine, the filling slurry with a mass concentration of 72% and cement consumption of 25% was carried out in the similar model test.

2.3 Test design

(1) Prepare the filling slurry according to the design proportion, make the specimens (diameter of 50 mm, and height of 100 mm) using the test filling slurry, and test the UCS (cured 28 days) and

cement content. The UCS and cement content regard as the standard to compare with the UCS and cement content of CTB cored in the similar stope model.

(2) Prepare the filling slurry according to the design proportion and after mixing fill the model through the inlet funnel. After the filling body is cured for 28 days, the backfill is sampled through cores. Beginning from the filling inlet side, samples are taken at intervals of 0.4m in the flow direction, a total of 9 rows, at intervals of 0.2m in the transverse direction, divided into 5 columns of A, B, C, D, E, respectively and upper, middle, lower layers in the vertical direction, which is shown in Figure 2. The test contents include: 1) the surface height of backfill at different positions; 2) the cement content of backfill at different positions; 3) the particle size distribution of backfill at different positions; 4) the strength of backfill at different positions.

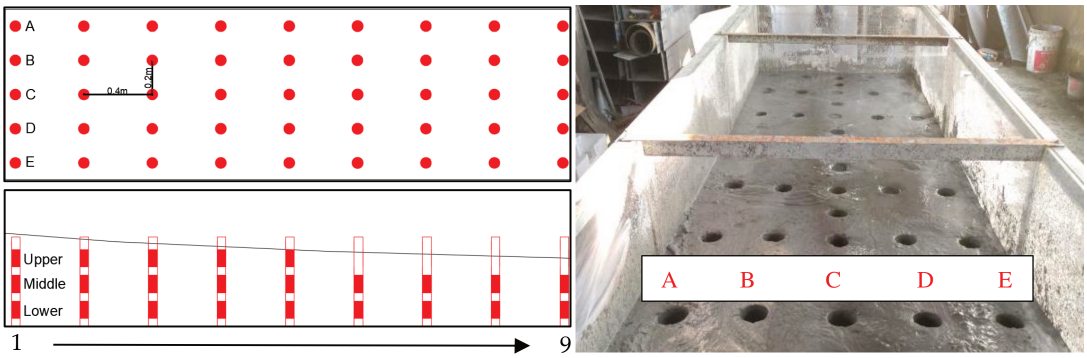


Figure 2 Diagram of backfill Sampled in similar stope model

RESULTS AND DISCUSSION

3.1 Flow and sedimentation characteristics of the filling slurry

Before and after the filling slurry in the model dewatered and set, the height of backfill along the flow direction was measured respectively. Figure 3 illustrates that the difference of height between before and after sedimentation is minimal on the filling inlet side and larger on the terminal side, which is 52mm.The height difference at the terminal end could be caused by cement hydration because the cement content was high at the terminal.

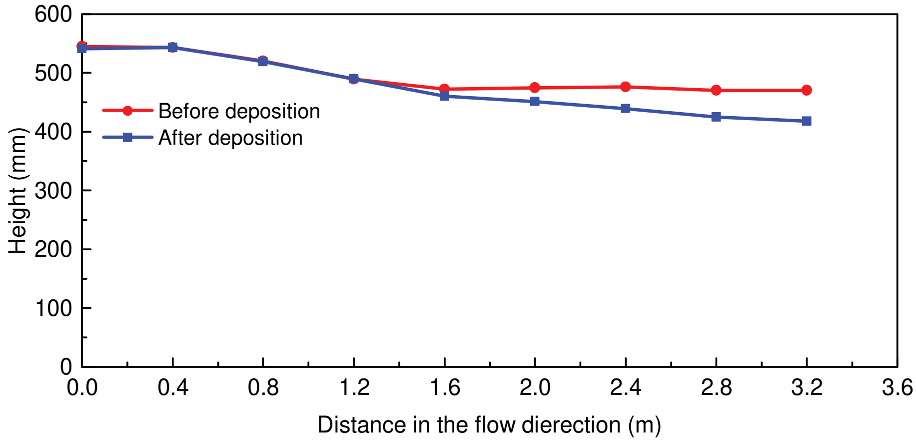
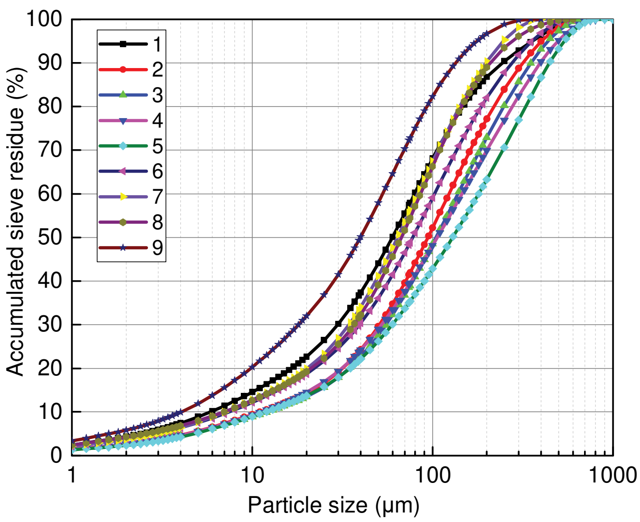


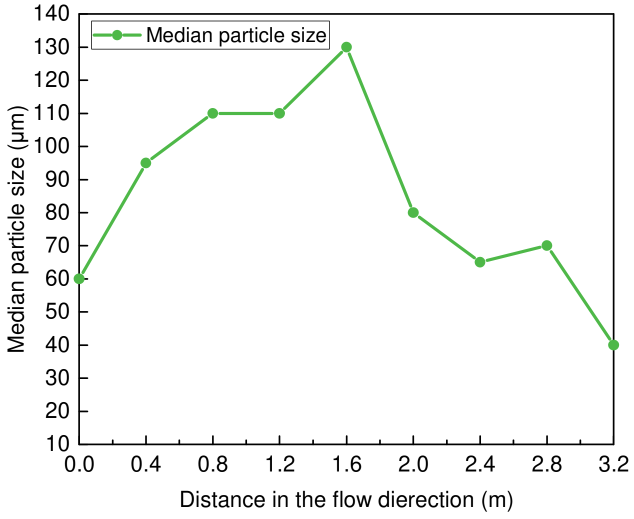
Figure 3 Height of backfill in flow direction before and after sedimentation

3.2 Particle size distribution characteristics of the backfill

The filling slurry was sampled at the sampling point at column C immediately after the model filled, and the filling slurry was dispersed with absolute alcohol. The samples' PSD test was using a Mastersizer 2000 Laser Particle Size Analyser. Figure 4(a) shows that the PSD curves of sample 1~4 and sample 6~8 are enveloped by the PSD curves of sample 5 and 9, which indicates that the particle size of backfill sampled at the endpoint has the minimum distribution range and backfill sampled at the midpoint has the maximum distribution range. Figure 4(b) shows that the median particle size of backfill first increases and then decreases in the flow direction, and reaches the maximum at 1.6m from the inlet point (about 1/2 the length of the model), which is consistent with the cement content distribution as below.



(a)

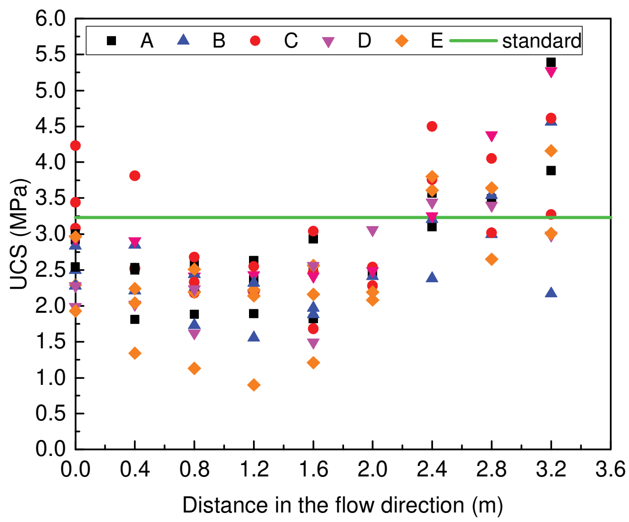


(b)

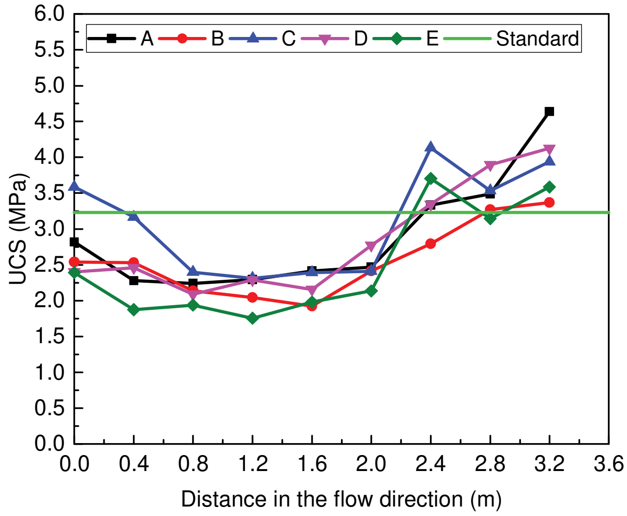
Figure 4 PSD of the sampled backfill

3.3 Strength distribution characteristics of the backfill

Backfill samples cored in the different positions of CTB in the model were processed into the standard test specimens and then tested for the UCS. The results are shown in Figure 5(a). The average strength of specimens belonging cored from to different layers (upper, middle and lower) in the same column was regarded as the strength of each column at the position where samples was located. Figure 5(b) shows the strength distribution characteristics of CTB samples in each column. Figure 5(b) illustrates that the strength first decreases and then rises in the flow direction, and the strength is at a minimum at 1.4m~1.6m from the inlet point(about 1/2 the length of the model).



(a)

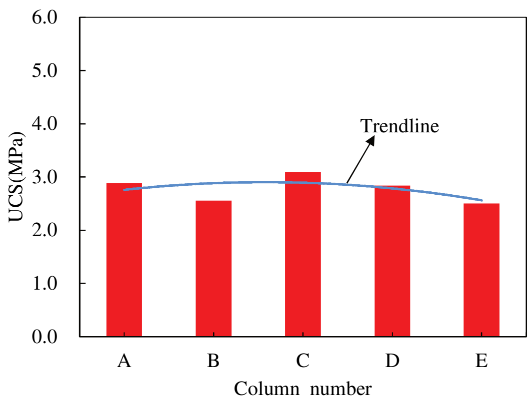


(b)

Figure 5 Backfill strength distribution in the flow direction

The average strength of all specimens (in different layers and at different positions) in the same column was regarded as the strength of each column. The strength distribution characteristics in the transverse direction are shown in Figure 6(a). The average strength of all specimens (in different columns and at different positions) in the same layer was regarded as the strength of each layer. The strength distribution characteristics in the vertical direction are shown in Figure 6(b). Figure 6 shows that the strength of CTB in column C (middle of the model in the transverse direction) is maximum and decreases from the middle to both sides, and that the strength increases with the increase of depth in the vertical direction.

(a)



(b)

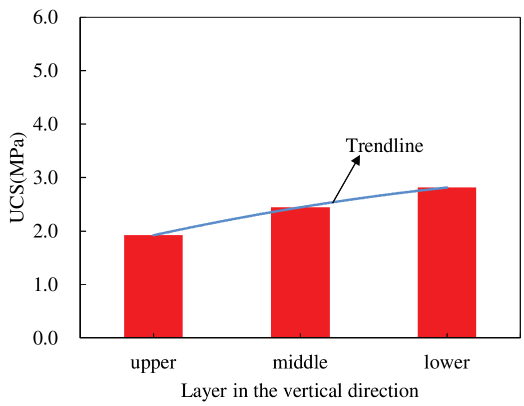
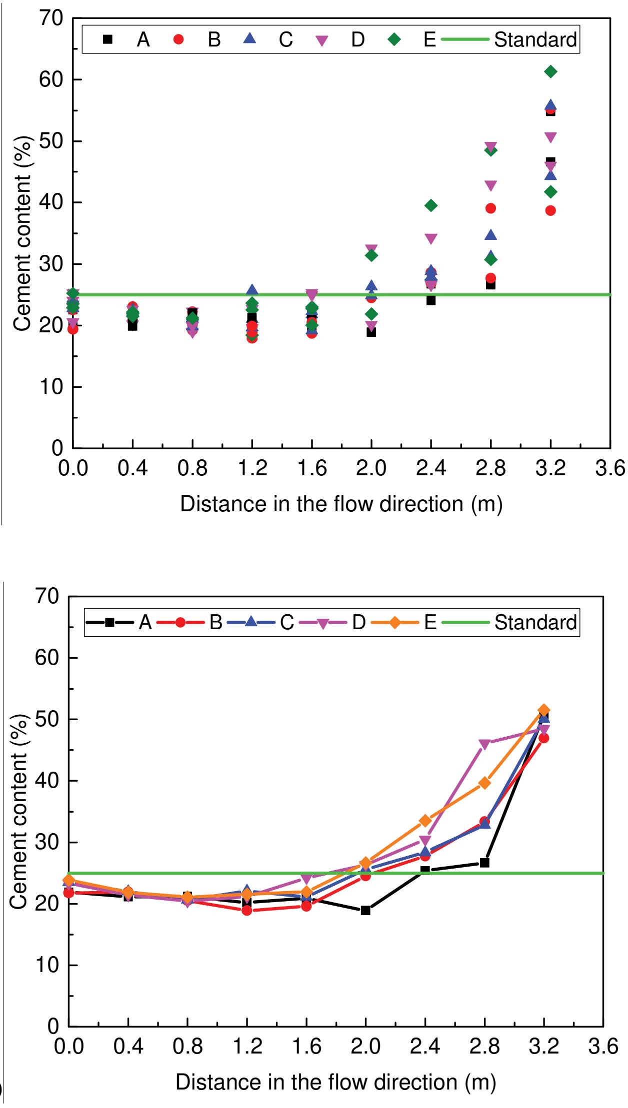


Figure 6 Backfill strength distribution in the transverse and vertical directions

3.4 Cement content distribution characteristics of the backfill

Cement content of the CTB specimens is determined after the UCS test using the EDTA titration method (Chen, X.Z et al 2018; Chen, X.Z et al 2019), and the results are shown in Figure 7(a). The cement content results were analyzed in a similar way to the strength results, and the distribution of cement content in the flow, transverse and vertical directions are shown in Figure7(b) , Figure 8(a) and Figure 8(b), respectively. Figure 7(b) illustrates that the cement content decreases slowly and then increases sharply and is higher than the standard cement content (25%) after 2.4m from the inlet point (3/4 the length of the model).



(a)

(b)

Figure 7 Cement content distribution in the flow direction

Figure 8(a) illustrates that the cement content of CTB in the column C (middle of the model in the transverse direction) is maximum and decreases from the middle to both sides like the strength distribution. Figure 8(b) illustrates that the cement content decreases with the increase of depth in the vertical direction.

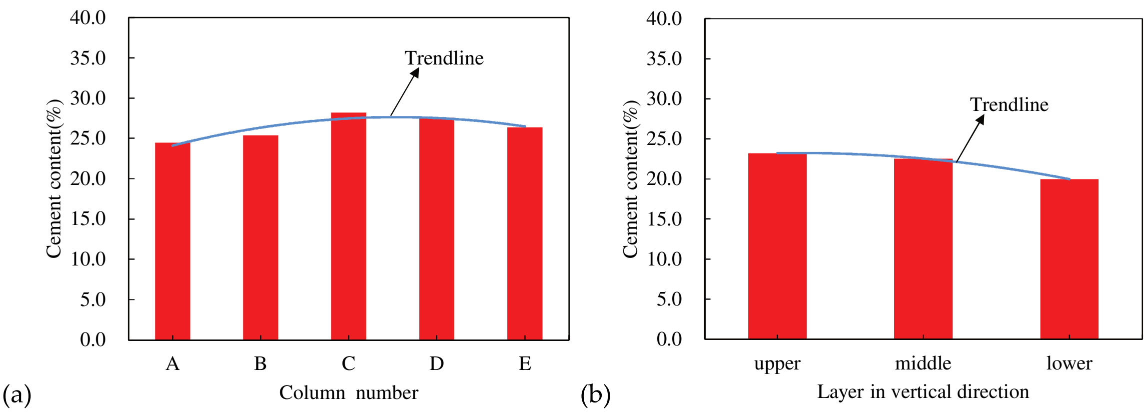


Figure 8 Cement content distribution in the transverse and vertical directions

3.5 Relationship between the strength and cement content

The results show that the strength and cement content of CTB in the similar stope model are inconsistent spatially. The strength of CTB is affected by the cement content, particle size and moisture content of backfill where the cement content usually has the most significant influence. Figure 9(a) and (b) show the relationship between backfill strength and cement content of column A and C in the flow direction, respectively and illustrate that the higher cement content of the backfill does not translate into higher strength in the example. The strength of CTB is positively correlated with cement content before 0.28m from the inlet point (about 3/4 the length of the model), while negatively correlated after 0.28m.

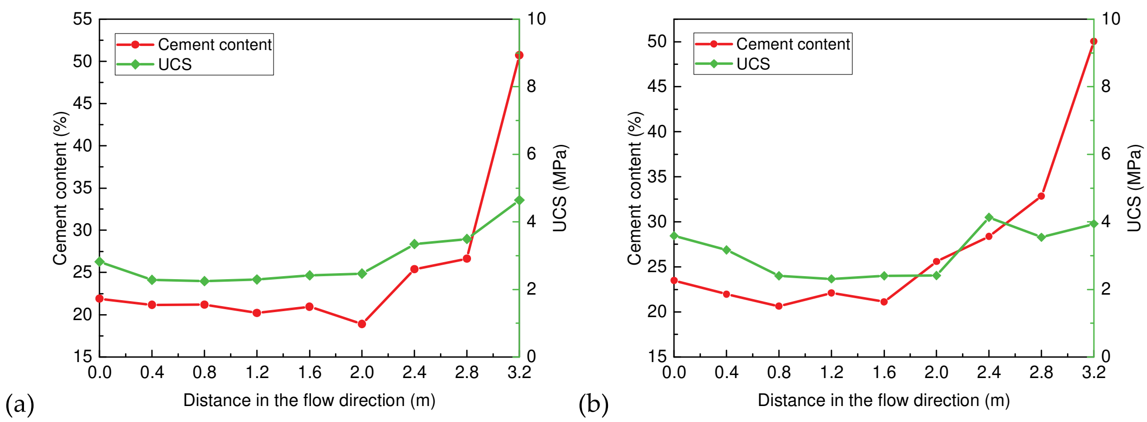


Figure 9 Relationship between backfill strength and cement content (a: A column, b: C column)

CONCLUSION

The height difference of backfill in the similar stope model between before and after sedimentation is minimal on the filling inlet side and larger on the terminal side.

The strength of CTB in the similar stope model is inconsistent spatially. In the flow direction, the strength first decreases and then rises, and the strength is at a minimum about 1.4m~1.6m from the inlet point (about 1/2 the length of the model).

In the transverse direction, the strength decreases from the middle to both sides and in the vertical direction the strength increases with the increase of depth.

The particle size distribution of CTB in the similar stope model first increases and then decreases in the flow direction, and reaching at a maximum about 1.6m from the inlet point (about 1/2 the length of the model).In the flow direction, the cement content decreases slowly and then increases sharply, and is higher than the standard cement content after 2.4m from the inlet point (3/4 the length of the model). In the transverse direction, the cement content decreases from the middle to both sides and in the vertical direction the cement content decreases with the increase of depth.

The backfill strength is affected by the interaction between particle size and cement content. In this experiment higher cement content of CTB did not translate into higher strength, and this may be because the CTB with high cement content has a poor aggregate gradation, i.e., the backfill with too many fine particles at the terminal end in similar stope model.

ACKNOWLEDGEMENTS

The Financial support from the National Key Research and Development Program of China (2018YFE0123000) is gratefully acknowledged.

REFERENCES

Yang, X.C＆Guo, L.J. (2018) *Tailings and waste rock comprehensive utilization technology*, Chemical Industry Press, China.

Xiao, L＆Xiao, W.G. (2005) 'Study on flowing law of fill slurry in stope', *Mining R＆D*, vol.25, no.2,pp.7-9.

Xu, W.Y, Yang, X.C＆Guo, L.J.(2011) 'Experimental research on inhomogeneous simulation of fill-body', *Metal Mine*, vol.40, no.5,pp.18-22.

Lu, H.J, Liang, P, Nan, S.Q, et al.(2016) 'Flow Track Exploration of Filling Slurry and Characteristic Analysis of Filling Material in Stope', *Metal Mine*, vol.45, no.10,pp.31-34.

Gan, D.Q, Shen M.F，Sun G.H, et al.(2016) 'Experimental study on strength distribution of filling body in metal mine', *Metal Mine*, vol.45, no.4,pp.32-35.

Lu, H.J, Liang. P, Gan, D.Q, et al. (2017) 'Research on flow and sedimentation law of filling slurry and mechanical characteristics of backfill body', *Rock and Soil Mechanics*, vol.38, Supp.1, pp.263-270.

Shi, C.X, Guo, L.J & Chen, X.Z.(2018) 'Experimental Study on the Law of Flow and Segregation of Filing Slurry in Stope', *Gold Science and Technology*, vol.26, no.4,pp.520-527.

Chen, X.Z, Yang, X.C, Guo, L.J, et al.(2018) 'Experimental study on the determination of cement content in cemented tailings backfill', *Nonferrous Metals Engineering*, vol.8, no.6,pp.69-74.

Chen, X.Z, Yang, X.C, Guo, L.J, et al.(2018) 'Effect of curing age on the determination of cement content in cemented tailings backfill by EDTA titration method', *Nonferrous Metals Engineering*, vol.9, no.4,pp.93-99.