The Change Laws of Strength and Selection of Cement-sand Ratio of Cemented Backfill

Xiaoming Wei[1], Changhong Li[1], Xiaolong Zhou[1], Baowen Hu[1] and Wanling Li[1]
[1]*School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China*
E-mail: xmweiustb@126.com
Corresponding Author: Changhong Li

ABSTRACT: Lilou Iron Mine is the largest domestic underground backfill mining and uses advanced whole tailings cemented filling process system. For the backfill, both the change law of strength development and the cement-sand ratio are important considerations for design. A differentiation analysis was performed of the strength of laboratory test blocks at the age of 28d and in situ cemented backfill samples. When the filling slurry concentration was 72% and cement-sand ratio was 1:4, the in situ coring strength was 2.98 MPa higher than that of laboratory-cured specimens; when the slurry concentration was 68% and cement-sand ratios were 1:4, 1:6 and 1:8, the in situ coring strength was 1.68MPa, 2.33 MPa and 1.44 MPa higher than that of laboratory-cured specimens. With an increase of filling height, the change laws has been explored of downward parabola in conditions that the strength difference is consistent with the bulk density difference of the cemented backfill. The stress of cemented backfill with different ratios were calculated and analyzed on the basis of ANSYS numerical simulation and similar filling mines. According to the position of stress concentration and change law of strength difference, this paper proposes an design scheme for high-stage cemented backfill with ratio parameters at different heights.

KEYWORDS: High-stage cemented backfill, Strength difference, Bulk density, Ratio design

1. INTRODUCTION

Compared to other mining methods, the cemented filling method has unparalleled advantages in improving the recovery rate, reducing th e dilution rate, controlling ground pressure and reducing industrial s olid waste emissions (Klein and Simon, 2006; Abdul and Fall, 2012; Zeng et al., 2010; Fu et al., 2014). Focusing on cemented filling stre ngth, mechanics models and cement-sand tests are typically made by domestic and foreign scholars to analyze the self-support strength (Kandiah and Nagaratnam, 2007; Belem and Benzaazoua, 2007; Wa ng, 2008). However, cement-sand ratio and strength values vary larg ely in different mines. In addition to different mining conditions, so far there has not been a good way of determining a reasonable ceme nted filling strength. With a cliff-style slump in iron ore prices, on th e premise of ensuring the filling strength, it is of paramount importa nce to defuse costs. As thus, this paper aims to detect the appropriate cement-sand ratio and reduce consumption of cement materials by a nalyzing the change laws of the strength of laboratory test blocks at t he age of 28d and in situ cemented backfill samples so as to better re duce the filling cost.

2. PROJECT OVERVIEW

Lilou Iron Ore is a large modern underground mine in China. Located in the alluvial plain in the upper reaches of the Huai River, the mineral deposits are formed as sedimentary-metamorphic deposits, with -103~-800m of the burial depth. The ore lies along the north-south direction, with a tendency to the west. It is 3.4 km long and the production scale is designed to be 7.5million t/a. According to ore body condition and industrial site layout, in order to meet the requirements of gravity flow stowing gradient, a total of three filling stations were set up, with a filling scale of 2.3 million m^3/a. After several years of practice, exploration, transformation and expansion, the entire filling process has been improved and optimized, thus forming an advanced whole tailings cement filling process system (Lu et al., 2009; Wei et al., 2014).

2.1 Mining method

Lilou Iron Ore was minded with open sloping with subsequent backfilling mining method. The ore was separated into rooms and pillars. The slope was arranged vertically to the orebody and each stage was 100m in height; the room and pillar width were 20m respectively and the length was the horizontal thickness of the orebody (50m on average). No studdings were left and continuous open sloping was divided into two steps.

2.2 Filling process

The filling slurry is prepared by vertical sand bunkers plus secondary mixing process. After making mud, tailings of a sand silo flow automatically into the hopper of the double-shaft mixer. Bulk cement in the cement silo will be conveyed to the hopper via the screw conveyor, and enter the high-speed mixing system after being sufficiently stirred with tailing slurry as per a certain percentage in order to prepare the filling slurry with a concentration of 68~72%. Then the filling slurry will be transported by the filling pipeline to underground stope to fill empty zones.

2.3 Physical and chemical properties of whole tailings

The CILAS 1064 Laser Particle Size Analyzer was employed to measure the particle size distribution of whole tailings, as shown in Table 1. Such physical properties as specific gravity, bulk density, porosity, and natural angle of repose of Lilou Iron Mine whole tailings were measured through experiments and displayed in Table 2, while the measurement results of the chemical composition are shown in Table 3.

Table 1 Particle size distribution

Particle size/μm	-5	-10	-20	-50	-75	-100	-150	-180	+180
Cumulation/%	7.68	11.62	17.96	38.36	53.44	65.92	80.43	85.5	100

Table 2 The measurement results of physical properties

Specific gravity	Loose bulk density t/m^3	Dense bulk density t/m^3	Porosity /%	Natural angle of repose /°
2.94	1.351	1.732	41.09	41.5

Table 3 The measurement results of the chemical composition

Chemical composition	TFe	CaO	MgO	Al_2O_3	SiO_2	S	Other
Content/%	10.67	0.19	0.85	0.4	76.85	0.045	10.995

2.4 Design strength of cemented backfill

The stress state of cemented backfill is linked to many factors, like the physical and mechanical parameters of the backfill itself, its geometrical shape, the interaction between the backfill and the surrounding walls, and stoping operations. By taking example by the filling strength similar to mine at home and abroad and strength of experiment blocks in different proportions, at the same time considering the influences of partial stress transfer and blasting in the upper rock of the filling body, the distribution of filling strength(Zhang, 2015) requirements in different segments of -400 m stage is shown in Figure 1.

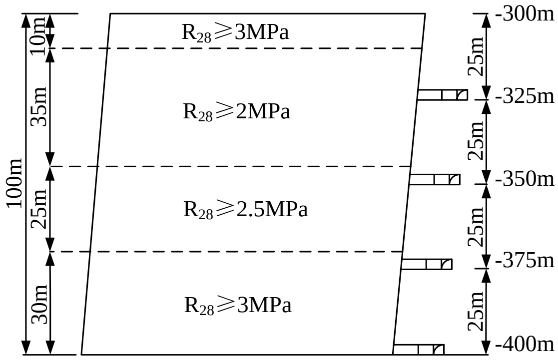


Figure 1 The first-step filling strength distribution of the high stage stope

3. SAMPLING OF LABORATORY AND UNDER-GROUND STOPES

In the surface filling process, sampling mold casting tests were performed in each bin. Because the strength of experimental blocks increased slowly after the cement and full tailings were combined, the blocks were placed in a curing chamber for 28d age. As shown in Figure 2, the temperature was controlled at (23±3)℃ and relative humidity was controlled in 96% (to simulate humidity and temperature of underground slopes). The mean value was taken as the strength value for laboratory test blocks.

Gradual filling began in Lilou Iron Ore from March 2014, which was the first-step stope. In order for safe stoping in the second-step, firstly, the cement-sand ratio of 1:4 was applied in 12-3#, 14-1# and 14-3# stopes; afterwards different cement-sand ratios were applied in 10-5#, 12-1# and 12-5# stopes.

In the -400m level a geological drill was used for coring detection, and the coring arrangement is shown in Figure 3. The in situ cores of six 100m filling stopes were complete overall, but some parts were broken. The fragmentation of cores was uniform and had some strength. In 3 stopes with the cement-sand ratio of 1:4, the core samples had complete molding, smooth surface and even thickness, as shown in Figure 4. In 3 stopes with mixed cement-sand ratios, the core samples had a smooth surface, even thickness, local fragmentations, but according to the clear corners of the fragments, fractures were expected to be caused by external forces, as exhibited in Figure 4.

(a) casting blocks

(b) curing blocks

Figure 2 Laboratory test blocks

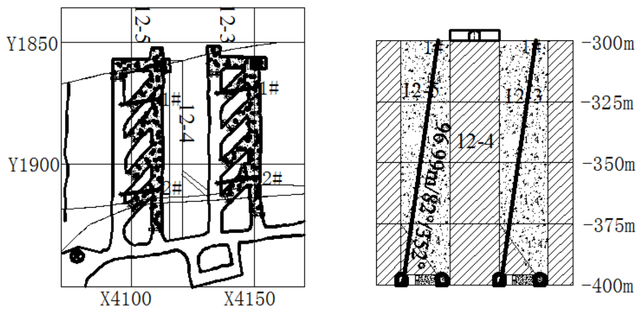


Figure 3 The coring arrangement of 12-3# and 12-5#stope

(a) 12-3#stope

(b) 12-5#stope

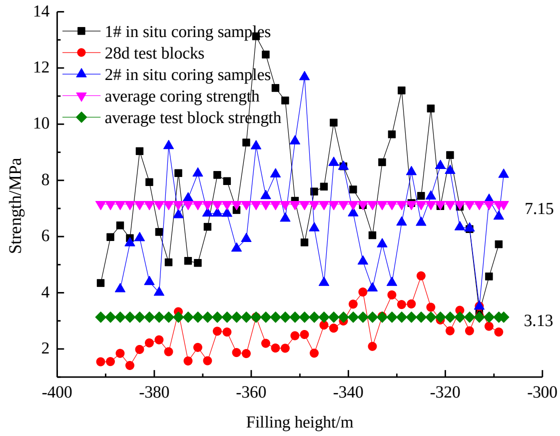
Figure 4 In situ cemented backfill samples

4. STRENGTH ANALYSIS

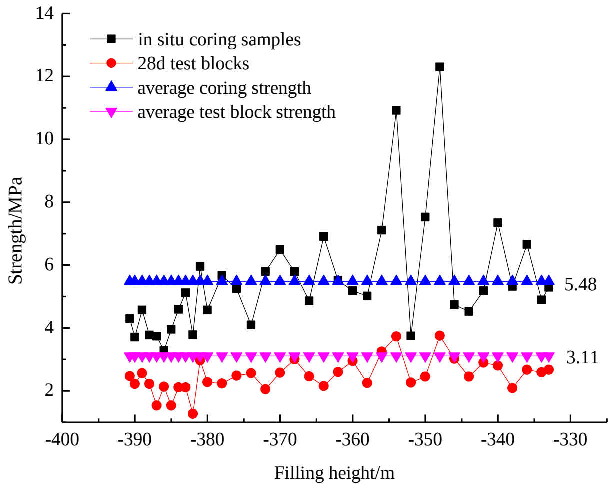
4.1 Strength analysis of the 1:4 ratio

The slurry concentrations of 12-3#, 14-1# and 14-3# stopes ranged from 71%~72%, with the cement-sand ratio of 1:4. The strength of test blocks at the age of 28d and in situ coring samples are shown in Figure 5, from which we can see the coring strength of underground stopes is far greater than the strength of test blocks. Wherein, the average strength value of test blocks was stable ranging from 3.11~3.18Mpa, which met the design requirements; the average strength of coring samples was relatively large ranging from 5.48~7.15MPa, exceeding the average test block strength of 2.98MPa.

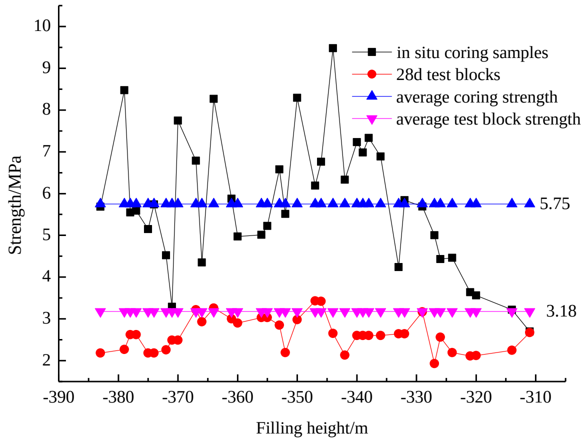
In order to grasp the change law of strength differences among different heights within 100m, combined with the bulk density difference, a unit of 10m was taken for an average analysis (Figure 6). Since there were few data values in -400m~-390m and -31~-300m, these two segments were left unconsidered. Figure 6 shows that with a rise in the fill height, there were slowly more significant strength differences between underground core samples and 28d test blocks, at -350m, reaching a peak of 4.71MPa, and then the strength differences has seen a gradual a decrease: the change of law of the bulk density difference conformed to the strength differences, reaching a peak of 0.12t/m3. It has been proved to an enhancement in underground backfill strength was relevant to an increase in bulk density. It could be attributed to the removal of excess pore wate r mainly due to the applied effective pressure



(a) 12-3#stope



(b) 14-1#stope



(c) 14-3#stope

Figure 5 The strength of 28d laboratory test blocks and in situ cemented backfill samples

during the curing process, which seems to improve consolidation process of the filling material and increased the density of the filling body. Laboratory specimens are (almost) always cured under zero total stress, so no effective stress develops. The results also account for the strength differences observed between laboratory samples and in situ samples. (Kesimal et al., 2003; Kesimal et al., 2004). The schematic representation of the effect of curing stress was shown in Figure 7. Origin numerical analysis software was adopted to fit a polynomial of strength differences, as shown in Formula 1,

$$y=-165.23-0.96668x-0.00138x^2 \quad (1)$$

Where y is strength differences (MPa); x is the filling height (m).

4.2 Strength analysis of mixed ratios

The slurry concentrations of 10-5# 、12-1# and 12-5# stopes ranged from 68%~69%, with a mixed cement-sand ratios. The cement-sand ratio was 1:4 in the section height of -400m~-370m and -310m~-300m, 1:6 in the section height of -370m~-325m, and 1:8 in section height of -325m~-310m. The average strength of in situ coring samples and test blocks at the age of 28d are shown in Table 4, from which we can see the law that the strength of test blocks < design strength < in situ coring strength. The strength difference between the in situ coring samples and test blocks with a cement-sand ratio of 1:4 was 1.59MPa~1.8MPa, average of 1.68MPa; the strength difference with a cement-sand ratio of 1:6 was 2.07MPa~2.67MPa, average 2.33MPa; the strength difference with a cement-sand ratio of 1:8 was1.28MPa~1.58MPa, average 1.44MPa. In the strength analysis of mixed ratios, the change laws of strength differences between the in situ coring samples and test blocks were basically consistent with filling stope at a 1:4 ratio (data unlisted), but the strength differences uniformly declined to varying degrees, which was relevant to the slurry concentrations, cement-sand ratios and cement materials of filling stopes (Helinski et al., 2007a; Helinski et al., 2007b).

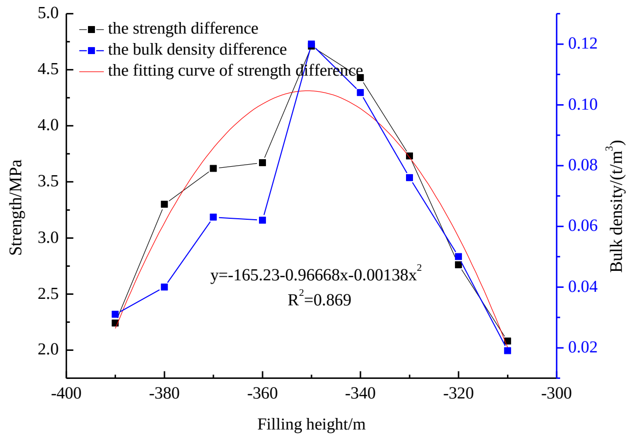
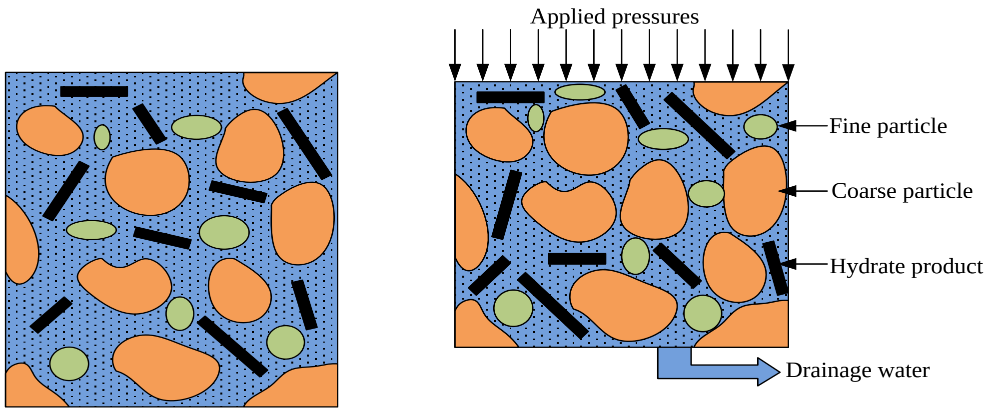


Figure 6 The strength difference and bulk density difference at 100m stage



(a) Laboratory curing(no stress) (b)In situ curing(effective stress)

Figure 7 Schematic representation of the effect of curing stress

Table 4 The average strength of in situ coring samples and 28d laboratory test blocks

Stope	Ratio	Design strength /MPa	28d test block strength /MPa	In situ coring strength/MPa	Strength difference
10-5#	1:4	3.0	2.86	4.66	1.8
	1:6	2.5	0.95	3.62	2.67
	1:8	2.0	1.21	2.79	1.58
12-1#	1:4	3.0	2.89	4.48	1.59
	1:6	2.5	1.53	3.78	2.25
	1:8	2.0	1.22	2.68	1.46
12-5#	1:4	3.0	2.65	4.31	1.66
	1:6	2.5	1.73	3.68	2.07
	1:8	2.0	1.24	2.52	1.28

5. RATIO SELECTION OF CEMENTED BACK-FILL

5.1 Similar filling mines

There are not many mines similar to Lilou Iron Ore at home and abroad. In China, only Anqing Copper Mine and Dongguashan Copper Mine are similar to it; in foreign countries, only Mount Isa Mine in Australia and Rauckh Copper Mine in Russia are resembling. The filling characteristics and filling strength of these mines are shown in Table 5 (Zhang and Yao , 2001; Guo and Yang, 2008).

Due to the different mining conditions and filling materials, diffrence mines select different cement-sand ratios, ranging from

1:4~1:15. The filling strength ranges from 0.63~3.94 MPa for tailings cement filling to 4.0~7.0 MPa for waste rock cement filling. These strengths can meet the sufficient lateral areas of adjacent pillars, with the exposure areas from 3000m^2~6000m^2, the exposure heights from 60m~120m. At the same time, the cemented backfill has good stability, and basically no collapse has taken place.

5.2 ANSYS numerical simulation of cemented backfill

In accordance with occurrence conditions of ore body, location of test stopes and the influential scope of the excavation, an ANSYS three-dimensional model was produced with 860m×220m×450m (length×width×height), to respectively simulate the stress states of cemented backfill at different cement-sand ratios. When subjected to compressive failure, the filling body would show strong plastic failure; the failure process was slow and gradual rather than abrupt, while tensile tests of a large number of cemented backfill specimens also demonstrate that the tensile strength was only about 1/15 of compressive strength. In this paper, The constitutive law used for material modeling was Mohr-Coulomb criteria and the tensile strength was taken as a failure criteria while also taking into account its compressive strength.

When the two-step stope just finished the ore drawing work but not conducted filling, as per the established model, the maximum principal stress, the minimum principal stress and the maximum displacement of the three ratios of cemented backfill were simulated, as shown in Table 6. Due to the limited space, the compressive stress distribution diagram at a 1:4 ratio was given as well as the tensile stress profile at mixed ratios, as shown from Figures 8 to 11.

Table 5 The similar filling mines

Mine	Ratio	Strength/MPa: Laboratory-cured blocks(28d)	Strength/MPa: In situ coring samples	Size/m: length×width× height	Lateral area /m^2	The stability of backfill
Anqing Copper Mine	1:4 1:6 1:8 1:10	3.94 2.47 2.23 1.29	Average increase of 1.25MPa	（40～60）×15×120	6000	Local rib spalling, increased the dilution
Dongguashan Copper Mine	1:4 1:6 1:8 1:10	3.66 1.67 0.98 0.63	Average increase of 1. 5MPa	82×15×（46～83）	4920	Good stability,no collapse
Mount Isa Mine	1：（11.5～15）	Waste rock cement filling 2.3 Tailing cement filling1.1		30×40×（100～240）	3100	Good stability
Rauckh Copper Mine	1：（8～10）	Tailing cement filling 4～7		50×20×90	4500	Good stability

Table 6 The stress and displacement of different ratios of cemented backfill

Ratio	The maximum principal stress/MPa	The minimum principal stress /MPa	The maximum displacement /mm
1:4	1.18	-0.08	80.8
1:6	0.93	-0.06	84.6
1:8	0.79	-0.05	79.8

Note：The compressive stress is “+”; the tensile stress is“-”,

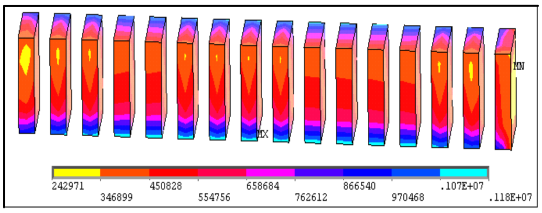


Figure 8 Compressive stress of 1:4 cemented backfill

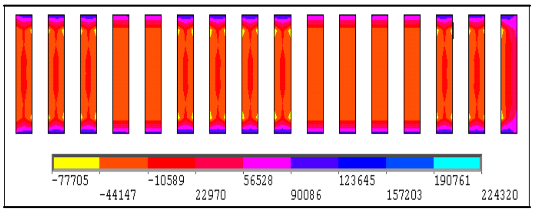


Figure 9 Tensile stress of 1:4 cemented backfill

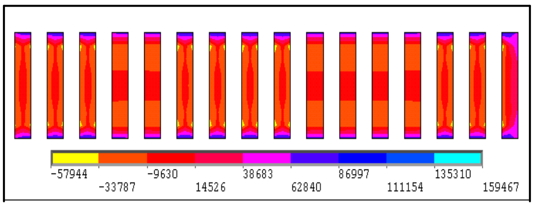


Figure 10 Tensile stress of 1:6 cemented backfill

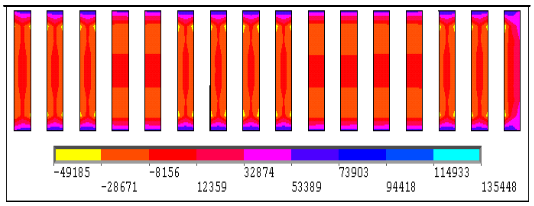


Figure 11 Tensile stress of 1:8 cemented backfill

5.3 Force characteristics and ratio parameter design

1) Table 6 exhibits obvious changes in compressive stress of cemented backfill at various proportions. When the ratios were 1:4, 1:6 and 1:8, the maximum compressive stresses of filling shall be 1.18MPa, 0.93MPa and 0.79MPa, respectively. With an increase in cement-sand ratios, the compressive stress of backfill has increased, mainly because a high proportion of cemented backfill results in irregular deformation of surrounding rocks, thus restricting self-supporting capacity of surrounding rocks and enlarging compressive stress in the filling body. No significant changes have been observed in the tensile stress of cemented backfill; when the proportions were 1:4, 1:6 and 1:8, the maximum tensile stresses of filling shall be -0.08 MPa, -0.06 MPa and -0.05 MPa, respectively. Little change has taken place in the deformation amount of cemented backfill. With respect to ore pillars, there is good flexibility, which also explains not only self-support strength should be taken into account as the strength required for cemented backfill to support stopes.
2) From the numerical simulation of ANSYS, the maximum compressive stress of cemented backfill is distributed in the upper and lower ends, as well as the upper and lower boundaries of surrounding rocks, as shown in Figure 8. The maximum tensile stress is distributed in the upper and lower ends, and arranged symmetrically; the cemented backfill is easily subjected to destruction in the region 12~17m top down and 12~20m bottom up. From the tensile stress profile of filling bodies at three kinds of proportions, the tensile stress appears in a wide range, as shown in Figs. 9 to 11.
3) According to mechanics parameters of cemented backfill in the laboratory (Deng et al., 2013; Fall, M. and Benzaazoua, M., 2005), when the ratios were 1:4, 1:6 and 1:8, the compressive strengths of test blocks at the age of 28d were 2.70MPa, 1.67MPa and 1.23MPa, respectively, and their tensile strengths were 0.31 MPa, 0.20 MPa and 0.16 MPa, respectively. For underground coring samples, when the ratios were 1:4, 1:6 and 1:8, the compressive strengths were 4.73MPa, 3.33MPa and 2.62MPa, respectively, while their tensile strengths were 0.68 MPa, 0.32 MPa and 0.27 MPa, respectively. The three kinds of cement-sand ratios could meet the strength requirements needed for numerical simulation. Therefore, from the mine economic considerations and backfill strengths, cemented backfill with a cement-sand ratio of 1:6 shall be adopted in the top and bottom; and in the middle cemented backfill with a cement-sand ratio of 1:8 shall be adopted (see Figure 12).

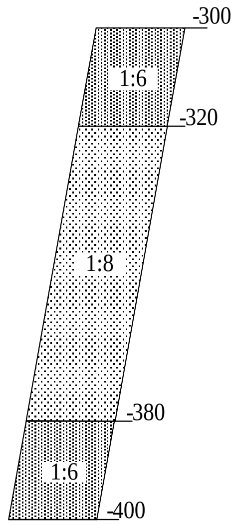


Figure 12 Design value of 100m segment with high stage cemented backfill

6. CONCLUSION

1) A comparison analysis was performed of the strength of laboratory test blocks at the age of 28d and in situ cemented backfill samples. It has been found that when the filling slurry concentration was 72% and cement-sand ratio was 1:4, the underground coring strength was 2.98 MPa higher than that of laboratory-cured specimens; when the slurry concentration was 68% and cement-sand ratios were 1:4, 1:6 and 1:8, the core sample strength were 1.68MPa, 2.33 MPa and 1.44 MPa higher than that of laboratory-cured specimens.
2) It has been evidenced that the strength of in situ cemented backfill has a direct relationship with the slurry concentration, cement-sand ratio, hydration reaction, filling rate and drainage system layout. With an increase in the filling height, the change law has been detected of downward parabola in conditions that the strength difference is consistent with the bulk density difference of the cemented backfill. Under the action of gravity, the filling body excluded pore water, which was in favor of the hydration reaction of cement and increased the density of the filling body.
3) In combination with ANSYS numerical simulation and the similar filling mines, stresses in the cemented backfill with different ratios were computed and analyzed. According to the position of stress concentration and change law of strength difference, the ratio of top 20 m and the bottom 20 m was 1:4 and the middle ratio was 1:6, which was conducted in the strength of cemented backfill.

7. REFERENCES

Klein, K.A., and Simon, D. (2006) “Effect of specimen composition on the strength development in cemented paste backfill”. Canadian Geotechnical Journal, 43, Issues 3, pp310−324

Abdul, H.N., and Fall, M. (2012) “Unsaturated hydraulic properties of cemented tailings backfill that contains sodium silicate”. Engineering Geology, 50, Issues 4, pp288–301.

Zeng, Z.K., Zhang, Y.P., and Wang, Y.M. (2010) “Research on the strength and stability on fill body of high-bench stope”. Metal Mine, Issues 1, pp31-34.

Fu, J.X., Du, C.F., and Song, W.D. (2014) “Strength sensitivity and failure mechanism of full tailings cemented backfills”. Journal of University of Science and Technology Beijing, Issues 9, pp1149-1157.

Kandiah, P. and Nagaratnam, S. (2007) “Arching within hydraulic fill stopes”. Geotechnical and Geological Engineering, 25, Issues 3, pp25–35.

Belem, T. and Benzaazoua, M. (2007) “Design and application of underground mine paste backfill technology”. Geotechnical and Geological Engineering, 26, Issues 2, pp147–174.

Wang, F.Z. (2008) “Filling technology of deep stope in Dongguashan copper mine”. Mining Research and Development, Issues 4, pp.4-5.

Lu, Y.Z., Guo, Z. and Jiang, R.Y. (2009) “Discussion on cementation-filling mass in Lilou iron”. Mining & Metallurgy, Issues 4, pp20-24.

Wei, X.M., Li, C.H., Zhang, L.X. (2014). “Selection of mining methods of steeply inclined large and thick ore body”. Metal Mine, Issues 4, pp31-34.

Zhang, L.X. (2015) “Study on stability parameters of the mining process of the large underground mining in the Lilou mine”. Changsha Mining Research Institute Co., Ltd & Anhui Mining Development Co. , Ltd, pp.226-227.

Kesimal, A., Ercikdi, B. and Yilmaz, E. (2003) “The effect of desliming by sedimentation on paste backfill performance”. Minerals Engineering, 16, Issues 10, pp1009–1011.

Kesimal, A., Yilmaz, E. and Ercikdi, B. (2004) “Evaluation of paste backfill test results obtained from different size slumps with varying cement contents for sulphur rich mill tailings”. Cement and Concrete Research, 34, Issues 10, pp1817–1822.

Helinski, M., Fahey, F. and Fourie, A.B. (2007a) "Numerical modelling of cemented paste backfill deposition". Journal of Geotechnical and Geoenvironmental Engineering, 13, Issues 10, pp1308–1319.

Helinski, M, Fourie, A.B., Fahey, F., and Ismail, M. (2007b) "Assessment of the self-desiccation process in cemented mine backfills". Canadian Geotechnical Journal, 44, Issues 10, pp1148–1156.

Zhang, S.C. and Yao, Z.L. (2001) "Analysis on the stability of fill of extra large stopes in Anqing copper mine". Mining Research and Development, Issues 4, pp12-15.

Guo, L.J. and Yang, X.C. (2008) "Study on mechanics stability of cemented backfill for mine deep stope". Mining & Metallurgy, Issues 3, pp10-13.

Deng, D.Q., Wang, L.H. and Wang, F.Z. (2013) "Ratio parameter design and engineering detecting of backfill in goaf". Journal of Fuzhou University (Natural Science Edition), Issues 2, pp207-212.

Fall, M., Benzaazoua, M. (2005) "Modeling the effect of sulphate on strength development of paste backfill and binder mixture optimization". Cement and Concrete Research ,42, Issues 2, pp301–314.