Experimental study on strength of cemented rock-tailings backfill

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Abstract. Waste rock tailings cementation filling is a filling technique that effectively disposes waste rock and tailings in mines, saves energy, and reduces costs. This paper systematically studies the cementation and filling strength of waste rock tailings. The relationship between compressive strength, shear strength and content ratio of waste rock and tailing sand, cement-sand ratio, concentration parameters and the variation of strength were analyzed by orthogonal test. Sensitivity analysis of factors affecting strength of backfill is conducted using extreme range in data process. Then the order of sensitivity is obtained as content ratio of waste rock and tailing sand > cement-sand ratio > concentration, the relationship between factor and strength is established and the optimal mixing proportion of materials is found. It provides the basis for the filling process design.

1. Introduction
Filling mining method has its unique advantages in efficiency and construction characteristics in dealing with goafs. It can also improve the recovery rate, reduce the loss rate, and protect the environment while ensuring safety. It is also widely used in practical production. According to the modern Mining concept, the solid waste filling technique is the most effective way to solve the series of problems brought about by mining activities. The preparation of low-cost and high-efficiency filling materials is a research hotspot in the field of filling mining in China [1]. Based on the current high performance, the filling materials have high cost and environmental pollution. Waste rock tailings cementation filling can be used to effectively treat waste rock and tailings in mines, save energy and costs, and make full use of mineral resources to reduce ore loss and depletion [2-3]. It is a new filling process based on the coagulation theory on the cemented tailings backfill and dry-placed filling [4], and there is little research on the strength of backfill.

After a large number of experimental studies domestic and foreign scholars believe that the backfill bears 20% to 70% stress [5-7]. The movement (or destruction) of the rock body is to maintain the integrity of the original rock by applying a certain stress to the backfill, and to support the ground pressure by mobilizing the original bearing capacity of the original rock. At present, the strength of backfill is mostly determined by the empirical method or the empirical analogy method. But the technical conditions of mine are different greatly, causing the cost is too high or the strength of backfill doesn’t meet the practical engineering requirements. So, the scientific and quantitative determination of the strength of backfill is the key to filling Mining technology. In this paper, the
strength of cemented rock-tailings backfill and the relationship between content ratio of waste rock and tailing sand, cement-sand ratio and concentration were studied in a metal mine in Yunnan. It provides some guidance and data basic for better promotion of waste tailings filling method.

2. Test design

2.1. Experiment material
The test selected the waste rock after mining in a metal mine in Yunnan and the tailings discharged from the plant as the main filling material and ordinary Portland cement (P.O, 42.5#) as raw materials. The basic characteristics of tailings are shown in Table 1, tail grain size < 0.005mm. The waste rock is a strong-moderately weathered schist, rock mechanics, granite, mudstone and other blocks of soil. The particle sizes are shown in Figure 1. The density is 2.72g/cm³, the natural water content is 7.73%, and the compactness is 0.204. The cohesive force is 0.20 MPa and the internal friction angle is 24.26°.

![Figure1. Grain-size distribution curve.](image)

| Grain-size | Density g/cm³ | Water Content ω (%) | Void Ratio e | Liquid Limit ωL (%) |
|------------|---------------|---------------------|--------------|---------------------|
| <0.005mm   | 2.97          | 61.41%              | 1.405        | 45.2                |

| Plastic Limit ωP (%) | Compression Coefficient a(MPa⁻¹) | Compression Modulus Es (MPa) | Cohesion C(KPa) | Internal Friction Angle φ(°) |
|----------------------|-----------------------------------|-------------------------------|----------------|-----------------------------|
| 27.1                 | 0.94                              | 2.60                          | 14.34          | 4.61                        |

2.2. Experiment method
According to domestic and international studies and concrete theory, the factors affecting the strength of backfills are: the characteristics of filling materials (waste rock and tailings), the proportion of filling materials (content ratio of waste rock and tailing sand), and cement content per unit volume (water-cement ratio, cement-sand ratio), mixing time, curing age, concentration, and conservation environment, It has been confirmed in a large number of studies [8-9] that the most significant effect of curing age on the sensitivity of filling body, which is no longer considered by the laboratory. In the many factors of influence, different content ratio of waste rock and tailing sand, cement-sand ratio, concentration, and intensity of backfill were selected to test the relationship between the three. The test reference specification GB/T 50081-2002 [10], make 9 samples of 0.15m × 0.15m × 0.15m in size, static in the laboratory at 20 ± 5 °C to 48 hours, in the number of split into a saturated solution to maintain. With reference to the growth law of different ages of concrete [11], the strength of filling body will increase with the increase of age, and it will grow slowly after 28 days, so all the samples are selected to be maintained for 28 days.
2.3. Test plan
In order to obtain better results with fewer trials, orthogonal experiments were designed. By referring to relevant research experience, at a certain age (28d), experimental points were arranged using 3 factors and 3 levels. The experimental factors are A(Content ratio of waste rock and tailing sand), B(Cement-sand ratio) and C(Concentration: the concentration of cement, tailings, and water mixture). Considering the variation range of each parameter, the uniaxial compressive strength and shear strength index under different mixing ratios were studied. See Table 2 for the factors and the corresponding levels.

| Levels | Factor A(Content ratio of waste rock and tailing sand) | Factor B(Cement-sand ratio) | Factor C(Concentration)/% |
|--------|------------------------------------------------------|-----------------------------|---------------------------|
| 1      | 1:2                                                  | 1:20                        | 60%                       |
| 2      | 3:5                                                  | 1:12                        | 65%                       |
| 3      | 1:1                                                  | 1:6                         | 70%                       |

2.4. Compression test
The uniaxial compression test uses a 200-C-1 hydraulic testing machine by Jinan Test Machine Factory as shown in Figure 2. Record the failure load $P(N)_{\text{max}}$.

$$\sigma_c = \frac{P(N)_{\text{max}}}{A}$$ (1)

In the formula: $\sigma_c$ is the uniaxial compressive strength, MPa; $P(N)_{\text{max}}$ is the maximum failure load of the specimen, N; $A$ is the compression area of the specimen, mm$^2$.

2.5. Shear Test
This test uses a YZW50 microcomputer-controlled electric stress type direct shear meter produced by Jinan Haiwei Instrument Co., Ltd. as shown in Figure 3.

3. The results
3.1. Test results
The experimental results were included in the orthogonal analysis Table 3, and the sensitivity of the influence factors of the compressive strength and shear strength of the filling body was analyzed by using the extreme difference, as shown in Table 4 and 5.
Table 3. Orthogonal analysis.

| NO | A (Content ratio of waste rock and tailing sand) | B (Cement-sand ratio) | C (Concentration)/% | Uniaxial Compressive Strength /MPa | Shear Strength /MPa |
|----|-----------------------------------------------|-----------------------|---------------------|-----------------------------------|---------------------|
| 1  | 1:2                                           | 1:20                  | 70%                 | 0.71                              | 0.38                |
| 2  | 1:2                                           | 1:12                  | 60%                 | 0.98                              | 0.45                |
| 3  | 1:2                                           | 1:6                   | 65%                 | 1.61                              | 0.67                |
| 4  | 3:5                                           | 1:20                  | 65%                 | 1.17                              | 0.55                |
| 5  | 3:5                                           | 1:12                  | 70%                 | 2.08                              | 0.74                |
| 6  | 3:5                                           | 1:6                   | 60%                 | 2.34                              | 0.81                |
| 7  | 1:1                                           | 1:20                  | 60%                 | 1.97                              | 1.03                |
| 8  | 1:1                                           | 1:12                  | 65%                 | 3.75                              | 1.29                |
| 9  | 1:1                                           | 1:6                   | 70%                 | 4.42                              | 1.67                |

Table 4. Range analysis of compression strength.

| Factors | Average compressive strength at each level /MPa | Very Poor |
|---------|-----------------------------------------------|-----------|
|         | Level 1 | Level 2 | Level 3 |                |
| A       | 1.10    | 1.86    | 3.38    | 2.28            |
| B       | 1.28    | 2.27    | 2.79    | 1.51            |
| C       | 1.76    | 2.18    | 2.40    | 0.64            |

Table 5. Range analysis of shear strength.

| Factors | Average shear strength at each level /MPa | Very Poor |
|---------|------------------------------------------|-----------|
|         | Level 1 | Level 2 | Level 3 |                |
| A       | 0.50    | 0.70    | 1.33    | 0.83            |
| B       | 0.65    | 0.83    | 1.05    | 0.40            |
| C       | 0.76    | 0.84    | 0.93    | 0.17            |

3.2. Data analysis

(1) By calculating the extreme difference between the compressive strength and the shear strength of various factors, it can be concluded that the order of the compressive and shear strength of the cemented rock-tailings backfill is different: A (Content ratio of waste rock and tailing sand) > B (Cement-sand ratio) > C (Concentration). Therefore, the sensitivity of each factor to the influence of the compressive and shear strength of the cemented rock-tailings backfill can be sorted. The first is the content ratio of waste rock and tailing sand; the second is cement-sand ratio; the third is the concentration.

(2) From Figure 4, we can see the general trend of compressive strength as a function of various factors: As the relative content of waste rock and cement-sand ratio increase, the uniaxial compressive strength increases linearly. When the concentration increases to a certain extent, the impact on the compressive strength is small. From Figure 5, the general trend of shear strength changes with various factors is shown: as each factor increases, the shear strength also increases rapidly. The shear strength increases rapidly with the content ratio of waste rock and tailings greater than 3:5.

(3) Based on the test data and the combination of logarithmic and exponential functions in conjunction with Figure 4, establish the following relationship and obtain the complex correlation coefficient $R^2$: ① The logarithmic function relationship between the content ratio of waste rock and tailing sand and compressive strength is $y = 0.584\ln(x) + 1.7656$, $R^2 = 0.9997$; ② The logarithmic
function relationship between cement-sand ratio and compressive strength is \( y = 1.377\ln(x) + 1.292, \ R^2 = 0.9993; \) ③ The exponential function relationship between concentration and compressive strength is \( y = 0.6204e^{0.5613x}, \ R^2 = 0.9988. \)

(4) According to the experimental data combined with the exponential and linear function in combination with Figure 5, establish the following relationship and obtain the complex correlation coefficient \( R^2: \)

① The exponential function relationship between content ratio of waste rock and tailing sand and shear strength is \( y = 0.2914e^{0.4892x}, \ R^2 = 0.9685; \) ② The exponential function relationship between cement-sand ratio and shear strength is \( y = 0.515e^{0.2372x}, \ R^2 = 1; \) ③ The linear function relationship between concentration and shear strength is \( y = 0.0833x + 0.6767 \) and \( R^2 = 0.9952. \)

(5)From Figure 4 and 5, The samples’ strength with the content ratio of waste rock and tailing sand 1:1, cement-sand ratio 1:6 and concentration 70% are the highest. The uniaxial compressive strength is 4.42 MPa and the shear strength is 1.67 MPa, meeting the practical engineering strength requirements. The ratio is the optimal material combination.

4. Conclusions

In this paper, the factors affecting the compressive strength and shear strength of cemented rock-tailings backfill were studied by orthogonal test, and the functional relationship between content ratio of waste rock and tailing sand, cement-sand ratio, concentration and strength was established. The following conclusions have also been obtained, providing a basis for filling process design.

1. The addition of waste rock coarse aggregates is beneficial to the improvement of strength, in which 1:1 addition amount of waste rock tailings can make cemented rock-tailings backfill have better strength.

2. The compressive and shear strength of the cemented rock-tailings backfill is less affected by the concentration, and the method of increasing the concentration is not selected to increase the strength of the filling body in actual production.

3. The strength of the cemented rock-tailings backfill is significantly affected by the content ratio of waste rock and tailing sand and cement-sand ratio. The waste rock forms a stable skeleton structure in the filling body, and the tail sand fills the pores in the structure, so that the entire filling body aggregate is in a tight interlocking state, thereby increasing the strength of the filling body.

4. The function relationship by test fitting provides a tool for calculating the strength of backfill and avoids the blindness of empirical estimation. At the same time, the best combination ratio of materials from orthogonal experiments provides data for Mines with similar production conditions.
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References

[1] Juanrong Zheng, Xiaoyu Lu, Zhenbo Zhao 2016 Study on influencing factors of the compressive strengths of low-strength cemented backfill Concrete 6 320
[2] Guo Lijie, Xiaocong Yang 2008 Test Study on cemented rock-tailings filling Journal of Wuhan University of Technology 30 11
[3] Side Yang 2008 Review of Cemented waste rock and tailings filling technology Express Information of Mining Industry 12 12
[4] Lianjun Zou 2004 Effect of the filling on the stability of field Master's thesis of Kunming University of Science and Technology 9
[5] Zhiwei Huang 2003 Study of tailing cement with watertechnology Metal Mine
[6] Zhifang Wang 1996 Study of cement-filling strength Chem-Mine Technology 25 3
[7] Yifan Li, Jianming Zhang, Fei Deng, Shiwei Bai 2005 Experimental study on strength characteristics of tailings cement backfilling at deep-seated mined-out area Rock and Soil Mechanics 26 6
[8] Guanghua Sun, Shasha Wei, Dongliang Su 2015 Optimal matching scheme for the full tailings-cemented filling based on the orthogonal experiment Metal Mine 4 466
[9] Jianxin Fu, Cuifeng Du, Weidong Song 2014 Strength sensitivity and failure mechanism of full tailings cemented backfills Journal of University of Science and Technology Beijing 9 36
[10] GB/T 50081-2002 Standard for test method of mechanical properties on ordinary concrete Ministry of Construction P.R.China
[11] Aiqin Shen 2000 Cement and cement concrete China Communications Press.