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Research Article

Influencing Factors on Strength of Waste Rock Tailing Cemented Backfill

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Tailing cement filling is an important development direction in mine filling, as it is a green and environmentally friendly method for efficiently treating solid waste in mines. Adding a certain amount of waste rock can effectively improve the backfill strength and better meet the filling strength requirements. To address the use of waste rock tailings in cemented filling materials, a uniaxial compression test was carried out on backfills with different cement/sand ratios and waste rock contents, and the influence of the cement/sand ratio and waste rock content on the strength of the backfill was studied. This study found that when the waste rock content is certain, the strength of the backfill increases with the increase in the cement/sand ratio, and the increase in strength slows with the increase in the cement/sand ratio until the strength of the backfill reaches a limit and no longer increases. When the cement/sand ratio is constant, the strength of the backfill first increases and then decreases as the waste rock content increases. When the cement content is constant, the addition of a certain amount of waste rock reduces the specific surface area of the solid materials in the backfill, increases the amount of cement per unit area, and improves the strength of the backfill. When the waste rock content is too high, due to the large particle size of the waste rock, the tailings cannot completely wrap around the waste rock, resulting in a weakening of the cement in the backfill, which reduces the strength of the backfill. This study found that the waste rock content and the cement/sand ratio in the backfill have a significant impact on backfill damage. The damage is mainly caused by insufficient cement strength. The presence of waste rock will change the original direction of crack propagation, resulting in more crack bifurcation, and the form of the destruction surface on the backfill is complicated and diverse.

1. Introduction

A cemented rock-tailing filling uses mine waste rock and tailings as aggregate and cement as the cementing material, and water is added according to a certain proportion to prepare a filling slurry, which is filled into the goaf through a filling pipeline system. Backfill mining can effectively control the deformation and destruction of surrounding rocks in the goaf and prevent surface subsidence. It can play dual roles of protecting the environment and utilizing solid waste in mines [1, 2]. This is an important direction for green mining [3, 4]. At present, scholars have conducted relevant research on full tailing cemented backfill and believe that the main factors affecting the strength of full tailing cemented backfill are the cement/sand ratio and the slurry concentration [5–10]. To assess backfills with different cement/sand ratios and slurry concentrations, scholars have conducted related strength research and obtained the influence law of backfill strength [11–17]. Scholars have done relevant research on the failure characteristics of different rocks [18–24].

Adding a certain amount of waste rock to the filling material can effectively improve the strength of the backfill and better meet the filling needs [25–32]. When the backfill reaches a certain strength, the space utilization of the goaf can be realized through a rational design of the filling, such as the construction of underground storage in the goaf [33].

The influence law of the addition of waste rock on the strength of the backfill and the influence mechanism of the cement/sand ratio and waste rock content on the structure and strength of the backfill are not yet clear. In this paper, through uniaxial compression testing of backfills with different cement/sand ratios and waste rock contents, the effect of the cement/sand ratio and the waste rock content on the strength of the backfill is studied, the damage characteristics of the backfill with different material ratios are analysed, and the effect of backfill destruction on the cement/sand ratio and waste rock content is studied. This is of great significance for the safety of mine goaf filling and the utilization of mine tailings.

2. Experiment

2.1. Material Ratio of Backfill. To study the strength influence of cemented rock tailing backfill from different factors, lead-zinc mine tailings and limestone with particle size less than 10 mm were selected as aggregates, and a typical P.O32.5 Portland cement was used as the cementing material. The particle size of distribution of tailings is shown in Figure 1 and basic physical properties of tailings is shown in Table 1. Backfill with different proportions was obtained by mixing filling materials in a certain proportion. Sixteen standard test pieces were obtained, with a waste rock content of 25%, 30%, 35%, and 40%; cement/sand ratios of 1 : 10, 1 : 8, 1 : 6, and 1 : 4; and slurry concentrations of 72%. The main parameters of each test piece are shown in Table 2.

2.2. Test Piece Procedures. The preparation and maintenance steps for the backfill are as follows:

(1) Weigh a certain mass of tailings, waste rock, and cement according to the ratio in Table 1, and mix them evenly to form a filling aggregate

(2) Weigh a certain amount of water, and add it to the filling aggregate. Use manual stirring for more than 5 minutes until the cemented filling slurry is evenly mixed

(3) Apply a layer of lubricating oil to the inside of the cylindrical cast iron trial mould with a diameter of 50 mm and a height of 100 mm

(4) Load the slurry into the trial mould 3 times, and vibrate densely on the vibration table each time

(5) After filling, let it stand for 48 h and shape and remove it from the mould

(6) After labelling the test piece, place it in a constant temperature and humidity curing box for curing at a constant temperature $(20 \pm 1)^{\circ}C$ and humidity $(95 \pm 1)\%$ for 28 days

2.3. Uniaxial Compression Test. When the curing age reaches 28 days, the cemented rock tailing backfill specimens, which are standard cylindrical specimens of 50 mm × 100 mm size, are weighed with an electronic scale, and the density of each specimen is calculated as shown in Table 2. A uniaxial compression test is carried out on a rock mechanics test system. The test device is shown in Figure 2. The test system consists of a host, a hydraulic source, a load control system, and a computer data processing system. It can complete a basic mechanical parameter test for materials such as rock, coal samples, and concrete under compression or shear.

Using computer control, the sample is loaded at a constant rate of 0.2 mm/min until the specimen is destroyed, as shown in Figure 3; intensity data are recorded, and pictures are taken of all specimens, and the test bench is cleaned.

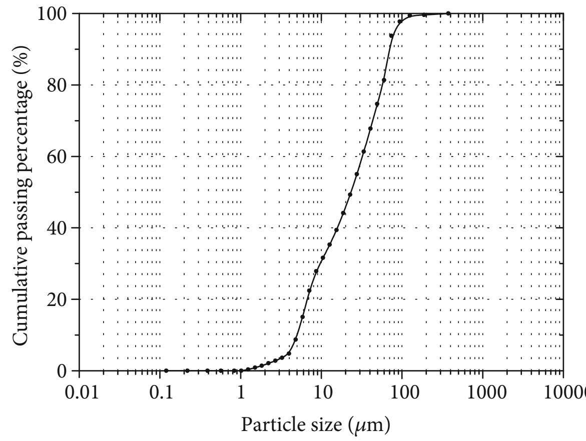


Figure 1: Rock mechanics test system.

Table 1: Basic physical properties of tailings.

Sample	Specific gravity (t/m^3)	Bulk density (t/m^3)		Porosity (%)	
		Loose	Thick	Loose	Thick
Tailings	2.852	1.229	1.545	56.92	45.82

Table 2: Piece parameters.

No.	Waste rock content	Cement/sand ratio	Density (g/cm^3)
Q1	25%	1 : 4	2.02
Q2	25%	1 : 6	2.01
Q3	25%	1 : 8	1.98
Q4	25%	1 : 10	1.99
Q5	30%	1 : 4	2.05
Q6	30%	1 : 6	2.07
Q7	30%	1 : 8	2.07
Q8	30%	1 : 10	2.07
Q9	35%	1 : 4	2.04
Q10	35%	1 : 6	2.09
Q11	35%	1 : 8	2.08
Q12	35%	1 : 10	2.09
Q13	40%	1 : 4	2.04
Q14	40%	1 : 6	2.00
Q15	40%	1 : 8	2.05
Q16	40%	1 : 10	2.01

Figure 2: Rock mechanics test system.

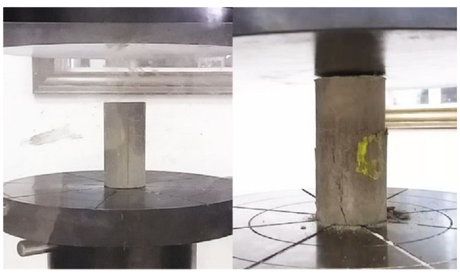


Figure 3: Rock mechanics test.

Table 3: Test parameters.

No.	Waste rock content	Cement/sand ratio	Uniaxial compressive strength (MPa)
Q1	25%	1 : 4	1.49
Q2	25%	1 : 6	1.26
Q3	25%	1 : 8	0.93
Q4	25%	1 : 10	0.62
Q5	30%	1 : 4	1.62
Q6	30%	1 : 6	1.42
Q7	30%	1 : 8	1.11
Q8	30%	1 : 10	0.86
Q9	35%	1 : 4	1.92
Q10	35%	1 : 6	1.85
Q11	35%	1 : 8	1.52
Q12	35%	1 : 10	1.09
Q13	40%	1 : 4	1.55
Q14	40%	1 : 6	1.24
Q15	40%	1 : 8	0.79
Q16	40%	1 : 10	0.39

3. Strength Characteristics Analysis

3.1. Uniaxial Compressive Strength. Under different waste rock contents and cement/sand ratios, the uniaxial compressive strength of the backfill is shown in Table 3. Table 3 shows that the uniaxial compressive strength of the backfill is significantly affected by the rock/tailing ratio and the cement/sand ratio. Generally, the higher the cement/sand ratio is, the higher the strength of the backfill. With the increase in waste rock content, the strength of the backfill increases first and then decreases. This is due to the structure of the backfill. It is known from Table 3 that when the waste rock content is 35% and the cement/sand ratio is 1 : 4, the maximum strength of the backfill is 1.92 MPa, and when the waste rock content is 40% and the cement/sand ratio is 1 : 10, the minimum strength of the backfill is 0.39 MPa.

3.2. The Influence of Waste Rock Content on Backfill Strength. Backfills with waste rock contents of 25%, 30%, 35%, and 40% were selected for uniaxial compressive strength experiments. The uniaxial compressive strength of the backfill under different waste rock contents is shown in Figure 4. When the waste rock content increases, the strength of the backfill increases first and then decreases. When the waste rock content is 35%, the strength of the backfill reaches the maximum value. When the cement/sand ratio is 1 : 4 and the waste rock content is 35%, the maximum strength of the backfill is 1.92 MPa.

The addition of waste rock can improve the strength of the backfill. After a small amount of waste rock is added, the tailings completely wrap around the rock. With the increase in the waste rock content, when the cement content is constant, the specific surface area of the solid material decreases, so the amount of cement distribution per unit area increases, which causes the strength of the backfill to increase. When the waste rock content continues to increase, due to the large particle size of the waste rock, the tailings cannot completely wrap around the waste rock. At this time, contact cement or pore cement is formed. The excessive waste rock content changes the cement type of the backfill, resulting in its strength being reduced.

3.3. The Influence of the Cement/Sand Ratio on Backfill Strength. Backfills with cement/sand ratios of 1 : 10, 1 : 8, 1 : 6, and 1 : 4 were selected for the uniaxial strength experiment. The uniaxial compressive strength of the backfill under different cement/sand ratios is shown in Figure 5. It can be seen in Figure 5 that when the waste rock content is constant, the higher the cement/sand ratio, the higher the cement content, the better the cementation effect of the backfill, and the higher the uniaxial compressive strength. When the cement/sand ratio is 1 : 4 and the waste rock content is 35%, the maximum uniaxial compressive strength of the backfill is 1.92 MPa.

When the waste rock content is 25%, the strength of the backfill increases with an increasing cement/sand ratio, and the increase in strength rate is stable. At this time, the waste rock content is low, the increase in cement content continuously enhances the cementing effect, and the increase rate in strength is stable. When the waste rock content increases to 40%, the waste rock content is higher at this time, and the cement content increases to a certain extent. When the cement/sand ratio is 1 : 6, by continuing to increase the cement/sand ratio, the cement content continues to increase, but at this time, the cementing reinforcement effect reaches its limit, and the increase rate in strength decreases despite the continued increase in the cement/sand ratio; its strength may reach a limit and not increase.

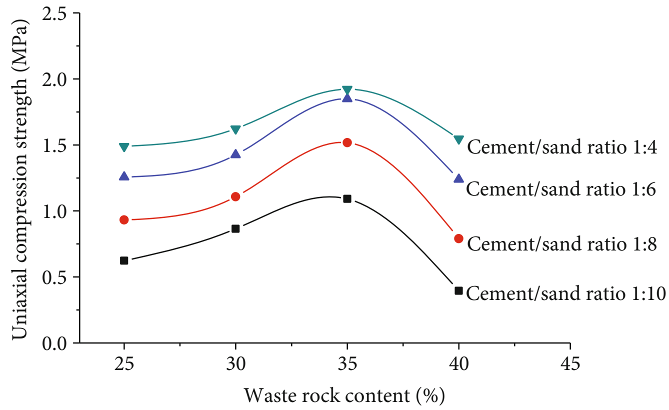


Figure 4: Uniaxial compressive strength under different waste rock contents.

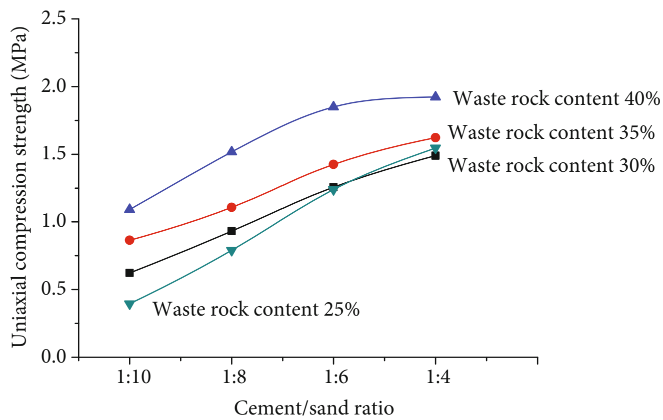
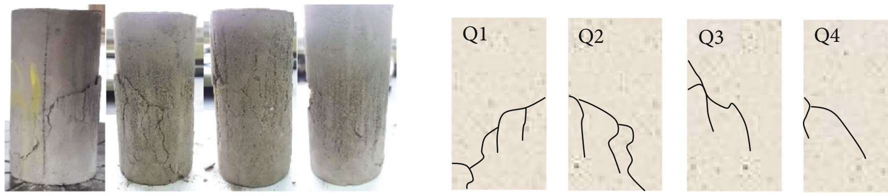


Figure 5: Uniaxial compressive strength under different cement/sand ratios.

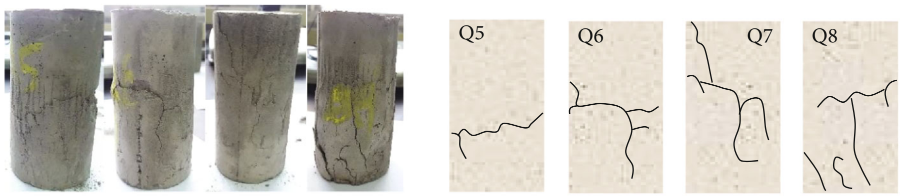
4. Damage Characteristics of Backfill

4.1. Damage Form of Backfill. Based on the uniaxial compression tests of the backfills with different cement/sand ratios and waste rock contents, the failure forms are shown in Figure 6. The Q1-Q4 specimens have a waste rock content of 20%, and the failure mode is similar to the shear failure of a single inclined plane. Due to the presence of waste rock, the crack does not fully develop on a flat inclined plane. With the increase in waste rock content, the crack development of the backfill is suppressed by the waste rock after stress, the cracks are more bifurcated, and the damage will no longer develop along a single slope. Multiple cracks develop. There are various types of failures, including X-type and Y-type failure surfaces, and some failures have developed multiple cracks. The Q1, Q5, Q9, and Q13 samples have a cement/sand ratio of 1 : 4, and the backfill is mainly damaged along a main near-horizontal crack in the middle of the specimen. Due to the large cement content, the overall cementation is good, the strength is high, and there are few cracks when the backfill fails. It can be seen from Figure 6 that as the cement/sand ratio decreases, the cement content decreases, the cementing effect is poor, the strength is low, and there are many irregular cracks when damaged.

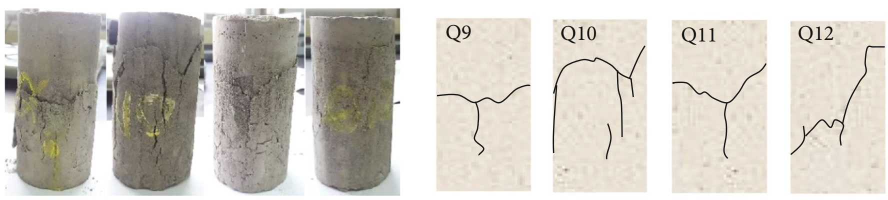
4.2. Damage Process of Backfill. Under the uniaxial compression load, the failure process of the backfill is shown in Figure 7. After being stressed, the backfill first passes through the pore fissure compaction stage, and the original microcracks are gradually closed. As the pressure increases, the backfill enters the stage of elastic deformation to the stable development of microelastic cracks. At this stage, microcracks begin to appear inside the backfill. The stress continues to increase, and the cracks of the backfill continue to develop and enter the stage of unsteady fracture development until the peak strength is reached. After the peak strength of the backfill is reached, it enters the postfracture stage, the internal structure is destroyed, the crack develops fast, and the fracture surface is formed, but some strength remains. It can be seen from Figure 7 that during the experiment, sporadic cracks first appear on the surface of the backfill. With increasing pressure, the cracks slowly develop and extend, and the cracks slowly penetrate and connect to form a fracture surface. The structure of the backfill, the waste rock content, and the cement/sand ratio in the backfill have a significant impact. The cemented strength is less than the strength of the waste rock. The damage is mainly caused by insufficient cemented strength. Cracks eventually lead to destruction. The crack passes the waste rock particles to form a series of cracks, which eventually lead to destruction.



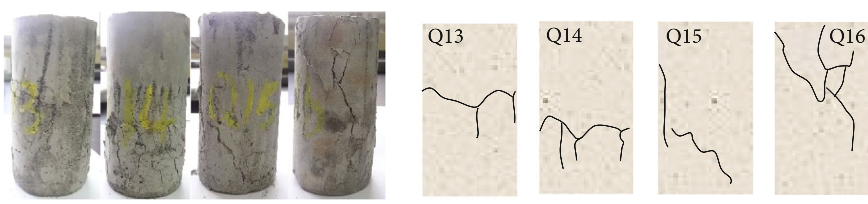
(a) Waste rock content 25%



(b) Waste rock content 30%



(c) Waste rock content 35%



(d) Waste rock content 35%

Figure 6: Damage form of backfills.

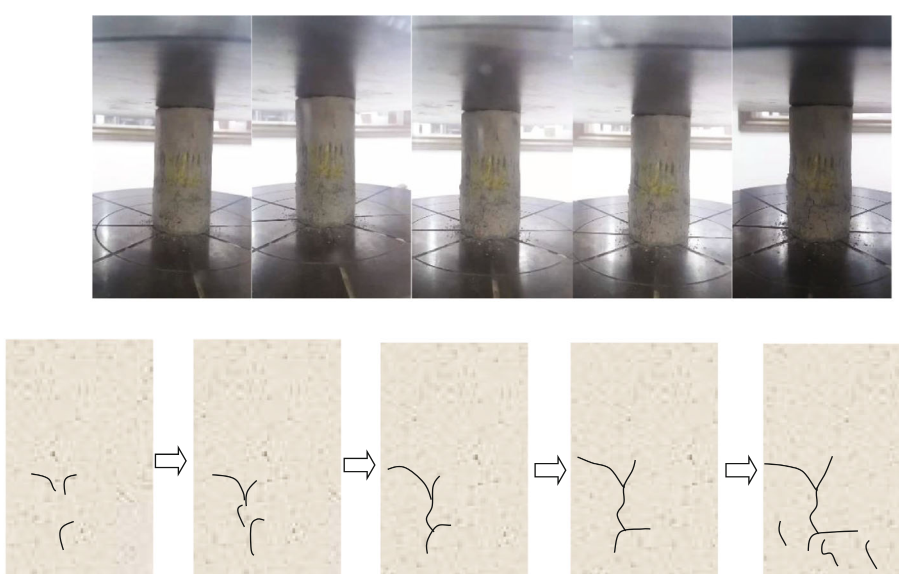


Figure 7: Damage process of backfill.

5. Conclusion

(1) When the waste rock content is constant, the strength of the backfill increases with the increase in the cement/sand ratio. The higher the cement/sand ratio is, the higher the cement content in the backfill, the better the cementing effect of the backfill, and the higher the uniaxial compressive strength. When the waste rock content is constant and the cement/sand ratio increases to a certain level, the increase in the strength of the backfill slows until the strength of the backfill reaches a limit and no longer increases

(2) When the cement/sand ratio is constant, as the waste rock content increases, the strength of the backfill increases first and then decreases. When the cement content is constant, the addition of a certain amount of waste rock reduces the specific surface area of solid materials in the backfill, increases the amount of cement per unit area, and improves the strength of the backfill. When the waste rock content is too high, due to the large particle size of the waste rock, the tailings cannot completely wrap around the waste rock, resulting in a weakening of the cement in the backfill, which reduces the strength of the backfill

(3) As the waste rock content increases, the crack propagation of the backfill is inhibited by the waste rock after the stress is applied, the cracks diverge more, and the damage no longer develops along a single slope. As the cement/sand ratio decreases, the cementing effect is poor, the strength is lowered, and there are more irregular cracks when the backfill is destroyed

(4) During the process of the backfill being damaged by force, sporadic cracks first appear on the surface of the backfill. With increasing pressure, the cracks slowly develop and extend, and the cracks slowly penetrate and connect to form a fracture surface. The backfill structure, the waste rock content, and the cement/sand ratio in the backfill have a significant impact. The cemented strength is less than the strength of the waste rock. The damage is mainly caused by insufficient cemented strength. Cracks eventually lead to destruction. The crack passes the waste rock particles to form a series of cracks, which eventually lead to destruction

Data Availability

The strength data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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