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# Influence of structural factors on uniaxial compressive strength of cemented tailings backfill

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## HIGHLIGHTS

- Structural effect on compressive strength of cemented tailings backfill (CTB) was studied.
- Increasing the filling time stages led to a remarkable decrease in CTB's strength properties.
- The CTB's compressive strengths decreased gradually with increasing filling interval time.
- The compressive strength showed an U-type distribution with increasing filling surface angles.
- Some empirical equations were developed between CTB's structural factors and strength gain.

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## ABSTRACT

In this paper, the influence of structural factors on the uniaxial compressive strength (UCS) of cemented tailings backfill (CTB) was experimentally investigated focusing on the filling time (FT), filling interval time (FIT) and filling surface angle (FSA). A number of CTB samples with a diameter × height of 50 mm and height of 100 mm were prepared at different FTs (1, 2, 3, and 4 stages), FITs (12, 24, 36, and 48 h), and FSAs (0, 15, 30, 45, and 60°) and subjected to UCS test to determine their mechanical strength performance. Results show that: (1) The UCS of the CTB samples decreased with the increase in FTs. The polynomial could represent the quantitative relationship between the backfill strength and FT. When the solid density (SD) within the CTB was constant, the value of the strength reduction coefficient $k$ gradually decreased with the increase in FTs. When the SD was 65–75 wt%, the corresponding value of $k$ remained between 0.592 and 0.967. (2) With the extension of the FIT, the UCS values of the CTB samples gradually decreased. The polynomial function could characterize the quantitative relationship between the UCS and FIT. The FIT only slightly influenced the strength performance of the CTB samples. The failure mode of the CTB samples may be tensile failure–transition from tensile failure to the shear failure-tensile shear pattern with the increase in the FIT. (3) The UCS showed a U-type distribution that decreased first and then increased with the increase in the FSAs. When the FSA changed from 0° to 60°, the UCS of the CTB samples first decreased and then increased with the FSA. The results presented in this study contribute to a better understanding of the effect of structural factors on CTB's mechanical properties.

## 1. Introduction

Underground mining is one of the important methods used to obtain mineral resources; but can result in a large number of underground goafs. As suggested by statistics [1], the total volume of mined-out areas in China has exceeded 25 billion m$^3$. Therefore, cemented tailings backfill (CTB) is a safe and reliable method in governing goafs. The backfill method, depending on the production capacity, is mainly divided into cut-and-fill and subsequent mining methods in China. The subsequent mining method has been extensively utilized in large-scale underground mines in China and abroad due to its large production capacity, low loss of poverty, and high safety. The method is generally applied to a thick ore body that exhibits favorable stability on a large scale [2]. Ore blocks are divided into rooms and pillars along or vertical the ore body. The length of the room and pillar is 15–22 m, and the level

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height is 60–150 m, with the application of large-diameter longhole blasting and large trackless equipments. The full tailings or deslimed tailings are used in cemented backfilling after room recovery, and uncemented tailings or waste rocks are used after pillar recovery. The method has been successfully applied in Dongguashan copper mine, Anqing copper mine, Caolou iron mine, and Lilou iron mine in China for many years, and it has achieved remarkable economic benefits.

The goaf after room recovery is approximately $10^4$–$10^5$ $m^3$, and such a giant space cannot be filled at one time, as the capability of filling stations in China is approximately 80–150 $m^3$/h. Therefore, several filling events (i.e., repeated filling application) are needed in the backfilling mining method. To fill stopes, many mines use a strategy in which backfilling is carried out in two stages which include a plug pour and final pour in order to reduce the pressures on the barricade. The curing period for a plug pour is often between 3 and 7 days which is a conservative approach. This delay will lead to CPB strength gain and thus protect the backfill barricade when the final fill is poured [3]. Simultaneously, the CTB is located in adjacent stopes, the stability of which is essential for the safe and efficient recovery of pillars. Fig. 1 shows the structural properties of a CTB in the subsequent mining method. Most mines utilize the underhand cut and fill mining method or box stoping method due to the relatively low rock quality in the ore zones and shallow dipping 25–45° ore body geometry [4].

Numerous studies on the physical properties of filling have been carried out [5–11, 38]. Curing temperature, cement type, and admixture have a considerable impact on mechanical strength properties of cemented paste backfill (CPB) [12–16]. A laboratory investigation was conducted to study the effect of curing and ambient temperatures on the reactivity of CPB [12]. They found that as the curing temperature increases, the reactivity generally decreases. Jiang [13] analyzed the strength characteristics of cemented backfill under a frozen state by using a temperature sensor. The porosity and water content were found to increase with elevated temperature. Wu [14] investigated the influence of various cement types and water qualities on the strength properties of CTB samples. They found that cement has an apparent influence on the UCS performance of CPB samples. An experimental study also demonstrated the effect of the addition of maple-wood sawdust on the mechanical and microstructural properties of CPB samples [16].

The abovementioned research mainly focused on an integral backfill sample. Therefore, the structural characteristics are not considered. During the past 20 years, several studies have been conducted to understand the factors that affect the UCS of CPB samples [17–19]. However, experimental data about the effect of structural factors on CPB's strength is quite limited. Moreover, most of the previous studies only investigated the mechanical properties of CPB samples. Studies on the strength properties of CTB samples affected by structural effects are still lacking. Ghirian and Fall [20]found that the filling sequence can affect some of the CPB behaviors or properties, such as hydraulic conductivity and evolution of suction when the filling strategy comprises three stages of filling and 24 h of curing time (or delay) between each lift. Cai [21] briefly described the phenomenon of stratification characteristics of CTB, but did not introduce it in depth. Liu [22] briefly calculated the strength of layered composite backfill with Dongguashan Copper as the engineering background. Cao [23–26] conducted interior researches considering the filling interval of CTB samples and the number of filling layers. It was shown that the strength characteristics of layered cemented tailings backfill (LCTB) and integral CTB materials were completely differed when they have the same cement-tailings ratio, solid density (SD), and curing period.

The main structural factors, such as filling time (FT), filling interval time (FIT), and filling surface angle (FSA) were studied to explore the influence of structural effect on strength properties of CTB samples. The samples with a diameter of 50 mm and a height of 100 mm prepared at different FTs (1, 2, 3, and 4 stages), FITs (12, 24, 36, and 48 h) and FSAs (0°, 15°, 30°, 45°, and 60°) were subjected to the UCS test. Unconfined compression tests were conducted by SANS testing system, and the results were recorded.

## 2. Materials and methods

### 2.1. Materials

#### 2.1.1. Tailings characteristics

Particle size distribution (PSD) of the tailings was analyzed using a SA-CP3 laser particle sizer under dry conditions in accordance with the ASTM D421 and D4222 standard procedures. Fig. 2 shows the PSD of the tailings sampled from Lai-xi gold mine in northeast China. As shown in Fig. 2, the percentage of fine particles with a size smaller than 12.13 μm reached 50%. The average particle size $d_{50}$ was 139.94 μm, the average particle size $d_{av}$ was 144.26 μm, the specific surface area was 1077.67 $m^2$/kg, and the specific gravity was 2.65.

Mineralogical analysis was performed on micronized tailings by X-ray diffraction (XRD), which used an Ultima IV X-ray diffractometer from Rigaku Corporation from Japan. The equipment parameters: working voltage is 40 kV, and scanning speed is 20°/min. The chemical property of the tailings sample is shown in Table 1. $SiO_2$ was the main mineral within the tailings (65.7%). The other important minerals were $Al_2O_3$ (14.3%), CaO (1.88%), MgO (0.49%), and Fe (3.05%). The main compositions of the tailings sample (e.g., $SiO_2$, $Al_2O_3$ and CaO) exerted a relatively positive effect on coagulation and strength development.

#### 2.1.2. Binders

Lai-xi gold mine is located in northeast China. Its main mining method is subsequent mining. This mine used ordinary Portland cement P.O. 32.5 to mix the tailings for backfilling. The ordinary Portland cement P.O. 32.5 was selected as the basic

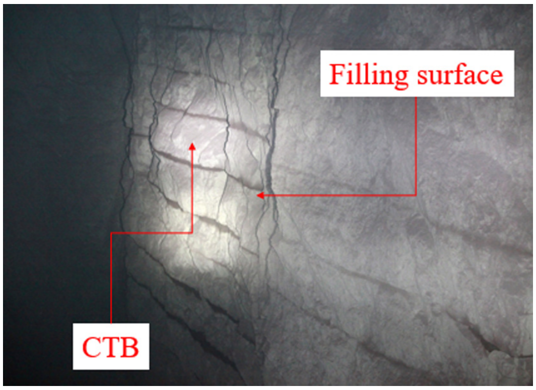

**Fig. 1.** Structural phenomenon in the underground cemented tailings backfill.

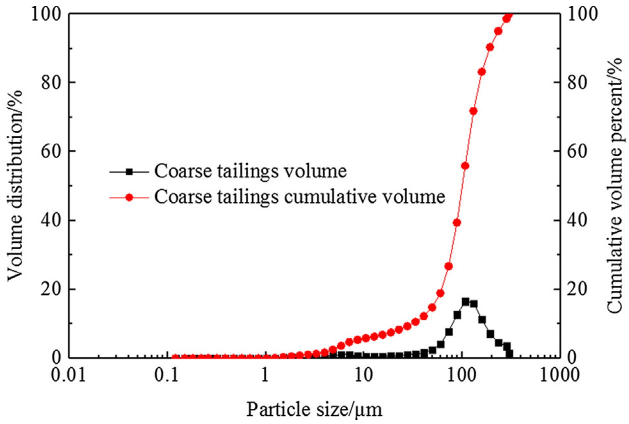

**Fig. 2.** The particle size distribution of the tailings studied.