Effect of Moisture Content on the Ductility of Cemented Paste Backfill

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Abstract. The ductility of cemented paste backfill at different moisture content were researched in this paper. The cemented paste backfill specimens at three different moisture content were prepared and the uniaxial compressive tests were conducted. The results show that the compressive strength of specimen decreases with the increase of moisture content. However, the ductility of specimen increases with the increase of moisture content. The elastic modulus and the rate of post peak stress reduction decreases with the increase of moisture content. The obtained results are helpful to better understand the behavior of the cemented paste backfill under different moisture condition, which could provide guidance for safe mining.

Keywords: Cemented paste backfill; moisture content; ductility.

1. Introduction
With the continuous high intensity mining in recent years, mining is gradually moving to the deep where the environment is more complex and the pressure problem is becoming more and more serious. Meanwhile, the tailings, a mining process waste, is threatening the healthy development of human for most tailings was stored by building tailings ponds [1].

The wide use of cemented paste backfill can be a good solution for these two problems. The major components of a typical cemented paste backfill is tailings, and the cement content is between 3 to 7%. Therefore, tailings can be fully utilized at a lower cost. Cemented paste backfill materials in the stopes can provide a safe platform for workers and a ground support. So the good mechanical properties are an important indicator of cemented paste backfill.

The last two decades have seen a growing trend towards the study of cemented paste backfill. Kesimal et al. [2] investigated the effect of properties of tailings and binder on the compressive strength of cemented paste backfill specimens. They reported that the strength development of paste backfill samples is related to the w/c ratio and the properties of tailings and binder. Bayram et al. [3] studied the influence of binder type dosage on the compressive strength of cemented paste backfill of sulphide-rich tailings, they noted that the mechanical performance of cemented paste backfill is associated with its susceptibility to sulphate attack. Wu et al. [4] carried out a series of experiments to investigate the coupled effects of cement type and water quality on the properties of cemented paste backfill. They reported that cement has an obvious influence on the unconfined compressive strength of cemented paste backfill while water quality barely affects that. Yi et al. [5] added polypropylene fibers into the...
cemented paste backfill to reduce the dosage of cement. Mangane et al. [6] reported an increase of the slump and mechanical strength of cemented paste backfill with the addition of super-plasticizers. However, the goaf often contains underground water to varying degrees. And free water will infiltrate into the cracks of cemented paste backfill, which will weaken the performance of the cemented paste backfill and reduce the mechanical strength of the backfill body [7]. Thus, it is important to understand the mechanical behavior of the cemented paste backfill with different water content. Although the strength variation of cemented backfill with cement-sand ratio of 1:4 at three different water content was studied by Nie et al. [8], the mechanical behavior of cemented paste backfill with a low cement content still remains unclear and need to be studied.

To investigate the ductility of cemented paste backfill at different water content, cemented paste backfill specimens with different water content were prepared, the uniaxial compression tests were carried out.

2. Experimental Part

2.1. Specimen Preparation

Tailings as shown in Fig. 1 was obtained from the south of Shandong Province, China. It is classified as sandy silt. Ordinary Portland cement was used in this study. The cement content of the cemented paste backfill was selected as 5% which is the common dosage of cemented paste backfill [9]. First, the tailings and cement were weighed on an electric scale and then poured in to a bucket. Then the water was added to achieve a solid content of 75%. All materials in the bucket were mixing manually for at least 10 minutes and then poured into a steel mold with a diameter of 5 cm and a height of 10 cm as shown in Fig. 2. After 24 hours, the specimens should be demold and cured in a humid chamber for 28 days. During the curing time, the temperature is kept at 20°C and water is sprayed regularly.

![Fig. 1 Tailings used in this research](image1)

![Fig. 2 Steel mold filled with slurry](image2)

Initial experiment has been done to determine the relationship between drying time and moisture content. Specimens after curing for 28 days were weighed immediately and stored in groups. No treatment were done to the specimens in group B. While the specimens in group A were oven-dried for 24 hours at 60°C to obtain the completely dried specimen. The specimens in group C were oven-dried for about 12 hours at 60°C until the target moisture content was achieved. Since there is no standard for the preparation of cemented paste backfill specimens, the drying temperature and curing temperature were determined according to the GB/T 23561.5－2009 and the previous research [10]. The moisture content of each specimens were calculated by the following equation:

$$\omega_c = \frac{m_c - m_d}{m_d}$$

(1)

Where $\omega_c$ is the moisture content of the specimen, $m_c$ is the mass of the specimen in the current state, $m_d$ is the dry mass of the specimen. The accuracy of the moisture content was 0.01.
Three moisture contents were selected in this study. The moisture content of specimen in group B was 25%, the moisture content of completely dried specimen in group A was 0%, the target moisture content of the specimen in group C was determined as 13%. The designation of specimens of different moisture content is shown in Table 1.

| Specimen | 5A | 5B | 5C |
|----------|----|----|----|
| Cement content (%) | 5 | 5 | 5 |
| Moisture content (%) | 0 | 13 | 25 |

2.2. Testing Machine and Methodology

The uniaxial compression tests were carried out on the TAW-200 electronic multifunctional material mechanics testing machine (Fig. 3), which developed by Qingdao University of Science and Technology and Changchun Chaoyang Testing Machine Factory. This machine has two loading modes: force loading mode and displacement loading mode.

Once the specimen reached its target moisture content, it should be placed between two steel plates of the testing machine and start the uniaxial compression test as soon as possible to avoid the change of moisture content. In the test, the displacement loading mode was selected and the loading rate was determined as 0.2 mm/min to observe the post-failure character of the specimen.

3. Result and discussion

The compressive strength of the specimen decreased with the increase of the moisture content as shown in Fig. 4. The elastic modulus as shown in Fig. 5 shows the similar trend as the compressive strength. It can be found from Fig. 4-5 that the reduction in the elastic modulus seems to be more dramatic compared to the reduction in compressive strength of cemented paste backfill with introduction of water. The reduction in compressive strength and elastic modulus with the increase of the moisture content may be due to the fact that water enters the gap between the particles which could reduce the inter-particle cohesion and the friction, and the decrease of friction between particles leads to the acceleration of the cracks formation. These results are in agreement with the research by Nie et al. [8].
The failure strain of the specimen was found to be increased with the increase of the moisture content as shown in Fig. 6. The failure strain of 5A specimen is 0.77%, which increases to 1.04% 1.48% for the specimen 5B, 5C. Furthermore, it is observed that the higher moisture content lowers the rate of post peak stress reduction and changed the brittle behavior of dry backfill specimens. In order to describe the effect of moisture content on the change of brittle behavior of cemented paste backfill specimens, the ductility parameter D was proposed [11]. The ductility index D is defined to describe the ductility of specimens containing water as the equation (2).

$$D = \frac{\varepsilon_c}{\varepsilon_d}$$  \hspace{1cm} (2)

Where $\varepsilon_c$ is the failure strain of the specimen, and $\varepsilon_d$ is the failure strain of the completely dry specimen.

The calculation results of the value of ductility index D are shown in Fig. 8. These results suggest that the ductility index D increased with the increase of moisture content, and the rate of the increase of ductility is growing with the increase of moisture content. The higher ductility index for the cemented paste backfill specimens indicate that the specimens with higher moisture content can bear larger deformation than the specimens with lower moisture content. This may due to the fact that the introduction of water reduce the friction between particles and lowers the stiffness of cemented paste backfill to achieve the more ductile behavior.
4. Conclusion
In this paper, influence of moisture content on the ductility of cemented paste backfill was researched. Specimens with three different water content were prepared, the uniaxial compressive tests were conducted. The gotten details from the present study can be jotted out as follows:

1) Compressive strength of cemented paste backfill specimen decreases with the increase of moisture content.
2) Elastic modulus of the specimen decreases with the increase of moisture content.
3) Specimens with higher moisture content have lower post-peak stress reduction rate.
4) The increase of moisture content can increase the failure strain and ductility index, which indicates that the specimens with higher moisture content have higher ductility.

As a result, this paper provides information for understanding the ductility of cemented paste backfill at different moisture content. The findings will provide guidance for safe mining.

Acknowledgments
The authors gratefully acknowledge support from the General Program of National Natural Science Foundation of China (51674149), and the Shandong Provincial Natural Science Foundation, China (ZR2019MEE082).

References
[1] G.Y. Xiaofei Jing, Zuoan Wei, Experimental study on flow characteristics of tailings dam outburst mud based on different types of breaches, Rock and Soil Mechanics 33 (2012).
[2] A. Kesimal, E. Yilmaz, B. Ercikdi, İ. Alp, H. Deveci, Effect of properties of tailings and binder on the short-and long-term strength and stability of cemented paste backfill, Materials Letters 59(28) (2005) 3703-3709.
[3] B. Ercikdi, A. Kesimal, F. Cihangir, H. Deveci, İ. Alp, Cemented paste backfill of sulphide-rich tailings: Importance of binder type and dosage, Cement and Concrete Composites 31(4) (2009) 268-274.
[4] A. Wu, Y. Wang, H. Wang, S. Yin, X. Miao, Coupled effects of cement type and water quality on the properties of cemented paste backfill, International Journal of Mineral Processing 143 (2015) 65-71.
[5] X.W. Yi, G.W. Ma, A. Fourie, Compressive behaviour of fibre-reinforced cemented paste backfill, Geotextiles and Geomembranes 43(3) (2015) 207-215.
[6] M.B.C. Mangane, R. Argane, R. Trauchessec, A. Lecomte, M. Benzaazoua, Influence of superplasticizers on mechanical properties and workability of cemented paste backfill, Minerals Engineering 116 (2018) 3-14.
[7] C.L. Hui Xie, Analysis of the influence of water content on the deformation characteristics of litholiths with high water content, Journal of sichuan university (engineering science) 45 (2013).
[8] N. Yalin, W. Xiaojun, H. Guangli, L. Shichao, Strength and Damage Model Analysis of Pure
Tailings CementedFilling Body with Different Water Content, BULLETIN OF THE CHINESE CERAMIC SOCIETY 37(6) (2018).

[9] Q. Chen, Q. Zhang, C. Qi, A. Fourie, C. Xiao, Recycling phosphogypsum and construction demolition waste for cemented paste backfill and its environmental impact, Journal of Cleaner Production 186 (2018) 418-429.

[10] Y. Pu, M. Qinyong, Split Hopkinson pressure bar tests on sandstone in coalmine under cyclic wetting and drying, Rock and Soil Mechanics 34(09) (2013) 2557-2562.

[11] M. Bekhiti, H. Trouzine, M. Rabehi, Influence of waste tire rubber fibers on swelling behavior, unconfined compressive strength and ductility of cement stabilized bentonite clay soil, Construction and Building Materials 208 (2019) 304-313.