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Technical Paper

Study On Mechanical Properties Of Cemented Paste Backfill Using Fly-Ash-Based Cementitious Materials

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Abstract: In Mongolia, the Ulan lead-zinc mine is now struggling with high backfill operating costs and poor Cemented Paste Backfill (CPB) mechanical performance after curing. To solve this problem, BGRIMM Technology Group has investigated an activator that could mix with fly ash from Choibalsan Power Plant in Mongolia as a supplementary cementitious material for backfill. In this study, the mechanical performance of CPB samples prepared with various fly ash content and activator types were studied to provide a basis for the industrial application of fly ash-based supplementary cementitious materials. The research results indicate that partially replacing cement with fly ash reduces the uniaxial compressive strength (UCS) of CPB samples. Compared with the CPB sample prepared with pure cement, when the fly ash substitution rate is 10%, 20%, and 30%, the UCS reduced by 15.66%, 18.69%, and 32.83%, respectively. With the use of chemical activators, the UCS of CPB samples could be significantly improved. Among them, CPB samples prepared by the activator sodium sulfate+ sodium chloride+ TEA have achieved the highest UCS. Overall, this study shows that the synergistic effect of fly ash and chemical activators could effectively enhance the mechanical performance of CPB, which is beneficial for mine backfill cost reduction and could provide a basis for the further industrial application of fly ash-based cementitious materials in mine backfill.

Keywords: Fly Ash, Chemical Activators, Cementitious Materials, Mine Backfill, Tailings.

1. Introduction

Tailings are solid waste discharged by mines after grinding ore and extracting valuable components. Nowadays, tailings are mainly stored in tailings impoundment. The large amount of tailings occupies land resources and seriously pollutes the environment. Tailings slurry, made of cement, tailings, and water, is transported hydraulically to the underground mined stope or void. After sedimentation and consolidation, cemented backfill can support the surrounding rock mass and maintain the stability of the void (Figure 1). This strategy is now the main way to consume a large amount of tailings, which is conducive to decreasing the surface storage of tailings and reducing the safety risks of tailings impoundment [1–3]. According to statistics, the filling cost of underground mining operations in China accounts for about 50% of the total mining cost, and cement accounts for almost 70%-80% of the filling cost. Therefore, an economic substitute for cement is highly desirable for reducing the filling cost during

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mining operations [4–6].

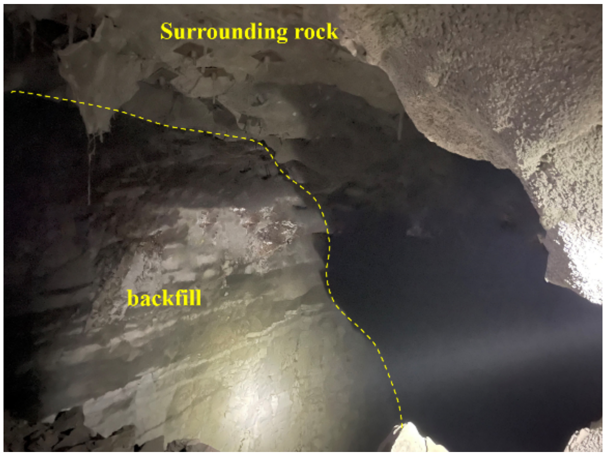

Fig. 1 – The backfill supports the surrounding rock

Wulan Mine in Mongolia adopts the full-tailings paste filling process, and the cementitious material is cement. The use cost of cementing material in 1m3 filling slurry is about 220 yuan, and the filling cost is high. Fly ash is a solid waste discharged from coal-fired power plants. Due to its low price and particular cementing activity, it has been widely used in mine filling [7–9]. Adding an appropriate amount of fly ash into the filling material can not only increase the slurry concentration, reduce the pipeline transportation resistance, improve the pumping performance of the paste, and promote the growth of the late strength of the backfill [10–12], but also reduce the filling cost, which has significant economic and environmental benefits.

This paper studies the effect of fly ash as a cementitious material on the strength of cemented backfill and also analyzes the activation effects of different types of chemical activators on fly ash-based cementitious materials. This investigation aims to lay a foundation for fly ash-based cementitious materials' safe, efficient, and economic application in mine filling.

2. Materials and methods

2.1. Raw materials

2.1.1. Cementitious material

P·O 42.5 cement (ordinary portland cement with strength grade of 42.5 MPa, OPC) was adopted in this study with chemical composition shown in Table 1, fly ash (FA) used was collected from the furnace bottom ash from the power plant in Choibalsan City, Oriental Province, Mongolia with chemical composition given in Table 1. The mineral composition of the FA is presented in Figure 2.

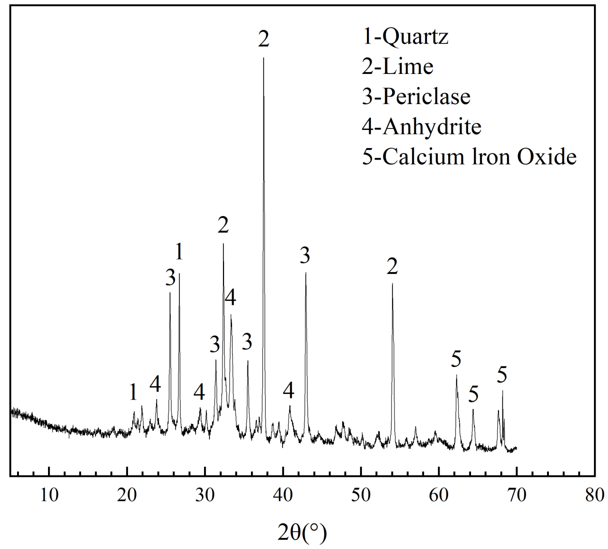

Fig. 2 – Mineral composition of fly ash

2.1.2. Tailings

The fine tailings (FT) were taken from the bottom stream of the thickener at the mine filling station, and was sampled at artificial intervals. The representative FA samples were obtained through the steps of settling, removing clear water, drying, mixing, and homogenization. After sample splitting, the physicochemical properties of FA were tested. Table 1 and Figure 3 demonstrate its chemical and mineral composition, respectively. The particle size distribution is provided in Figure 4 and the specific gravity of the tailings is 3.144 $\mathrm{g/cm^3}$.

2.1.3. Activators

The tests were conducted with three types of self-developed activators from BGRIMM Technology Group, which are sodium thiosulfate+ triethanolamine (TEA), sodium sulfate + TEA, sodium sulfate+ sodium chloride+ TEA. The addition of activator can accelerate the depolymerization of amorphous vitreous in fly ash and generate more hydration products.

Table 1 – Chemical composition (wt/%) of raw materials

Raw materials	Chemical composition (%)								
	CaO	SiO2	Al2O3	Fe2O3	MgO	SO3	Na2Oeq	MnO2	TiO2
OPC	60.18	22.46	4.18	3.22	2.25	2.41	0.56	0.12	0.08
FA	31.13	20.60	8.41	9.35	9.10	6.12	0.27	0.71	0.12
FT	12.87	46.59	10.66	17.48	1.16	3.45	0.43	0.98	0.14

Table 2 – Experimental mix proportion

Sample	Filling concentration(wt.%)	Binder-tailing ratio	Binder(wt.%)		Activator(wt.%)
			OPC	FA	
CFTB	68	1:4	100	0	0
CFTB_10	68	1:4	90	10	0
CFTB_20	68	1:4	80	20	0
CFTB_30	68	1:4	70	30	0
CFTB_30TSS_3	68	1:4	70	30	3
CFTB_30TS_3	68	1:4	70	30	3
CFTB_30TNS_3	68	1:4	70	30	3

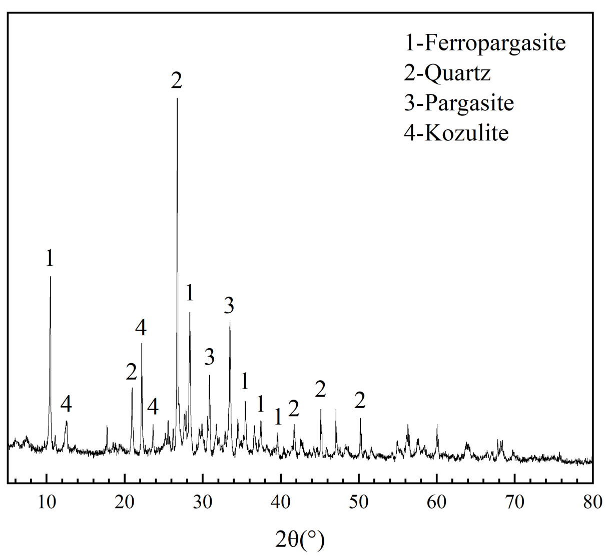

Fig. 3 – Mineral composition of tailings

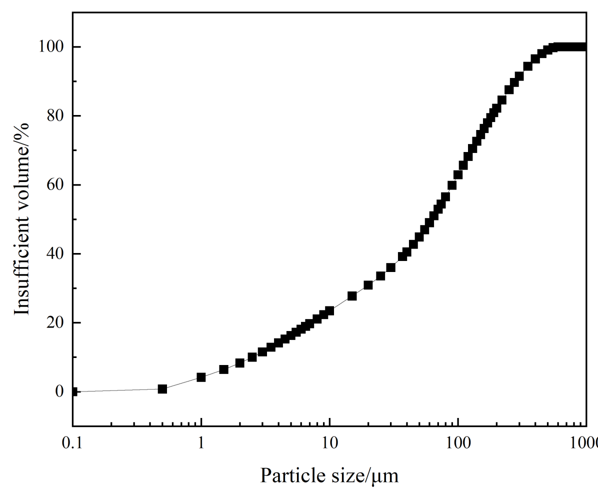

Fig. 4 – Distribution of tailings particle size

2.2. Test methods

2.2.1. Preparation and molding of filling slurry

1. Preparation of filling slurry

   The filling concentration was set at 68%, and the binder-tailing ratio was 1:4. The cementitious material, activator, FA and water were weighed according to the design ratio in Table 2. The filling slurry was then mixed uniformly by using planetary tailing mixer (model: JJ-5) at a rotational speed of 140r/min for 3min.

2. Molding and curing of the Cemented Paste Backfill (CPB)

   The well-mixed filling slurry was poured into a 70.7mm×70.7mm×70.7mm cubic mold for molding. After pouring, scrape the top opening of the mold and cover it with plastic wrap, and then put it into concrete standard curing box (model: YH-40B) for curing until the specified age (7d, 14d, 28d). The curing temperature was set at 20 ± 1°C, with curing humidity > 90%.

2.2.2. Mechanical Properties Testing of CPB

Computerized electro-hydraulic servo compression testing machine (model: YAW-300C) was used to test the UCS of CPB samples. Three samples were tested in each group and averaged to minimize error.

2.2.3. Fluidity Properties Testing of CPB

The fluidity of the backfill slurry is tested according to GB/T 8077-2016 (Chinese standard method).

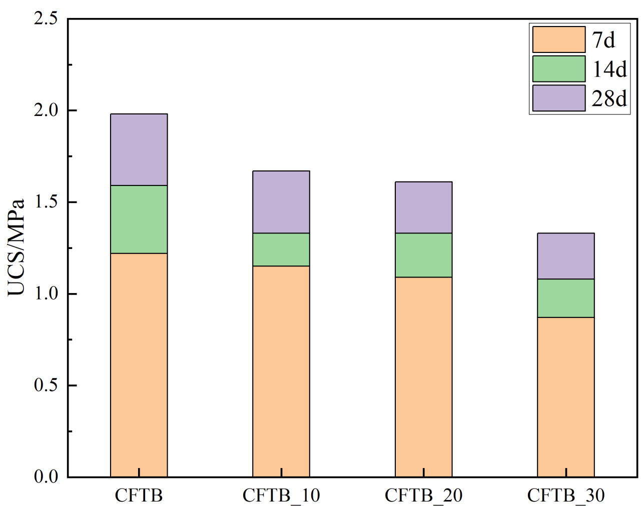

Fig. 5 – Changes in UCS of fly ash partially replacing cement backfill

3. Results and discussion

3.1. Effects of fly ash on the mechanical strength of cemented backfill

Figure 5 illustrates the influence of fly ash content on the UCS of the cemented backfill. It can be observed that the addition of fly ash is not conducive to the development of the backfill strength, and the higher the fly ash content, the greater the reduction in backfill strength. For the cemented backfill without fly ash (CFTB), the strengths are 1.22 MPa, 1.59 MPa, and 1.98 MPa for curing ages of 7 days, 14 days, and 28 days, respectively. For fly ash contents of 10%, 20%, and 30%, the strengths of CFTB_10, CFTB_20, and CFTB_30 after 7 days of curing are 1.15 MPa, 1.09 MPa, and 0.87 MPa, respectively, which represents reductions of 5.74%, 10.66%, and 28.69% compared to the 7-day strength of CFTB. After 28 days of curing, the strengths of CFTB_10, CFTB_20, and CFTB_30 are 1.67 MPa, 1.61 MPa, and 1.33 MPa, respectively, which indicates reductions of 15.66%, 18.69%, and 32.83%, respectively, compared to the 28-day strength of CFTB. This is because the pozzolanic activity of fly ash is relatively low. After adding fly ash, due to the reduction of cement dosage, the hydration products in the primary hydration reaction process are reduced, and the strength of the backfill is reduced.

3.2. Effects of fly ash on the fluidity of cemented backfill

The influence of fly ash content on the fluidity of cemented backfill is shown in Figure 6. It can be seen that the addition of fly ash will reduce the fluidity of the backfill slurry, and with the increase of fly ash content, the fluidity of the backfill slurry will decrease. The fluidity of CFTB, CFTB_10, CFTB_20 and CFTB_30 is 18 cm, 17.5 cm, 17.1 cm and 16.5 cm, respectively, and the fluidity of CFTB_10, CFTB_20 and CFTB_30 is 2.78%, 5.00% and 8.33% lower than that of CFTB, respectively. This is because the particle size of fly ash is finer than that of cement, and the water requirement of backfill slurry increases and the fluidity decreases after addition.

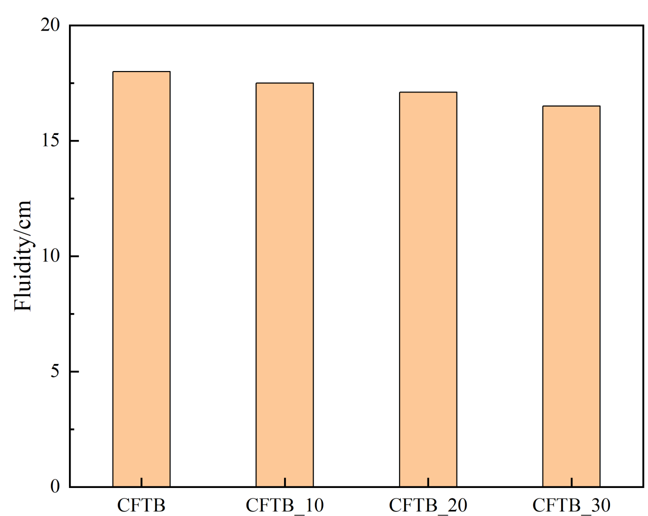

Fig. 6 – Changes in fluidity of fly ash partially replacing cement backfill

3.3. Effects of the activator on mechanical strength of fly-ash-based cemented materials

Figure 7 illustrates the variation in strength of the fly-ash-based cemented backfill with the addition of the activator. It can be observed that the addition of activators can significantly improve the strength of the fly-ash-based cemented backfill. Of all activators, the TNS improves the performance of the backfill most. For the cemented backfill without fly ash (CFTB), the strengths are 1.22 MPa, 1.59 MPa, and 1.98 MPa for curing ages of 7 days, 14 days, and 28 days, respectively. For the fly ash content of 30%, after the addition of TSS-type, TS-type, and TNS-type activators, the 7-days strengths of CFTB_30TSS_3, CFTB_30TS_3, and CFTB_30TNS_3 are 1.43 MPa, 1.50 MPa, and 1.51 MPa, respectively. This represents increases of 17.21%, 22.95%, and 23.77%, respectively, compared to the 7-day strength of CFTB. After 28 days of curing, the strengths of CFTB_30TSS_3, CFTB_30TS_3, and CFTB_30TNS_3 are 2.19 MPa, 2.18 MPa, and 2.21 MPa, respectively. This indicates increases of 10.61%, 10.10%, and 11.62%, respectively, compared to the 28-day strength of CFTB. The addition of activators to the fly ash-cement system can not only increase the liquid phase pH value, promote the leaching of active substances in fly ash but also maintain a relatively high level of liquid phase pH value in the later stage, promoting the secondary hydration reaction of fly ash and cement, thus promoting the hydration of fly ash and cement [13–15].

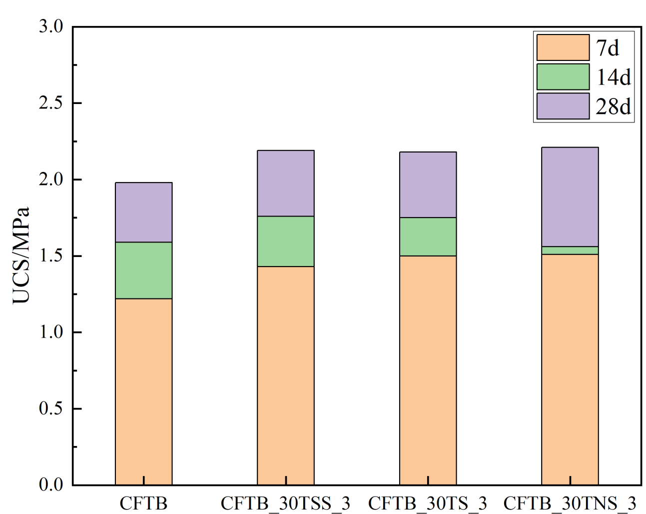

Fig. 7 – Changes in backfill UCS under the action of different activators

3.4. Effects of the activator on fluidity of fly-ash-based cemented materials

Figure 8 illustrates the fluidity change of the fly-ash-based cemented backfill with the addition of the activator. It can be seen that the addition of activator has little effect on the fluidity of backfill slurry. The fluidity of CFTB, CFTB_30TSS_3, CFTB_30TS_3 and CFTB_30TNS_3 is 18.0 cm, 18.2 cm, 17.8 cm and 18.5 cm, respectively. This is mainly because the content of activator is only 3%, the content is small, and the influence on the fluidity of backfill slurry is correspondingly small.

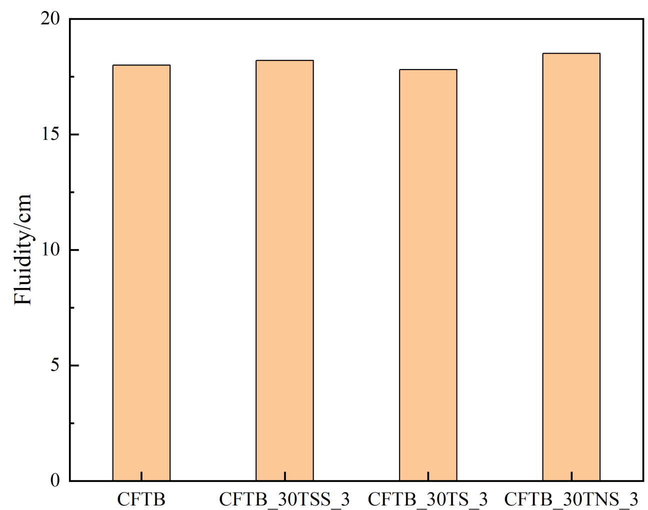

Fig. 8 – Changes in backfill fluidity under the action of different activators

4. Conclusions

1. Fly ash can be used as cementitious material for mine filling, but the use of fly ash alone to replace cement is not conducive to the growth of strength of CPB. Therefore, it is necessary to resort to the synergistic activation of activators to increase the dosage of fly ash to ensure the strength of CPB.

2. With the use of chemical activators, the UCS of CPB samples could be significantly improved. Among them, CPB samples prepared with sodium sulfate+ sodium chloride+ TEA have achieved the highest UCS.

3. The 28days UCS of CPB samples (filling concentration 68%, binder-tailing ratio 1:4, fly ash content 30%, TNS content 3%) prepared

with sodium sulfate+ sodium chloride+ TEA were 2.21 MPa, 11.62% higher than the UCS of CPB samples prepared without fly ash and activator. This shows that the synergistic effect of fly ash and chemical activator can effectively enhance the mechanical performance of CPB, which is conducive to reducing the amount of cement and the cost of mine filling. The research results of this paper can be applied to similar metal mines.

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References

[1] Yue Zhao, Y. Z., et al. (2022). Effect of saturation condition on the mechanical performance of mine backfill material. *ARMA US Rock Mechanics/Geomechanics Symposium*.

[2] Guo, L., et al. (2022a). Experimental study on direct tensile properties of cemented paste backfill. *Frontiers in Materials*, *9*, 864264.

[3] Zheng, D., et al. (2023). Initial pore distribution characteristics and crack failure development of cemented tailings backfill under low impact amplitude. *Frontiers in Earth Science*, *11*, 1330766.

[4] Guo, L., et al. (2022b). Non-bf slag-based green cementitious materials. *Frontiers in Materials*, *9*, 978032.

[5] Ma, Q., et al. (2023). Physical model investigation on effects of drainage condition and cement addition on consolidation behavior of tailings slurry within backfilled stopes. *International Journal of Minerals, Metallurgy and Materials*, *30*(8), 1490–1501.

[6] Sun, Q., et al. (2019). Preparation and microstructure of fly ash geopolymer paste backfill material. *Journal of Cleaner Production*, *225*, 376–390.

[7] L, L., S, R., C, Q., et al. (2021). Co-disposal of magnesium slag and high-calcium fly ash as cementitious materials in backfill. *Journal of Cleaner Production*, *279*, 123684.

[8] P, Y., L, L., Y, S., et al. (2023). Mechanical properties, pore characteristics and microstructure of modified magnesium slag cemented coal-based solid waste backfill materials: Affected by fly ash addition and curing temperature. *Process Safety and Environmental Protection*, *176*, 1007–1020.

[9] Q, S., S, T., Q, S., et al. (2019). Preparation and microstructure of fly ash geopolymer paste backfill material. *Journal of Cleaner Production*, *225*, 376–390.

[10] Behera, S. K., et al. (2021). Utilization of mill tailings, fly ash and slag as mine paste backfill material: Review and future perspective. *Construction and Building Materials*, *309*, 125120.

[11] Qi, T., et al. (2015). Effects of fly ash content on properties of cement paste backfilling. *Journal of Residuals Science & Technology*, *12*(3), 133–141.

[12] Li, M., et al. (2020). Reutilisation of coal gangue and fly ash as underground backfill materials for surface subsidence control. *Journal of Cleaner Production*, *254*, 120113.

[13] Cheng, B., et al. (2022). Effects of fly and coal bottom ash ratio on backfill material performance. *Construction and Building Materials*, *319*, 125831.

[14] K, B. S., P, M. D., P, S., et al. (2021). Utilization of mill tailings, fly ash and slag as mine paste backfill material: Review and future perspective. *Construction and Building Materials*, *309*, 125120.

[15] I, C., E, Y., & O, Y. A. (2021). Sodium silicate effect on setting properties, strength behavior and microstructure of cemented coal fly ash backfill. *Powder Technology*, *384*, 17–28.