การตรวจสอบสมบัติของวัสดุเหลือทิ้งในการป้องกันการพังทลายของเหมืองใต้ดินด้วยวิธีถมกลับ

Investigation of Waste Material Properties on Collapse Prevention in Underground Mine under the Backfilling Method

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บทคัดย่อ

วัสดุเหลือทิ้งถูกเลือกเป็นวัสดุสำหรับการถมกลับในเหมืองใต้ดินเนื่องจากมีจุดเด่นในการป้องกันการทรุดตัว มีต้นทุนที่คุ้มค่า และมีการกำจัดหางแร่ของเหมืองผิวดินตลอดอายุการทำเหมือง สมบัติของวัสดุเหลือใช้ที่ใช้ในการถมกลับอาจมีผลอย่างมีนัยสำคัญต่อพฤติกรรมของมวลหินโดยรอบ งานวิจัยนี้มีวัตถุประสงค์เพื่อตรวจสอบสมบัติของวัสดุเหลือทิ้งในการป้องกันการพังทลายของเหมืองใต้ดินด้วยวิธีถมกลับ วัสดุเหลือใช้ที่ใช้ในการศึกษานี้ ได้แก่ เปลือกหอยนางรม หางแร่ดินขาว ฝุ่นหิน และยิปซั่มคุณภาพต่ำ ซึ่งถือว่าเป็นวัสดุไม่มีค่าและไม่เป็นอันตราย วัสดุถมกลับ 5 ชนิดที่ทำขึ้นจากการผสมวัสดุเหลือทิ้ง ซีเมนต์ น้ำ และตัวเชื่อมประสานในสัดส่วนที่ต่างกันถูกนำมาทดสอบความสามารถในการไหลโดยวิธีวัดค่าการยุบตัว และทดสอบความสามารถในการรับแรงอัดในแกนเดียว ณ 3 ช่วงเวลาการบ่มเพื่อให้วัสดุผสมแข็งตัวที่แตกต่างกันคือ 8, 16 และ 28 วัน ผลการวิจัยพบว่าวัสดุผสมทั้งหมดอยู่ในเกณฑ์มาตรฐานในการทดสอบค่าการยุบตัว ยกเว้นวัสดุผสมที่มียิปซั่มคุณภาพต่ำเป็นส่วนประกอบ นอกจากนี้แนวโน้มโดยรวมของกำลังรับแรงอัดของวัสดุผสมเพิ่มขึ้นเมื่อเวลาในการบ่มเพิ่มขึ้น วัสดุผสมที่มีหางแร่ดินขาวมีกำลังอัดสูงสุด เท่ากับ 6 MPa ที่เวลาการบ่ม 28 วัน ในขณะที่วัสดุผสมที่มียิปซั่มเกรดต่ำมีกำลังอัดต่ำสุด โดยมีค่าเพียงครึ่งหนึ่งของกำลังอัดของวัสดุผสมที่มีหางแร่ดินขาว การมีหางแร่ดินขาวมีผลกระทบอย่างมากต่อความแข็งแรงเนื่องจากความสามารถในการลดฟองอากาศภายในส่วนผสมปูนซีเมนต์ นอกจากนี้การเพิ่มเวลาในการแข็งตัวยังส่งผลให้ความแข็งแกร่งของวัสดุถมกลับเพิ่มขึ้นอีกด้วย

คำสำคัญ: วัสดุเหลือทิ้ง การถมกลับ เหมืองใต้ดิน

Abstract

Waste material has been selected as an effective backfill in underground mines due to its advantages of collapse prevention, cost-effective, and less surface disposal of mine tailing during mining life. The properties of waste-backfilled materials may significantly support the behavior of the surrounding rock mass. This study aimed to investigate waste material properties on collapse prevention in underground mine under the backfilling method. Waste materials, regarded as valueless and harmless, used in this study were oyster shell, kaolin tailing, stone dust, and low-grade gypsum. Five different mixtures of backfill material made from different ratios of waste materials, cement, water and interface agents were subjected to slump test and uniaxial compressive strength test performed at 3 different curing times including 8, 16 and 28 days. The results showed that all mixtures were within the standard of the slump test except the one with low-grade gypsum as an ingredient. In addition, the overall trend of compressive strength of the mixtures increased as the curing time increased. The mixture with kaolin tailing exhibited the maximum compressive strength of 6 MPa at curing time of 28 days, whereas that with low-grade gypsum exhibited the lowest compressive strength, twice less than the compressive strength of the mixture with kaolin tailing. The presence of kaolin tailing has a significant impact on strength due to its ability to reduce bubbles inside cement mixtures. Furthermore, increasing in curing time leads to an increase in backfill strength.

Keywords: Waste material, Backfilling, Underground mine

1. Introduction

Underground mining has been used to extract the ore, which is located deep from earth's surface [1]. There are many mining methods for underground mining, however, the mining method should offer suitable technique, ease of operation, little capital and operating costs, safety and healthy working conditions [2], [3]. During the mining operation, the ore was excavated and then became large voids or caving, these are the causes of mine collapse, surface subsidence, and unsafe working conditions [4]-[6], so the appropriate choice of backfilling materials in underground mine should be taken into account, which can support the weight of soil over the excavated area (i.e., a hanging wall), regional stability, and controlling surface subsidence [7]-[9]. The main factors considered for materials include the backfill properties, deformation capacity, economic benefits, and readily available, as well as environmental impact. In these conditions, waste materials are selected in the rational choice of backfilling materials [10], [11].

This study aimed to investigate waste material properties on collapse prevention in underground mine under the backfilling method. Waste materials used in this study were oyster shell, kaolin tailing, stone dust, and low-grade gypsum.

2. Materials and methods

Underground mining is an alternative mining technique used to extract minerals when surface mining is not economically feasible. Minerals can be extracted throughout the mining process based on the orientation of mineral veins or strata. In addition, it is imperative to take into account the strength characteristics of both mineral deposit and surrounding rock mass while selecting underground mining techniques [12]. The extraction process results in the creation of voids. There are several ways to deal with the void [13]. The backfilling mining approach significantly decreases surface subsidence compared to strip mining and caving mining methods [5].

2.1. Backfill

The materials are often used for backfill, such as granular material, cemented material, high-water-content materials, waste rocks, and metallurgical processed tailings [4], [14]. The waste materials that received more attention to be selected for backfilling underground mines, such as mine tailing, industrial waste, and used materials. It is recommended that backfill materials should be chosen locally near the mine [15]. Backfill are transported to the void known as "stope" through the pipelines. Moreover, the backfill are general in form of slurries for ease of transport [7]. In this study, alternative waste materials from surrounding mine are considered to study the behavior of backfill, that is oyster shells, kaolin tailings, stone dust, and low-grade gypsum, as shown in Figure 1. All materials are ground to an average size of -60 to +200 mesh before being mixed together.

2.2. Experimental design

There are five different samples of backfilling materials which mixed in different proportion. The mixture consists of waste material, cement, water, and interfacing in an appropriate proportion by weight. In addition, ordinary Portland Cement type I was selected for experimental studies, as well as perlite, rice husk ash, sand, wood ash, and dolomite as admixture cement. The backfill mixture is shown in Table 1.

2.3. Specimens and testing

A backfill mixture was prepared and mixed in different proportions as mentioned in the test plans. The backfill mixture was then compacted into 3 layers, with each layer receiving 25 blows from a rammer, following the slump test standard (ASTM C143 / C143M) and measuring the flowability of the mixture.

The specimens were prepared by filling the mixture into a PVC pipe of 55 mm (dimension) x 127 mm (height) and curing age at 8, 16, and 28 days (Figure 2) Increasing the solid content, it is necessary to eliminate air bubbles by shaking the slurry. The typical measure of backfill strength is determined by going through the UCS tests. The testing was carried out on three samples from each time period, as demonstrated in Figure 3.

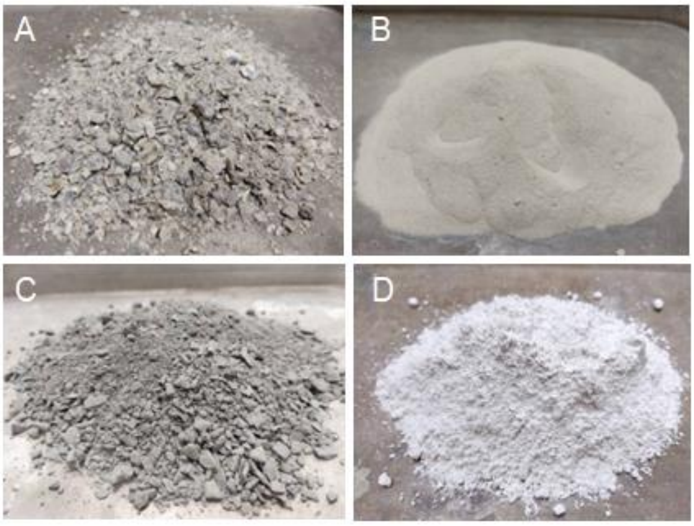

Figure 1 Waste materials used in this study
(A) Oyster shell, (B) Kaolin tailing, (C) Stone dust, and (D) Low-grade gypsum

Table 1 Backfill mixtures used in this study

Test	Material mixture	Mixing ratio
1	Oyster shells: Cement: Water: Perlite	5:2:4:1
2	Kaolin tailings: Cement: Water: Sand	4:2:4:3
3	Stone dust: Cement: Water: Rice husk ash	6:2:5:1
4	Low-grade gypsum: Cement: Water: Wood ash	3:2:4:1
5	Oyster shells: Cement: Water: Dolomite	6:2:3:2

Figure 2 Preparation of specimens for UCS test

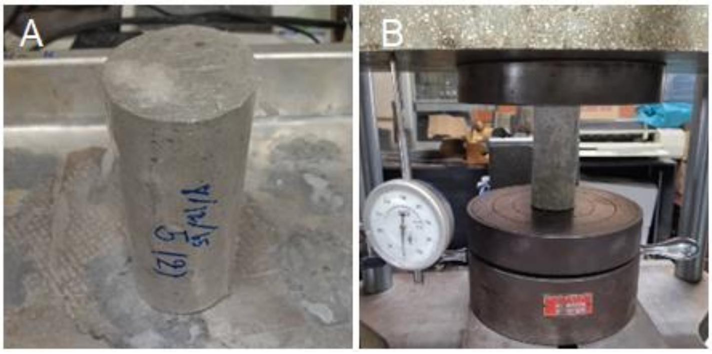

Figure 3 (A) Specimen used for UCS test; (B) Compressive strength (UCS) test of backfill

3. Results and discussion

3.1. Flowability of the backfill mixture

The flowability of Test Nos. 1, 2, 3, and 5 was within the standard of between 15 cm and 25 cm for the cemented paste backfill [16], following the slump test are 22, 24, 24, and 21 cm, respectively. However, the low-graded gypsum resulted in a flowability of 28 cm over the maximum standard, as shown in Figure 4. The dimensions of the backfill mixture for Test Nos. 1 to 5, which follow the flow test are 44, 40, 48, 50, and 34 cm, respectively.

3.2. Backfill strength

The backfill was carried out to determine the strength of a mix proportion by the UCS tests at different curing ages. In engineering practices, the suggestion for the UCS of the backfill ranges from 0.2 to 0.4 MPa, which is relative to the UCS of the surrounding rock mass between 5 MPa and 240 MPa [17]. Figure 5 shows a strength of backfill at 8, 16, and 28 curing ages. In addition, the average strength of Test Nos. 1 to 5 is approximately 2.05, 3.61, 3.25, 2.33, and 3.44 MPa, respectively. The strength of all tests experienced an increase as curing ages increased. Particularly, the strength of backfill indicates that a curing age of approximately 28 days would give a higher strength than a lower curing age. Furthermore, Test No. 2 represents the Kaolin tailing mixture that experienced the highest compressive strength of 6 MPa at 28 days, influenced by the adhesion of kaolin tailings, cement and sand. Test No. 4 refers to the low-grade gypsum mixture exhibited a minimum compressive strength lower than the Kaolin tailing mixture around 2 times.

The strength rate of backfill was simulated in a simple equation from the results of the UCS tests. The strength rate can be increased by curing ages. The equation of Test Nos. 1 to 5 described the strength rate of each test as below:

$$f(x)=\begin{cases}0.2562x, & if\ x\in[0,8]\\ 0.1575x+0.79, & if\ x\in[8,16]\\ 0.0225x+2.95, & if\ x\in[16,28]\end{cases} \quad (1)$$

$$f(x)=\begin{cases}0.4512x, & if\ x\in[0,8]\\ 0.0486x+3.22, & if\ x\in[8,16]\\ 0.1667x+1.33, & if\ x\in[16,28]\end{cases} \quad (2)$$

$$f(x)=\begin{cases}0.4062x, & if\ x\in[0,8]\\ 0.0425x+2.91, & if\ x\in[8,16]\\ 0.05833x+2.66, & if\ x\in[16,28]\end{cases} \quad (3)$$

$$f(x)=\begin{cases}0.2912x, & if\ x\in[0,8]\\ 0.00875x+2.26, & if\ x\in[8,16]\\ 0.05167x+1.57, & if\ x\in[16,28]\end{cases} \quad (4)$$

$$f(x)=\begin{cases}0.43x, & if\ x\in[0,8]\\ 0.03125x+3.19, & if\ x\in[8,16]\\ 0.04417x+2.98, & if\ x\in[16,28]\end{cases} \quad (5)$$

Where:

x = curing ages

$f(x)$ = strength rate of backfill

3.3. Influence of backfill on overburden condition

Table 2 shows the calculated depth of each test according to given unit weight of the surrounding rock mass. In this case, assuming the overburden is sandstone with a unit weight of 2,650 kg/m^3. The depth from the ground surface can be determined by Vertical stress due to gravitational loading of the overlying mass of overburden $(\sigma=\gamma h)$, and the backfill was filled and supported this total weight [17]. Test No. 2 referred to the kaolin tailings mixture, which has significantly prevented the collapse in underground stope much than other backfill mixtures. In contrast, Test No. 4, which used a low-grade gypsum mixture had the lowest depth by around 50% in same curing age condition.

4. Conclusion

A comprehensive summary of the results based on experimental results as follows:

(1) The flowability of all backfill mixtures was within the standard of the slump test (ASTM C143 / C143M) except low-grade gypsum, which had flowability higher than the maximum value of the standard (ASTM C143 / C143M).

(2) The use of waste materials due to different types of material has a significant influence on the strength of backfill. Specifically, the use of kaolin tailings plays a significant role in preventing deformation due to their ability to reduce bubbles inside cement mixtures. In addition, the strength of backfill increases as curing times increase.

5. Acknowledgements

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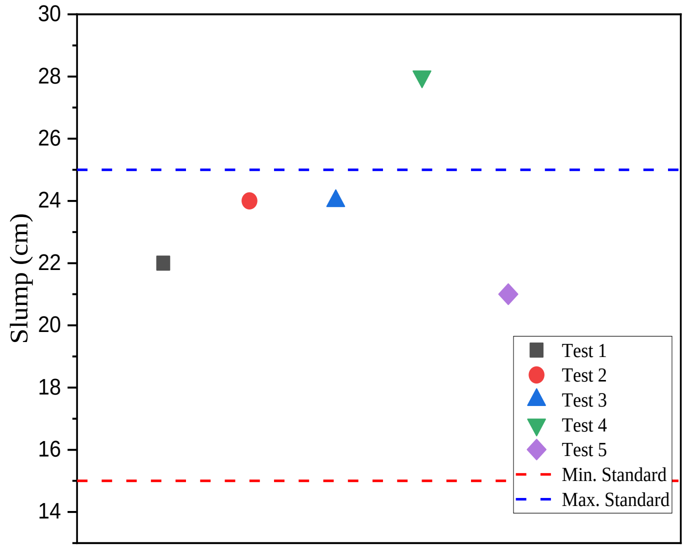

Figure 4 Results obtained from slump test of different backfills (Tests 1-5)

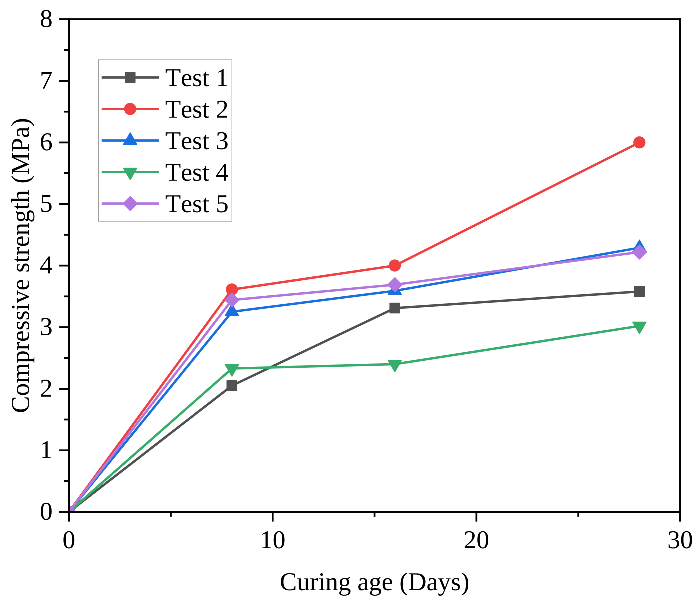

Figure 5 The average strength of backfills at different curing ages

Table 2 The maximum depth of backfills under the overburden of the sandstone condition

Test	Depth (m) at different curing ages		
	8 days	16 days	28 days
1	80	130	140
2	140	150	230
3	130	140	170
4	90	90	120
5	130	140	160

6. References

[1] Gligoric, Z. and et al. 2015. Underground lead-zinc mine production planning using fuzzy stochastic inventory policy. **Archives of Mining Sciences.** 60(1): 73-92.

[2] Mijalkovski, S. and et al. 2021. Methodology for underground mining method selection. **Mining Science.** 28: 201-216.

[3] Mijalkovski, S. and et al. 2021. Mining method selection for underground mining with the application of VIKOR method. **Underground Mining Engineering.** 39: 11-22.

[4] Ukah, B.U., Igwe, O. and Ubido, O.E. 2022. Modeling and characterization of mine pit backfilling/reclamation materials around Gyel'A'and Kantoma areas of Plateau state using integrated method. **Modeling Earth Systems and Environment.** 8(3): 3385-3398.

[5] Zhang, Q. and et al. 2015. Design and application of solid, dense backfill advanced mining technology with two pre-driving entries. **International Journal of Mining Science and Technology.** 25(1): 127-132.

[6] Sahu, H., Prakash, N. and Jayanthu, S. 2015. Underground mining for meeting environmental concerns–a strategic approach for sustainable mining in future. **Procedia Earth and Planetary Science.** 11: 232-241.

[7] Sivakugan, N., Veenstra, R. and Naguleswaran, N. 2015. Underground mine backfilling in Australia using paste fills and hydraulic fills. **International Journal of Geosynthetics and Ground Engineering.** 1: 1-7.

[8] Li, B. and et al. 2020. Surface subsidence control during deep backfill coal mining: A case study. **Advances in Civil Engineering.** 2020: 6876453.

[9] Chang, Q. and et al. 2014. Implementation of paste backfill mining technology in Chinese coal mines. **The Scientific World Journal.** 2014: 821025.

[10] Turuallo, G., Mallisa, H. and Rupang, N. 2020. Sustainable development: using stone dust to replace a part of sand in concrete mixture. **MATEC Web of Conferences.** 331: 05001.

[11] Zhang, Q. and et al. 2012. Backfilling technology and strata behaviors in fully mechanized coal mining working face. **International Journal of Mining Science and Technology.** 22(2): 151-157.

[12] Hustrulid, W.A. and Bullock, R.L. 2001. **Underground Mining Methods: Engineering Fundamentals and International Case Studies.** Littleton: Society for Mining, Metallurgy & Exploration.

[13] Potvin, Y., Thomas, E. and Fourie, A. 2005. **Handbook on Mine Fill.** Crawley: Australian Centre for Geomechanics.

[14] Zhang, J. and et al. 2019. Properties and application of backfill materials in coal mines in China. **Minerals.** 9(1): 53.

[15] Grice, T. 1998. Underground mining with backfill. In: **Proceedings of the 2nd Annual Summit-Mine Tailings Disposal System,** 24-25 November 1998. Brisbane, Australia.

[16] Belem, T. and et al. 2016. Gravity-driven 1-D consolidation of cemented paste backfill in 3-m-high columns. **Innovative Infrastructure Solutions.** 1: 37.

[17] Belem, T. and Benzaazoua, M. 2008. Design and application of underground mine paste backfill technology. **Geotechnical and Geological Engineering.** 26: 147-174.