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THE DEVELOPMENT OF A NOVEL BACKFILLING TECHNOLOGY: CONCEPT AND BEHAVIOUR

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ABSTRACT: A novel backfilling method for underground coal mines has been recently proposed at the University of Wollongong. Different from traditional backfilling technology (i.e. solid backfilling and paste backfilling), the main feature of this technology is that cementitious material with high water-to-solid ratio is directly pumped into the gob filled with coal reject aiming to fill the large number of voids. To verify the feasibility and potential advantages of this new technology compared to its counterparts, a series of compression tests have been conducted. A total of four cubic samples with the dimension of 300 mm and the height of 150 mm have been tested to better understand the effect of cementitious material on the compressive behaviour of the combined backfill. The experiment results show that the strength of combined material with confinement is significantly affected by the coal reject filling coefficient. Based on the experimental observations, the compressive behaviour of the combined backfilling consisting of three typical stages, namely initial compacting stage, support improving stage and stable sedimentation stage has beendetermined.

INTRODUCTION

Environmental accountability is becoming a greater consideration for mining industries. Impacts on the environment and the local community have had a large effect on the feasibility and success of mining operations. It is therefore critical to minimize the quantity of waste production and develop a cost-effective method to dispose of the coal reject for coal operators. Backfilling technology has become a basic method to control ground subsidence and provide sufficient support for surrounding mine structures. It is also believed to be an effective disposal approach for the mine tailings which are space-consuming and harmful to the environment.

During the past decades, various backfilling methods have been developed and put into practical application to meet different geological conditions around the world. Among them, solid waste backfilling and paste backfilling technology are the two main methods widely accepted due to their high performance (Kesimal *et al.,* 2005; Deng *et al.,* 2016). A solid waste backfilling system always consists of transport, feeding and mine filling devices. To provide sufficient support to overlying strata, a build-in compaction mechanism is designed to compact the crushed solid waste material with a large content of voids aiming at improving the overall effectiveness (Deng *et al.,* 2016). Ahigh pressure compaction mechanism is therefore required, resulting in increased investment. Different from solid waste backfilling, the voids content can be significantly eliminated bythe use of high density slurry for paste backfilling technology. However, the large investment and complex pumping system is regarded as the obvious drawback for paste backfilling technology (Chen *et al.,* 2017; Emad *et al.,* 2015).

Metropolitan Colliery is one of the earliest underground longwall coal mine in Australia with a history of more than 120 years. Mining subsidence caused by longwall extractions has presented great threats to the Colliery (Chang *et al.,* 2009; Gillespie 2007; Cremonini *et al.,*

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2015). To deal with the subsidence issue and abandoned rejects, Metropolitan Colliery has currently been operating the onlycoal reject emplacement project in Australia (Tarrant *et al.,* 2012). The high density slurry consisting of Teetered Bed Separator (TBS) is pumped from the surface to underground because it is not permitted to commence backfilldeployment prior to the completed longwall production (Moroney 2017). It can definitely ensure the slurry does not enter to the working face and cause some complications. However, it is therefore more difficult to maintain the effectiveness of backfilling. In particular, the void between the overlying strata and backfill material will still lead to unexpected subsidence of overburden.

Against this background, this paper presents a conceptual backfilling method for underground coal mines which has been recently proposed at the University of Wollongong. The novel backfilling technology is believed to be a cost-effective method to improve the backfilling effectiveness compared to its counterparts (Yu *et al*., 2019). A series of compression tests have been conducted to demonstrate its potential advantages.

NOVEL BACKFILLING TECHNOLOGY

Different from traditional backfilling technology (i.e. solid waste backfilling and paste backfilling), the main feature of this technology is that the cementitious material with high water-to-solid ratio is directly pumped into the gob filled with coal reject aiming to fill the large amount of unexpected voids.

Taking the pumping system in Metropolitan Colliery for example, the characters of this novel backfilling technology as shown in Figure 1 are summarized as follows

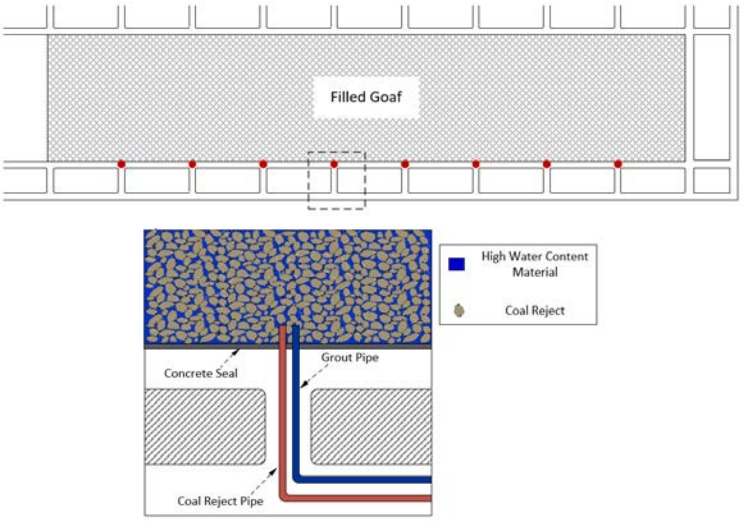

Figure 1: The proposed backfilling method based on existing pump system used in Metropolitan Colliery

(1) The coal reject is pumped from the surface using the existing pumping system;

(2) Cementitious material is injected into the goaf after the backfilling of coal reject through the separate pump system underground.

(3) A portable pumping system can be used to transport cementitious material to the goaf;

(4) The cementitious material used herein has a high water-to-powder ratio.

EXPERIMENTAL PROGRAMME

Test specimens

A total of 20 specimens including four cubic specimens and 16 cylinder specimens have been prepared and tested at the High-bay lab in the University of Wollongong. The cylinder specimens with a diameter of 150 mm and height of 300 mm were tested to understand the compressive behaviour of unconfined samples, whereas, the other cubic samples with the dimension of 300 mm and height of 150 mm are tested to explore the effect of confinement provided by the steel box. The constant water-to-powder ratio (i.e. 2.0) was adopted for all specimens with cementitious material.

Coal reject filling coefficient f_c, the ratio between the filling volume of coal rejects and the total volume of sample is designed as the test variable in the present research. To determine the filling effect for goaf underground, in which the filling materials are in confined conditions, a series of confined compressive tests with four filling coefficients, namely 0.0, 0.33, 0.67, 1.0, were carried out.

Material properties

- Coal reject

To determine the size distribution of coal rejects used for the study, a sieve analysis was undertaken as per the following method: Australian Standard 1289.3.6.1: Soil classification tests— Determination of the particle size distribution of a soil—Standard method of analysis by sieving (Standard 1995). A total of 1002.39 g coal rejects were used for the test. As listed in Table 1, the sieve result shows that the particle size of most coal rejects fall within the range of 13.2mm to 19mm.

Table 1: Result of sieve analysis

Particle size (mm)	Sample weight(g)	Retained (%)	Pass (%)
19.00	110.80	11.05	88.95
13.20	828.30	82.63	6.31
9.50	57.50	5.74	0.58
6.70	1.59	0.16	0.42
4.75	0.00	0.00	0.42
<4.75	4.20	0.42	

- Cementitious material

FB200 pumpable grout with high water-to-powder ratio was provided by Minova Australia. It is a high yield cementitious powder that only requires the addition of water and a suitable placing machine. The data shown in Table 2 was obtained from the technical data of FB200. It is apparent that the compressive strength of FB200 is closely relevant to the water-to-powder ratio.

Table 2: Parameter of FB200 pumpable grout

Water-to-powder ratio	Compressive strength (MPa) at different ages		
	1 day	7 days	28 days
2:1	0.6	3.3	7.5
2.5:1	0.65	1.4	4.5

Preparation of specimens

The preparation procedure of the samples included the following steps as shown in Figure 2:

- Welding the steel box with designed size and thickness;

- Filling up the steel box with the required amount of coal reject and marking the position inside the steel box;
- Mixing the cementitious material with water in a bucket;
- Pouring the mixed slurry to the steel box until all voids have been filled up;
- Covering the samples with plastic covers until the testing data (i.e. 7 days).

Figure 2: Preparation of specimens

Instrumentation and testing procedure

For each specimen, two Linear Variable Displacement Transducers (LVDTs) were used to measure the axial deformation of the specimen. All confined compression tests were conducted using a 500 tons Avery compression testing machine with a constant displacement controlling rate of 1 mm/ min (Figure 3). Considering the requirement of practical application, all tests were terminated when the axial deformation exceed 15 mm, about 10% of the overall height of the sample.

Figure 3: Test set-up

EXPERIMENTAL RESULTS AND DISCUSSIONS

The typical failure mode of confined samples is presented in Figure 4. It is clear that the unconfined samples show brittle failure mode during the compression test. Whereas, the confined samples after test still show stability, which can be found from Figure 4 in which the outer steel box has been removed. It indicates that the backfilling material under the confined condition is much different from its counterpart without confinement.

(a) (b)

Figure 4: The final failure patterns of specimens in confined compressive tests

The stress-strain curves for samples under confined compression are presented in Figure 5. For all samples, firstly, the stress increased very slowly with deformation increasing, indicating that their support capacity was very limited during this period. When the axial strain reached about 0.012, stress began to go up rapidly with higher curve slopes. Take the sample with f_c = 0.67 for example, the curve slope suddenly rose from 54.0 MPa to 264.1 MPa, which means that the sample could support higher loading with less deformation compared with it at the previous stage. Later on, the increase of stress slowed down with a lower and stable curve slope. It can be seen that the curve for pure grout without coal rejects was much flatter than others and the stress remained at a quite lower level, which indicates that pure grout backfilling without coal rejects may lead to a poor filling performance.

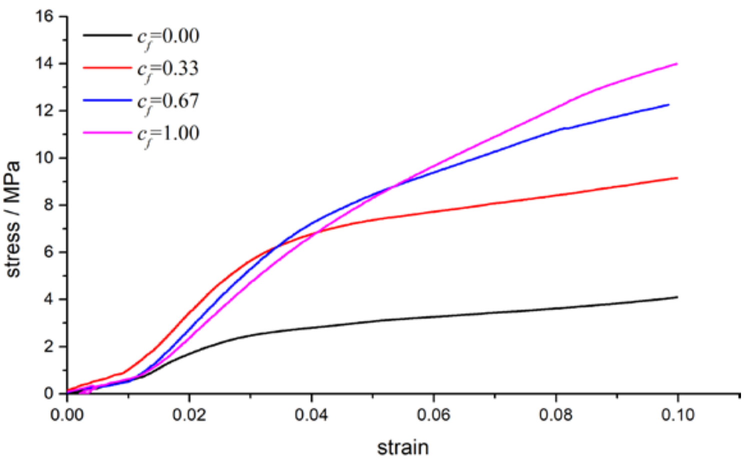

Figure 5: Stress-strain curves for samples with different filling coefficients under confined compression

In general, three stages can be concluded for filling materials with high-water content material in confined compressive tests. Take the sample with filling coefficient of 0.33 for example (Figure 6), the three stages can be described as follows:

- **Initial compacting stage**

At this stage, the filling materials suffers an obvious subsidence under loadings at a quite low level. It shows that the filling material fails to resist deformation effectively at the beginning period. This may be regarded as a defect of high-water content filling material. As there is a high proportion of water within the filling material, some water that doesn't combine well with cement may be squeezed out, resulting in an obvious initial deformation. Long curing time or proper weight ratios between water and grout may be helpful for controlling this problem.

- **Support improving stage**

After being compacted, the filling materials begin to take effect at this stage. It is considered that it's the best stage for the filling material where the most advantage of the filling material can be made.

- **Stable sedimentation stage**

When the loading is beyond filling material's support capability, the filling material will finally experience continued deformation. It means that overburden strata or ground foundations can cause serious subsidence even if the goaf has been filled with the high water content filling materials.

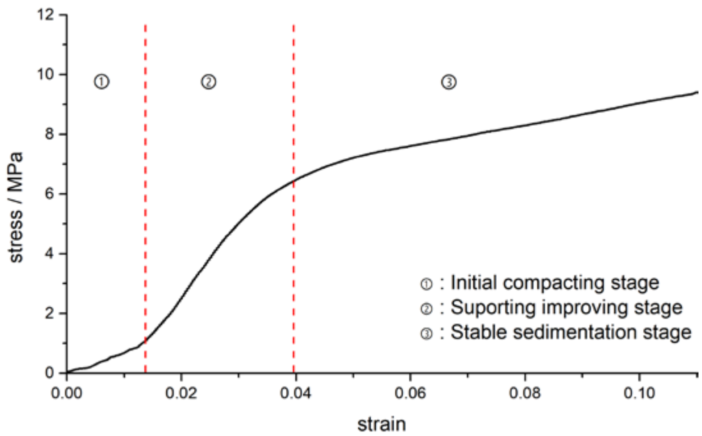

Figure 6: Three typical stages for samples with filling coefficient of 0.33 under confined compression

The best-fit curve as well as the equation between coal reject filling coefficient and confined compressive strength is shown in Figure 7. It's evident that the there is a perfect exponential relationship between them as the determination coefficient for the fitting exponential function reaches as high as 0.9999.

Coal reject filling coefficient has a distinct effect on filling material's strength in different loading conditions. With the increase of filling coefficient, confined compressive strength of filling material increases exponentially while its unconfined compressive strength shows a decreasing trend. As the bonding strength between coal reject and grout is relatively low, failure is easy to appear in the bonding plane and coal rejects are then squeezed outward without confinement. Consequently the coal rejects have a negative effect on filling material's strength. In confined compressive tests, as the lateral deformation is restricted, coal rejects are forced to bear axial loading. As a result, filling material strength is improved.

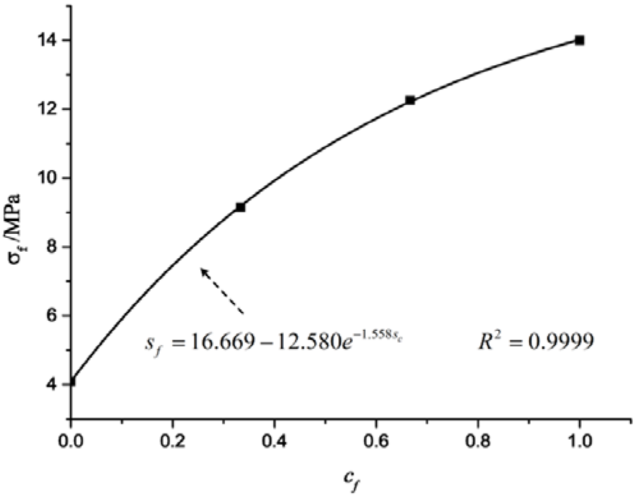

Figure 7: The relationship between coal reject filling coefficient and confined strength

CONCLUSIONS

This paper presents a novel backfilling technology based on the current pumping system used in Metropolitan Colliery. The additional application of the pumpable grout which can be set up in the roadway outside the working area is believed to be a cost-effective and safe method to improve the load carrying capacity of backfilling materials. The preliminary test on the confined box tests show that the higher coal reject filling coefficient contributes to higher filling strength. When the coal reject filling coefficient reaches 1.0, namely the goaf was filled up with coal rejects before grouting, the best filling performance is expected.

In practical engineering, however, full filling with coal rejects may be difficult to put into practice with coal reject amount, budget or some other factors taken into consideration. Based on the positive exponential relationship between coal reject filling coefficient and filling strength, an optimal coal reject filling coefficient can be determined to meet the balance between filling performance and engineering factors.

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