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Improving workability of cement paste backfill using new binders

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ABSTRACT: In this study effects of binder type and content and curing time on the compressive strength development of cement paste backfill (CPB) is investigated. Moreover, the effects of binder type and content and water content on the rheological properties of CPB material were studied. To undertake an experimental study, tailings of a copper mine in South Australia are mixed with binder and water. A new slag-cement called Mine Cement (MC) and ordinary Portland cement (PC) are used as the primary binder materials. Furthermore, fly ash (FA) is used as an additive to reduce the amount of the cement. Some CPB samples were cured under pressure to be more representative of the field conditions. MC exhibited better performance that PC regarding compressive strength development. Fly ash improved the compressive strength of CPB. However, this binder observed to be much less cementitious compare to MC. Strength performance of the CPB sample significantly improved when there were cured under pressure. Based on the results obtained from the test undertaken using a rheometer, it was found that increasing the water content results in lower yield stress. The results also show that MC improves the rheological properties of the CPB.

1 INTRODUCTION

Cemented paste backfill (CPB) has become an essential component of underground mining operations. CPB is a mixture of tailings, water, and cement used to fill underground stopes. The mechanical and rheological characteristics of CPB depend on the physical, chemical, and mineralogical properties of the tailing, water, binder type, and ratio used. Port-land cement (PC) is often used as the primary binder. Some reports indicate that the cost of backfill tends to vary from 10% to 20% of the total operating cost of the mine and cement represents up to 75% of total CPB cost (Bloss, 2014). Reducing backfilling cost by decreasing cement content may increase ore dilution from poorly performing backfill exposures. Alternatively, increasing cement content will raise the costs; however, it could increase the productivity through improved mining system cycle times. In order to reduce the cost and keep the CBP strength at its required level, use of other binder materials may reduce the cost while maintaining its optimal strength performance. Some researchers used different materials, such as Nano Silica, fly ash and superplasticisers to reduce the amount of cement in CPB (Koohestani et al. 2016, Klein & Simon, 2006, Mishra & Karanam, 2006, Fall et al. 2007, Zhang et al. 2018).

Fresh CPB is transported by gravity, or is pumped through pipelines and boreholes; thus, the flowability of the paste backfill is an essential parameter in paste design. Various studies have been conducted to better understand CPB's rheological behaviour and its affecting factors (Kwak et al., 2005, Ouattara et al., 2017). It is known that a change in the composition and temperature of fresh cementitious materials (e.g. CPB) will affect the rate of cement hydration and therefore its rheological properties. The rheological properties are associated with the amount of energy consumed to ensure flowability (Wu et al., 2013). Optimising the CPB flowability in mines will help to optimise the energy consumed by pumping, and to reduce the risk of pipe clogging (Paterson, 2012). However, there are limited studies available on rheo-logical properties of cement-fly ash paste backfill.

The main aim of this study is to investigate the application of slag and fly ash as a binder to reduce the amount of cement. Fly ash is a by-product of coal combustion in power stations. It has been proved that it improves the overall performance and quality of concrete (Li, 2004). Blast-furnace slag is obtained by quenching molten iron slag from a blast furnace in water or steam. Slag may be used to produce slag-cement. Slag cement is a hydraulic cement formed when granulated blast furnace slag is ground to suitable fineness and is used to replace a portion of Portland cement. Slag-cement has been used as a mortar for various civil engineering applications (Nath & Kumar, 2016).

In this study Mine cement (MC) which is a newly released slag-cement, specially designed for backfill purposes, is used as the primary binder. Its performance regarding strength development and rheological properties are compared with ordinary Portland cement (PC). Furthermore, fly ash (FA) is used as an additive to replace some amount of cement.

2 CEMENT PASTE BACKFILL MATERIAL

The processed tailings used to study the rheological properties of the paste backfill were sourced from a copper-gold underground mine in South Australia. The tailings samples thoroughly dried in an oven to accurately control binder and water content. Two cement type and one additive were used as a binder material. They included a general-purpose Portland cement (PC), and a newly released slag-cement especially designed for backfill purposes, referred to as Mine Cement (MC). Type C fly ash (FA) was also used as an additive to replace the main binder partially. The water that is obtained after mineral processing in the mine, called here processed water, was used to prepare samples for the laboratory testing.

3 EXPERIMENTAL METHODOLOGY

3.1 *Compressive testing*

A closed-loop servo-controlled testing machine with a loading capacity of 250 kN and a loading rate capability in the range 0.001–10mm/s were used. The loading system is equipped with a linear variable differential transformer (LVDT) to measure axial displacement and control axial loading. The load and strain data are acquired automatically by a data acquisition system.

Unconfined compression tests were carried out in accordance with ASTM C39–18. Tailings and binder were weighed and mixed with a measured volume of water in a bakery mixer. The mixer thoroughly mixed the paste with the binder and then with water until a smooth consistency slurry was reached. For unconfined compression (UC) tests, the paste was placed in the 42mm x 100mm cylinder mould in one-third length increments, each being tamped 25 times with a rod. A 2mm thick permeable stone was placed on the bottom of the cylinder to ensure an even drainage of the sample. The samples then were cured in a fog room maintained at approximately 70% humidity at 25 ˚C for 7, 14, 28, 56 and128 days. At the beginning of the experiment, few tests were repeated and consistent results were obtained. The rest of the tests were undertaken without any repeat.

In addition to binder type and content and curing time, mechanical properties of CPB is also dependent on curing condition as well as self-weight consolidation (Yilmaz et al. 2011). For this purpose, special CPB curing equipment is developed and utilised in this study to cure the samples under different backfill-weight of 50m, 100m, 150m overburden pressure. This overburden pressure represents vertical stress. Passive horizontal stress was applied to the samples by the cell as a result of active vertical stress. The sample were allowed to drain from the bottom during curing. These samples were prepared in addition to the samples that were cured under atmospheric pressure. The aim was to investigate how much mechanical properties change when CBP backfill material are cured under pressure.

3.2 *Rheometer testing*

To measure the viscosity of CPB, different mixtures having a different amount of MC and PC with and without FA were prepared and mixed with different amount of water. All the samples were prepared at a room temperature of 25 ˚C. The tailings materials, binders and water were mixed and homogenised for about 5 min to produce the desired CPB mixture. After that, the CPB slurries were heated or frozen by the MCR 102 Rheometer to a designed temperature before testing. CPB with 3% MC, 23% water that was prepared at a room temperature of 25 ˚C was considered as the benchmark samples.

Rheometer vane testing allows for the measurement of the rheological properties of different materials. The MCR rheometers are based on a concept in which the low friction-bearing (Vane) resides at the cutting edge of the sample. Flow curve method was used to measure shear stress and viscosity of the samples (Boger, 2006). In this method, a vane rotates at different rotation speeds, which increases in a stepwise manner from 5 rpm to 135 rpm. At each rotation speed, shear stress and viscosity were recorded after reaching equilibrium. The data that were collected had to be fitted into rheological models for further analysis. For this purpose, the Bingham Model, ‘which describes the flow curve of a material with a yield stress and a constant viscosity at stresses above the yield stress, was utilised (Anton, 2006).

4 RESULTS

4.1 *Compressive strength*

Figure 1 illustrates the variations of peak strength against cement content for the samples that were prepared with MC and cured at various curing times. At any given curing time, the higher the MC content, the higher the peak strength, following a monotonically–increasing trend, with the former, the binder content, portraying a more pronounced role. The 1.5% MC sample cured at 7 days, for instance, exhibited a peak strength of 272.1 kPa, while the inclusion of MC=2.5% and 3%, with the same 7–day curing condition, resulted in peak strength equal to 375.5 kPa and 476.5 kPa, respectively. Similarly, for any given MC content, an increase in curing time promoted a significant increase in the peak strength up to 56 days curing, beyond of which the effect of curing was found to be marginal. The inclusion of 3% MC at 7 days curing, for instance, resulted in peak strength of 476.5 kPa, while higher peak strength values of 619.5 kPa, 719.3 kPa, 800.6 kPa and 812.6 kPa were noted for the same 3% MC inclusion at 14d, 28 d, 56 d and 128 d curing, respectively.

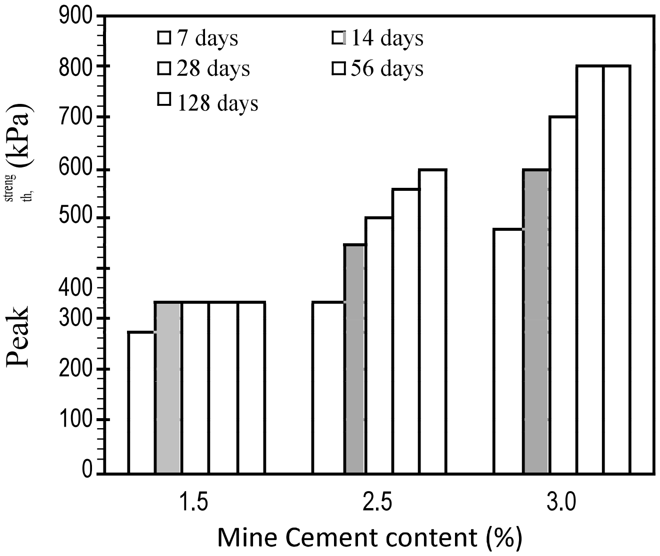

Figure 1. Variations of peak UC strength against MC content

Figures 2a and 2b show the variations of peak strength against FA content for the samples mixed with MC of 1.5% and 2.5%, respectively. At any given curing time, the greater the FA content, the higher the peak strength, following a monotonically– increasing trend, with all MC =2.5% blends holding a notable advantage those mixed with 1.5% MC. For MC =1.5%, with the same 7–day curing condition, the addition of 0.5%, 1%, 1.5%, 2% and 2.5% FA resulted in peak strength of 282.8 kPa, 292.8 kPa, 305.4 kPa, 313.9 kPa and 320.7 kPa, respectively. Similar mix designs treated with MC=2.5%, however, promoted higher a peak strength, as the values above in-creased to 384.4 kPa, 404.8 kPa, 425.1 kPa, 429.3 kPa and 429.6 kPa, respectively. Similarly, for any given MC+FA content, an increase in curing time promoted a significant increase in the peak UC strength up to 56 days curing, beyond of which marginal variations were noted.

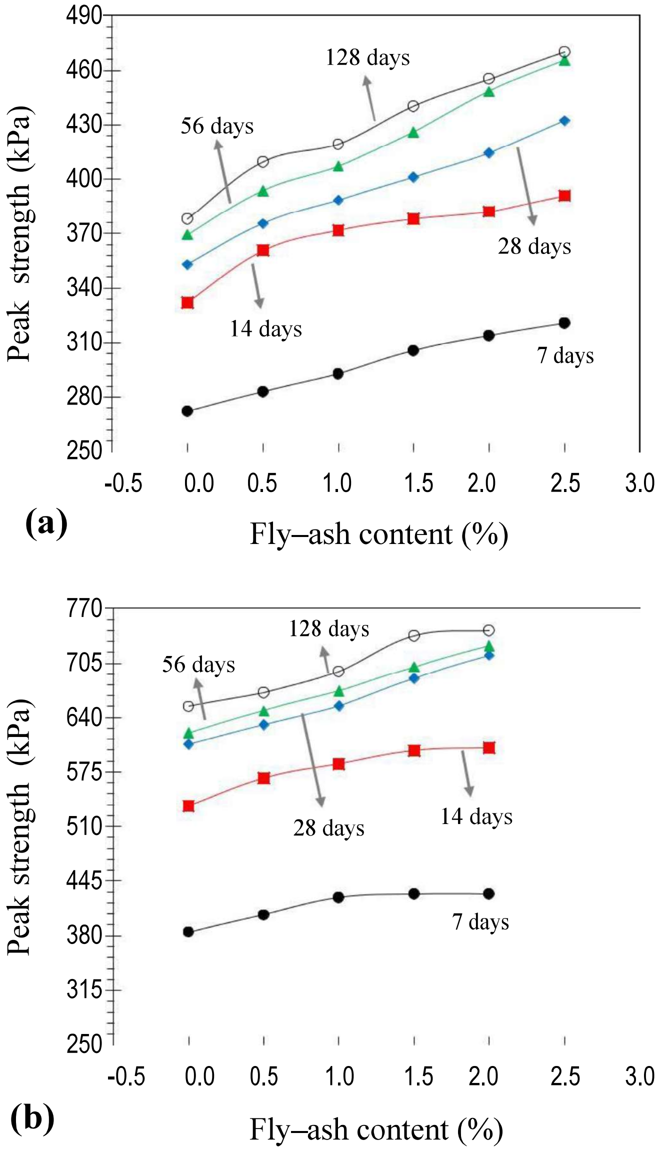

Figure 2. Variations of peak strength against FA content for the samples containing a) 1.5% MC, b) 2.5% MC

4.2 *Comparison between MC and PC*

In this section, the performance of MC is compared with ordinary Portland cement (PC), regarding uniaxial compressive strength development. In this case, PC is used as a reference binder material which is very common in mining with backfill. Figure 3 shows the variations of peak strength against FA content for CPB sample being mixed with different amounts of MC and PC and being cured for 14, 28 and 56 days. Regardless of the cement type that is used, similar to the previous results, the addition of FA has a positive influence on the properties of CPB in terms of peak strength. At any given FA content, for the samples that are cured for 14 days, the strength of CPB samples with MC = 3% and 2.5% are higher than the peak strength of PC = 4% samples. This demonstrates a superior performance for the MC regarding improving mechanical properties of CPB with less amount of binder. Effect of curing on improving the mechanical properties, however, is more significant for PC samples. Having said that, the samples with MC=2.5% show better performance in terms of com-pressive strength in all curing periods.

As it is evident from Figure 2, the peak strength for various mixtures ranges between 272 kPa and 760 kPa and therefore satisfies the requirement for eliminating liquefaction in underground disposal applications (Tariq 2012, Jewell & Furrie, 2002).

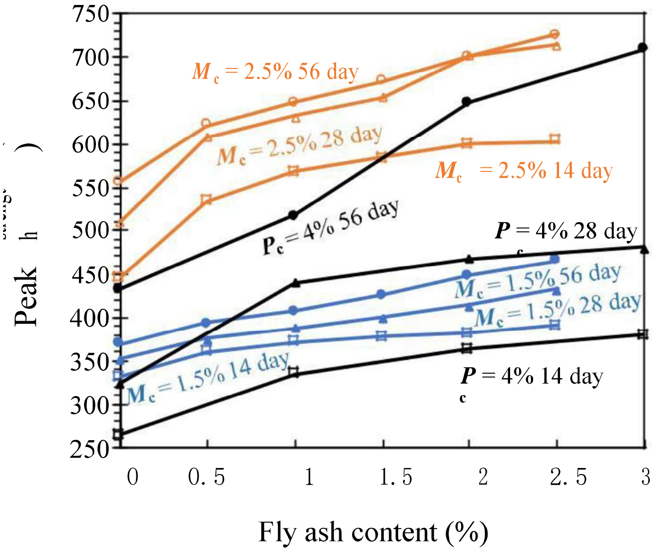

Figure 3. Variations of peak strength against FA content for MC and PC samples after different curing period.

4.3 *Effect of backfill-weight consolidation*

Figures 4a and 4b show the axial stress-strain relations for the samples that are cured under atmospheric pressure (i.e. CD=0) and different consolidation pressure of CBP after placement (i.e. 50m, 100m and 150m overhead backfill pressure) for 7 days and 28 days curing respectively. From the figures, it is apparent that curing conditions (with and without applied pressure) impact the compressive strength development of CPB samples. Self-consolidation is significantly improved the compressive strength of the samples. This influence has become more pronounced when curing period increases. For example, the samples which have gone through a self-consolidation of 50m, 100m and 150m of overburden, respectively, show an increase of 38%, 52% and 130% in compressive strength after 7 days curing. After 28 days curing, however, 57%, 119% and 150% increase in compressive strength is observed for the sample that are cured under pressure of 50m, 100m and 150m overburden, respectively. The results can be explained by the combined effects of applied consolidation pressures during curing and the removal of excess water, which accelerates the binding reaction, thereby increasing the compressive strength (Yilmaz et al. 2011).

Curing under backfill-weight consolidation, however, reduced the ductility of the sample. The results show that with an increase in curing depth, the behaviour becomes more brittle, post-peak behaviour exhibits more strain softening trend. However, the improvement in peak strength for all MC–treated mixtures may compensate the exhibited reduction in ductility.

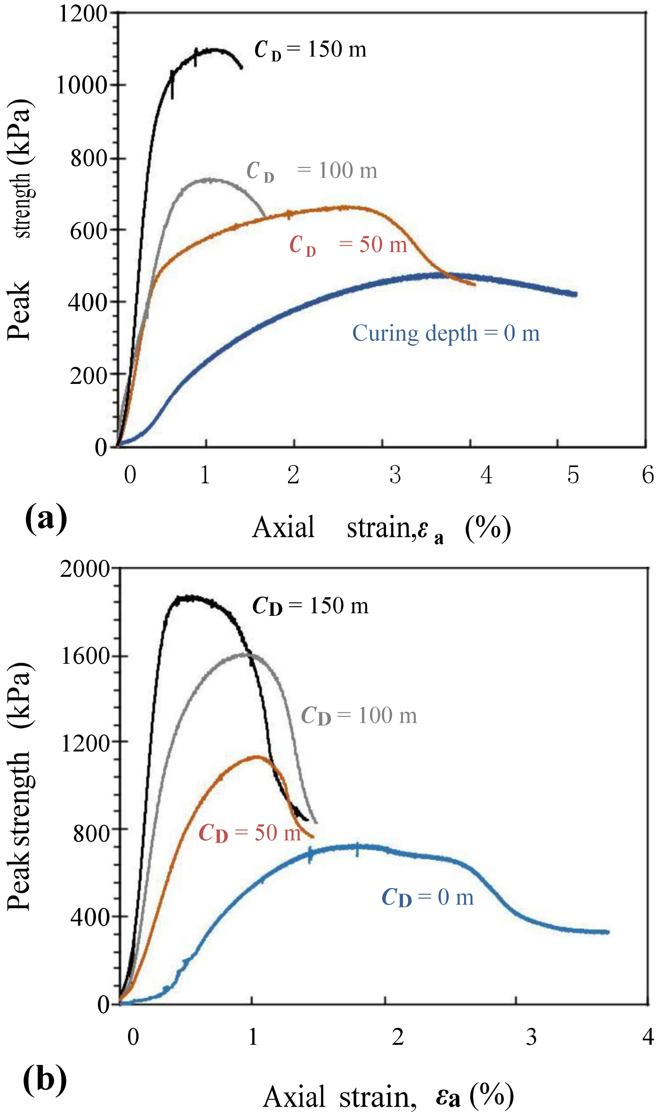

Figure 4. Stress-strain relation of CPB with 3% MC under different curing conditions: a) 7 days curing, b) 28 days curing.

4.4 *Rheological behaviour*

Figure 5 shows the relations between the shear stress versus water content for three different binders (MC, PC and FA) when the binder content is 3%. The figure shows that, regardless of binder type, the yield stress decreases with an increase in water content. This is due to the reduced number of direct particle-particle contacts and the increased thickness of the lubricating film around the solid particles in the higher-water-content specimens, making it easier for the solid particles to slide past one another during shearing.

The results also show that the yield strength of CPB that is mixed with MC is much more sensitive to water content change than the one mixed with PC. For CPB with 23% or more water content, the use of MC results in a more workable paste, even with the same binder content. Fly ash contributes less to the slurry's yield stress than do each of the primary binders.

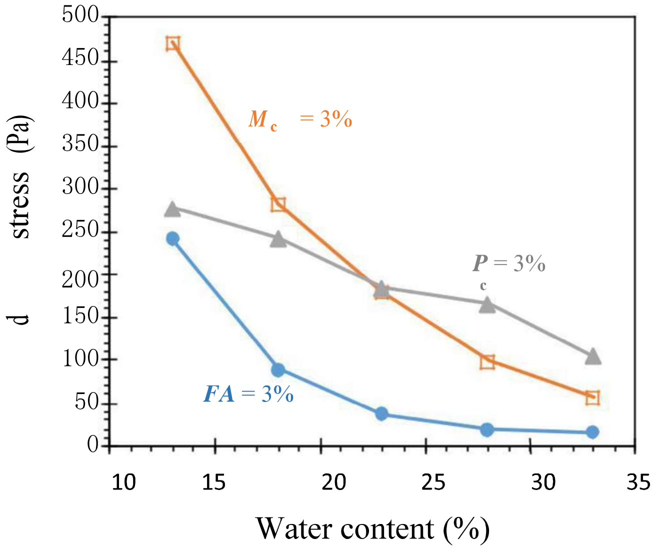

Figure 5. Yield stress versus water content for CPB that is mixed with three different binders.

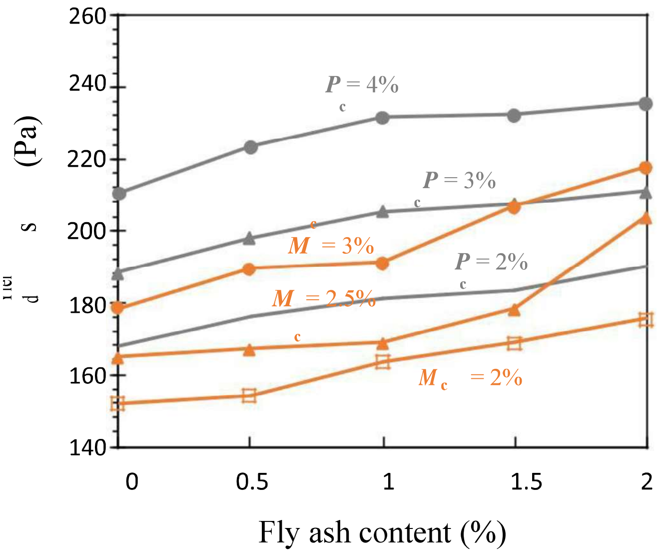

Figure 6. Effect of binder type and content on yield stress development using 23% water at 25 ˚C.

One of the aims of this study was to compare the influence of cement type on the rheological behaviour of CPB. Figure 6 compares the yield stress of CPB samples that are mixed with different types of cement of different percentages and mixed with a different amount of FA as an additive when the water content is equal to 23%. The figure shows that, in general, with the same amount of binder, the CPB with MC has better rheological properties when compared with those mixed with PC. The original CPB mixture in the mine includes 4% Portland cement (PC) and 23% water. In section 4.2 it was shown that 2.5% MC shows better performance than 4% PC regarding compressive strength. Obviously, 2.5% MC mixture has a significant advantage over 4% PC mixture regarding rheological properties.

5 CONCLUSIONS

This study investigated the strength properties and rheological performance of CPB material when mixed with different binder types and contents. Portland cement (PC) and a new binder, Mine Cement (MC), which is prepared mainly as a mixture of cement and slag, were used as the main binders, while fly ash (FA) was used as a supplementary binder. To undertake compressive testing, the samples were cured both under atmospheric pressure and under pressure for different curing periods. Based on the results obtained, the following conclusions appear to be warranted:

1. With the adding of fly ash (FA) as additive under given Mine Cement (MC) content, the increasing FA content leads to higher compressive strength. However, the partial replacement of 1.0 % MC with 2.5% FA does not result in higher or even similar strength after any curing period. The FA observed be much less cementitious compare to MC.
2. MC performs much better than Portland cement (PC) in all the curing periods regarding improving the compressive strength development.
3. Curing under pressure significantly increase the compressive strength of CPB. It also reduces the ductility. The improvement in peak strength for all MC–treated mixtures, however, outweighs the exhibited reduction in ductility.
4. Regardless of binder type, the yield stress decreases with an increase in water content. However, the MC mixture showed a more substantial increase in fluidity after an increase in water content. Hence, the viscosity variations of CPB with MC appears to be more sensitive to water-content change.
5. Of the two primary binders, MC and PC, MC showed better viscosity properties after mixing for a constant UCS requirement. The FA additive increased the yield stress of the CPB mixtures. However, lower increments were shown for MC mixtures when compared to those mixed with PC.

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