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Centrifuge model studies on the stability of fibre-reinforced cemented paste backfill stopes

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A B S T R A C T

Cemented paste backfill (CPB) is used extensively in Australia for providing ground support during underground mining operations. This paper considered the use of polypropylene fibres to reinforce the partial or whole body of CPB models in laboratory centrifuge tests. Specimens were cast as non-reinforced (tailings, cement and water), quarter-height, half-height and full height fibre-reinforced CPB model stopes. The stability of CPB models with vertically exposed faces was investigated by a series of centrifuge tests. The modelling data showed that the prototype height of fibre reinforced CPB stopes could be much higher than that of unreinforced stopes depending on the extent of reinforcing. The vertical displacement and failure mass ratio of CPB models were also compared and discussed. The distinct failure modes showed that fibre reinforcement was effective in preventing the CPB failing into the strong box. Furthermore, virtually no fragments were spalled from the exposed faces of reinforced sections of the stopes. It indicated that the application of fibre reinforcement would potentially reduce ore dilution and recovery costs, because the risks of failure would be lowered and prototype stope sizes be enlarged.

1. Introduction

The application of cemented paste backfill (CPB) has become increasingly common in Australia and Canada over the past decades (Potvin et al., 2005; Fourie et al., 2015). It is a practical operation for many cut-and-fill underground mines (Fourie et al., 2007). Typical CPB is the mixture of mine tailings, Portland cement and water, which is comprised of 70%–85% solids by total mass. The general dosage of cement in CPB is 1%–10% by dry mass of tailings, which represents around 15% costs of the mining operation (Belem and Benzaazoua, 2004). Therefore, the CPB design should achieve an economical operation as well as ensuring stability and safety.

Different factors that may affect the performance of CPB have been considered in previous studies, such as the properties of CPB components (Benzaazoua et al., 2002, 2004; Fall and Benzaazoua, 2005; Fall et al., 2008; Belem and Benzaazoua, 2008; Ercikdi et al., 2010, 2012), curing conditions (Fall and Samb, 2009; Huang et al., 2011; Yilmaz et al., 2014a; Walske et al., 2016) and in-situ circumstances in terms of arching effects (Belem and Benzaazoua, 2008; Fahey et al., 2009; Thompson et al., 2012) and self-weight consolidation (Belem et al., 2006; Yilmaz et al., 2009, 2014b; Fahey et al., 2011). The majority of research efforts are concentrated on the strength development, especially the unconfined compression strength (UCS) of CPB that is widely accepted as the most important parameter for backfill design. CPB will usually serve as a working floor, a replacing roof or a self-supporting wall during a specific mining cycle. The durability and deformation behaviour need to be considered since CPB structures should remain stable and allow deformation in a ductile fashion instead of undergoing sudden failure, as illustrated in laboratory tests by Yi et al. (2015).

Mitchell and Stone (1987) compared several kinds of reinforcement in cemented fill using drop-box model testing, and their results showed that fibre reinforcement was a promising technique to improve the stability of cemented backfill and potentially reduce cement usage. Based on this evaluation, Festugato et al. (2013) and Yi et al. (2015) have demonstrated that the addition of polypropylene fibres enhanced not only the shear strength but the ductility of the CPB. However, fibre reinforced CPB has until now not been adopted in the mining industry, and performance under realistic field conditions is untested. Due to the high cost of field-scale tests and the need to validate the technology before embarking on expensive field trials, the centrifuge modelling technique provides an appropriate alternative technique for evaluating the effectiveness of fibre-reinforcing at the prototype scale. Mitchell (1986, 1989) designed centrifuge model tests for comparing the predicted prototype heights of backfilled stopes obtained from centrifuge tests and from UCS tests, and for investigating the effects of hanging wall-foot wall dip angles and closure stress on the stability of cemented

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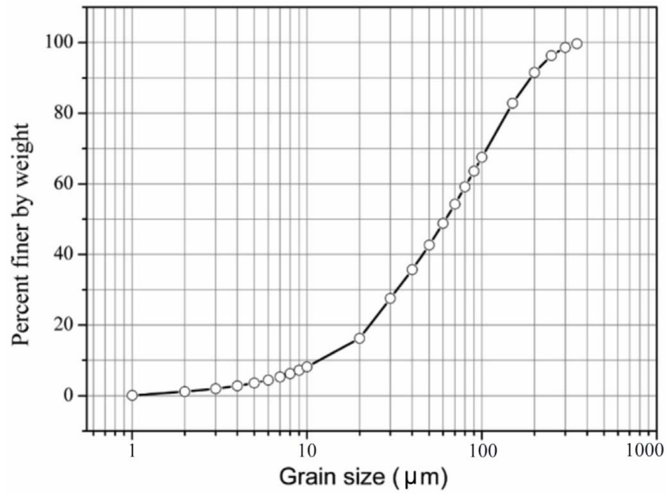

Fig. 1. Particle-size distribution.

Fig. 2. Monofilament polypropylene fibres.

backfill. His tests were found to accurately represent full-scale stopes with exposed faces, and credible testing results were achieved.

The purpose of this paper is to explore the contribution of fibre reinforcement to the potential increase of prototype heights of CPB stopes and improving the safety of stopes by utilising a material that is significantly more ductile than conventional CPB. This was done by conducting centrifuge tests on eight models using four different reinforcement configurations. These results are also compared with predicted stable stope heights obtained from UCS tests. The design of the models was based on the evaluation of previous studies on reinforced CPB and centrifuge tests. Characteristics of the failure behaviour (i.e. whether brittle or ductile) and failure mass ratio are presented and discussed.

2. Experimental program

2.1. Materials

The tailings used in the models were from a copper mine in Southern China. Fig. 1 shows the particle-size distribution curve and Table 1 shows the chemical composition of the tailings. The tailings have specific gravity of 2.83 and liquid limit of 24%. Ordinary Portland cement was chosen as the binder. Monofilament polypropylene fibres were used for reinforcement (Fig. 2), which were 19 mm in length and 18 μm in diameter according to previous studies (Consoli et al., 2013; Festugato et al., 2017). The fibre has an ultimate tensile strength of 600 MPa and a specific gravity of 0.91. Distilled water was used to mix the tailings, cement and fibres.

2.2. Testing models

Eight centrifuge model stopes in four different reinforcement configurations (i.e. two replicates of each configuration) were cast in wooden moulds 100 mm by 100 mm by 500 mm high, and transferred to the strongbox in the moulds after being cured for 28 days. The lateral plates of the moulds were vertical and were relatively smooth, which could thus not simulate the roughness of stope walls in-situ. However, it did make comparison of the relative performance of different reinforcement configurations easier. Separately, 3 specimens were cast into cylindrical plastic moulds 50 mm in diameter and 100 mm high for UCS tests on unreinforced and reinforced specimens in order to facilitate comparison of the predicted prototype heights with centrifuge results.

All models contained 2.5% cement content by dry mass of tailings based on the study of Consoli et al. (2017). Models 1 (0H-1) and 2 (0H-2) were unreinforced, while models 3 (1H-1) and 4 (1H-2) were reinforced over the full stope height with 0.5% fibres by mass of the total solids. Previous studies have shown that the compressive strength of reinforced cemented soils could be significantly increased when the fibre content was between 0.25% and 0.75% of total solids (Consoli et al., 2011, 2012; Zaimoglu and Yetimoglu, 2012; Dehghan and Hamidi, 2016; Estabraph et al., 2017). Models 5 (H/4–1) and 6 (H/4–2) followed the same formula of fibre reinforcement but were only reinforced from the bottom up to ¼ model height, and models 7 (H/2–1) and 8 (H/2-2) were reinforced over only the bottom half of the stope height (Fig. 3).

The CPB mixture was prepared at a solids content of 78% and a slump value of 8.2 inches, which were representative of values used at the site. The unreinforced and fibre reinforced CPB mixture were produced at the same time, and poured in sequence, depending on the reinforcement configuration, into the individual model stope moulds. The prepared models and specimens then were sealed and cured for 28 days before starting centrifuge tests and UCS tests.

Table 1
Chemical composition of the tailing.

Chemical composition	Amount: %	Chemical composition	Amount: %
CaO	53.05	K_2O	0.70
SiO_2	20.61	CuO	0.44
MgO	19.88	TiO_2	0.22
Fe_2O_3	2.44	Na_2O	0.10
Al_2O_3	1.36	SO_3	0.08
MnO	1.02	P_2O_5	0.06
ZnO	0.03	Cl	0.03

2.3. Testing equipment

In this study, the tests were carried out using the geotechnical beam

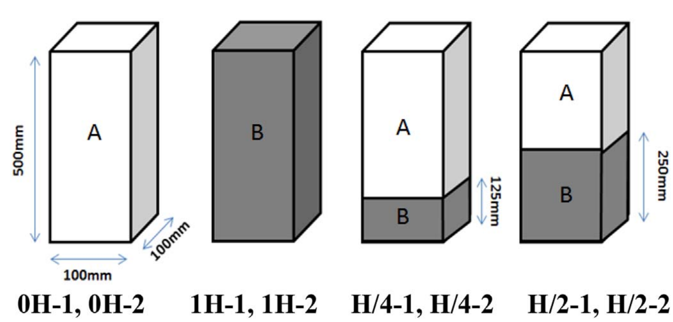

Fig. 3. Testing models 1–8: (A) unreinforced; (B) fibre-reinforced.