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Compressive behaviour of fibre-reinforced cemented paste backfill

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ABSTRACT

Reinforcement of cemented paste backfill (CPB) with polypropylene fibres was investigated as a way of improving the stability of backfilled underground mine stopes. A series of unconfined compressive strength (UCS) tests were carried out on both non-reinforced and fibre-reinforced cemented tailings. Sandy silt tailings from a nickel mine in Western Australia were used in the study. Ordinary Portland cement at concentrations of 3–5% by weight of tailings and 0–0.5% Adfil-Ignis polypropylene fibres by weight of total solids were used for specimen preparation. The stress–strain curves from the UCS tests showed the inclusion of fibres increased the UCS and significantly reduced the post peak strength loss. Accordingly, the fibre-reinforced specimens were found to be much more ductile than unreinforced specimens, which is highly desirable in many backfill applications. Sliced images acquired from X-ray computed tomography (CT-scan) demonstrated that the observed ductile behaviour of reinforced specimens could be explained by the restraint to crack growth provided by the mobilised fibre tensile strength. At large strains, fibre-reinforced specimens had virtually zero dislodged fragments and retained their integrity as shown in both experimental photos and CT sliced images. This was different from unreinforced specimens, which developed large, wide cracks that resulted in fracturing of the tested specimens. The potential for improving the self-supporting capacity of the fill mass using fibre reinforcing but less cement is discussed and potential advantages, such as reduced ore dilution when excavating adjacent stopes are discussed.

1. Introduction

Mill tailings are the main waste stream from mineral processing. Rather than storing this waste material on surface, where it presents environmental and safety risks, there is increasing interest in using mill tailings for backfilling of underground voids, thus providing additional structural support to future excavations and minimising the loss of ore due to dilution. Unfortunately, mill tailings often contain fine particles that can impede drainage rates, leading to the initial preference in the mining industry for use of coarser hydraulic backfill. Paste backfill was first developed in the early 1980s at Bad Grund Mine, Germany (Dave, 2001; Yilmaz et al., 2004). Cemented paste backfill (CPB) is generally comprised of full stream tailings, with water and a small amount of cement (of the order of 5% by dry mass). The mass concentration of CPB ranges from 75% to 85% solids by weight of total solids and it does not segregate when flowing to stopes. Considering the advantages of CPB, such as reduced risk of barricade failure and stable flow through delivery pipes, paste backfill has been increasingly accepted as a preferred mine fill method.

During the mining process, the fill mass is usually used as either temporary or permanent pillars to support the mined regions or as self-supporting structures to prevent the exposure of unstable excavated stopes (Yumlu, 2001). Throughout the period of mining adjacent stopes, the mine backfill should maintain sufficient strength to ensure the stability of the working area (Sivakugan et al., 2006). However, at least twelve barricade failures were reported between 2003 and 2006, many of them being due to filling rates that were too fast (Helinski et al., 2011). Obviously a filled stope with a small proportion of binder is weak and failure may be induced by impact stresses from the country rock (Aubertin et al., 2003), as it is common to have falling rock fragments when excavating adjacent stopes, owing to the brittleness of filling materials. This would increase the ore dilution, where previously-placed backfilled material is entrained with the ore extracted from the new stope and loss of mineral products occurs (Dirige and De Souza, 2008).

Fibre-reinforced concrete (FRC) is increasingly popular in civil engineering, being used to increase the tensile and flexural

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strength of structures in the last few decades. In ordinary concrete, the internal micro-cracks contribute to the failure of structures and associated poor ductility. Inclusion of fibres helps rectify the weakness of materials by mobilizing tensile strength along the failure planes (Ramesh et al., 2003). Many laboratory tests reported that randomly mixed fibres such as metal, glass, synthetic and carbon, in plain concrete provided a crack-arresting ability and enhanced the strength, toughness, ductility and post-cracking resistance (Balaguru and Shah, 1992; Chen and Carson, 1971; Fanella and Naaman, 1985; Mansur et al., 1997).

In addition, studies on fibre-reinforced sand and fibre-reinforced cemented soil have also been reported. Maher and Gray (1990) carried out triaxial compression tests to observe the behaviour of sands reinforced with randomly distributed fibres. The inclusion of fibres significantly increased the ultimate strength and stiffness of the sands tested. Similar results from triaxial compression tests of geosynthetic-reinforced sand were reported by Latha and Murthy (2007). Consoli et al. (2003, 2007b) conducted plate load tests and ring shear tests on polypropylene fibre-reinforced sandy soil, and at large strains, the stress–strain behaviour had distinct differences from that of non-reinforced soil. Other investigators (e.g. Consoli et al., 2007a, 2009, 2010b, 2011a; Tang et al., 2007; Dalla Rosa et al., 2008; Rattley et al., 2008) presented the mechanical behaviour of cemented soils reinforced with different fibres. All these studies indicated that randomly mixed fibres within the soil mass provided an increase of shear strength without specimens exhibiting distinct failure planes.

In mining engineering, Mitchell and Stone (1987) first proposed the method of fibre reinforcement for the design of mine backfills in order to reduce the overall cement usage. Their laboratory investigation compared the stabilities of layered fills and bulk fills reinforced with metal shotcrete fibres and anchored fibres. For the same safety factor, the fibre-reinforced tailings demonstrated a remarkable reduction in cement usage, providing potentially significant cost savings for backfilling operations. As a solution for tailings disposal, Zou and Sahito (2004) studied the use of fibre-reinforced tailings for shotcrete to support underground openings and strengthen pillars. The flexural strength was found to be increased by 59% with polymer fibres and by 25% with the same mass of steel fibres. Based on previous research of fibre reinforcement, Festugato et al. (2013) conceived the potential strength improvement of fibre-reinforced CPB and studied the shear response of fibre-reinforced CPB under cyclic simple shear tests. The fibre inclusions were found to provide resisting forces and increase the load-carrying capability of the CPB. However, CPB has different properties from concrete and cemented sand, in terms of having finer particles and wider particle size distributions, much lower cement content and various chemical components from the tailings and process water that may affect strength. The mechanical behaviour of fibre-reinforced CPB has rarely been studied before (Festugato et al., 2013). Therefore, the purpose of the laboratory tests in this paper is to primarily explore the effects of polypropylene fibres on the compressive strength of CPB through a series of unconfined compression tests. The X-ray tomography technique was used to examine the internal deformation behaviour of non-reinforced and fibre-reinforced CPB and explain the observed stress–strain response.

2. Experimental program

2.1. Materials

The tailings adopted in this study were from a nickel mine located 42 km south of Kambalda, Western Australia. The particle size distribution of the tailings is shown in Fig. 1. It is classified as sandy silt with a specific gravity of 2.81 and a liquid limit of 26%. The chemical composition of the material is listed in Table 1.

Monofilament polypropylene fibres termed Adfil-Ignis (Fig. 2) were used to reinforce the CPB. The selection of Adfil-Ignis fibres was mainly based on the experience from previous research (e.g. Festugato et al., 2013) as well as considerations of economy and availability. The Adfil-Ignis fibres were 6 mm long and 18 μm in diameter, with a tensile strength of 600 MPa and specific gravity of 0.91. The fibre supplier reported the Adfil-Ignis product has excellent acid and alkali resistance capabilities and has a non-absorbent character. Furthermore, the mining process requires exposure of cemented backfilled stopes as soon as possible after placement of the backfill, to expedite ore extraction. As shown later in the paper, even after 28 days there was no indication of a decrease in strength. Thus although the question of fibre durability in the presence of mine process water is an important one, it was not considered a major factor in the present study. If fibre-reinforced CPB were to be used in an application where long-term strengths were a consideration, or other fibres were to be used, additional studies of fibre durability would certainly be warranted. The effects of fibre content on reinforced cemented soils have been studied previously and the results showed a fibre percentage between 0.25% and 0.75% (by dry mass) resulted in a significant increase in compressive strength (Consoli et al., 2011b, 2012; Zaimoglu and Yetimoglu, 2012). The fibre contents chosen in this study were 0.3% and 0.5% by mass of the sum of dry tailings and cement.

The binder used was ordinary Portland cement. The most common cement dosage ranges between 1% and 10% in Australian sites (Potvin et al., 2005). Both non-reinforced and reinforced specimens with 3% and 5% cement content by dry mass of tailings were tested to compare the contributions of cement and fibres to the compressive strength and ductility of reinforced CPB.

The water from the mine site was utilised in the laboratory to prepare testing specimens (details of the process water quality are provided in Table 2). The salt content of the process water was much higher than that of domestic tap water. Some laboratory studies have demonstrated the influence of salt on the backfill strengths during the curing process (Wang and Villaescusa, 2000; Li et al., 2003). Nevertheless, it was essential to reproduce the site conditions as accurately as possible, hence the use of process water. Specimens were prepared at a solid content (by total mass) of 75%, which is representative of the value used at the site in question.

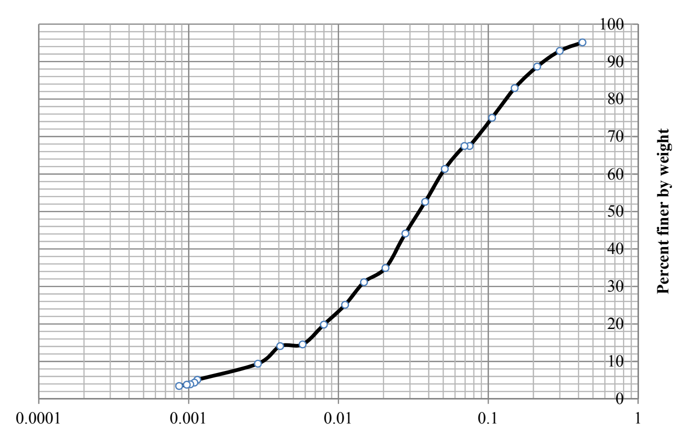

Fig. 1. Particle size distribution.