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Temperature dependence of the reactivity of cemented paste backfill

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ABSTRACT

The environmental performance of cemented paste backfill (CPB; a mixture of tailings, water and binder), which contains sulphide mineral-bearing tailings, is strongly influenced by its reactivity. However, our understanding of the reactivity of CPB under various thermal loading conditions as well as its evolution with time is limited. Hence, a laboratory investigation is conducted to study the effects of curing and ambient (atmospheric) temperatures on the reactivity of CPB. Oxygen consumption (OC) tests are conducted on CPB specimens cured at different temperatures to study their reactivity. Furthermore, microstructural analyses (e.g., x-ray diffraction (XRD), mercury intrusion porosimetry, and thermogravimetry/derivative thermogravimetry) are performed to assess the microstructural characteristics of the tested CPBs. The results show that the reactivity of CPB is temperature-dependent. As the curing temperature increases, the reactivity generally decreases. The reactivity is also affected by the ambient temperature. The reactivity increases as the atmospheric temperature increases. However, the extent of the effect of the temperature depends on the curing time and is generally more pronounced at the early ages. Furthermore, the presence of sulphate in the pore water of CPB can significantly affect the reactivity of CPB cured at high temperatures (50 °C). The findings of this study will therefore help to better assess and predict the environmental behavior of CPB under various field thermal conditions.

1. Introduction

Historically, mining has been imperative to human and social development, and the industry will continue to make investments that meet the increasing needs of society (ICMM, 2012). Yet the mining industry generates a substantial volume of solid wastes as by-products (Lottermoser, 2010), which mainly consist of rock wastes and tailings, that can have environmentally, socially and economically long lasting and detrimental consequences (Kitula, 2006). Tailings are considered to be the largest waste by-product (Dold, 2014), and sulphide bearing tailings in particular are considered to be a serious environmental issue that the mining industry is facing worldwide (Öhlander et al., 2012).

Generally, tailings are a slurry of grounded rock and process effluents generated by mine processing plants and usually deposited into impoundments (Davies and Rice, 2001). These conventional methods of tailings storage and disposal have several environmental, geotechnical (e.g., failure of tailings dams) and economic issues for the mining industry (Dold, 2014). The management of sulphidic mine tailings is one of the greatest challenges for the mining industry worldwide (Öhlander et al., 2012) because they cause acid mine drainage (AMD) which is produced as a result of the oxidation of sulphide minerals (e.g., pyrite) found in tailings (Kumari et al., 2010). This drainage can have long-term adverse effects on the environment (Johnson and Hallberg, 2005). Therefore, the storage or disposal of tailings, in particular sulphidic mine tailings, on the surface of the ground, either in impoundments or dams, incurs the most substantial environmental liability throughout the operating and decommissioning stages of mines (Martin and Davies, 2000). The risks and consequences associated with conventional tailings impoundments, substantial operation and maintenance costs of these impoundments as well as public perception and more strict regulations on the disposal of such waste have driven the mining industry to search for alternative methods that can prevent and/or minimize the effects (Alakangas et al., 2013; Fall et al., 2009). As a result, a number of alternative techniques for the disposal or management of tailings have been developed in the recent past, such as the use of sub-aqueous techniques, application of high density thickeners, filter pressing of tailings and then stacking them (dry stacking) or mixing the tailings with cement and then pumped underground (cemented

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paste backfill (CBP)). Among these alternative techniques, cemented paste backfilling has been the most novel and promising technology for the management of mine tailings, including sulphide bearing tailings. Therefore, this technology has now become a commonly used method and extensively practiced in the mining industry worldwide. The implementation of cemented paste backfilling has several advantages, such as minimizing the amount of storage tailings on the surface of mine site, increasing mining production, controlling the oxidation of sulphides and mobilisation of metals (Alakangas et al., 2013; Yilmaz et al., 2004; Hassani et al., 2001; Hassani and Archibald, 1998).

CPB is an engineered mixture that is mainly prepared from three ingredients: mine tailings (75–85% wt.), hydraulic binder (3–7% wt.), and water (Alakangas et al., 2013; Fall et al., 2008; Yilmaz, 2010). Despite the advantages of using CPB, its environmental performance is still not well understood. In particular, the role of the geochemical reactivity of CPB in terms of its environmental behavior, durability and stability is not well known. Therefore, the reactivity of CPB should be assessed before it is placed into underground mines to avoid potential environmental and economic impacts. Cemented paste backfilling should not be a method that transfers the environmental problems of mine tailings from the surface of the ground to the underground (Ouellet et al., 2006).

Most of the previous studies on CPB have focused on its mechanical properties and economic advantages (less binder consumption and cost optimization) (e.g., Ghirian and Fall 2014; Wu et al., 2012; Fall et al., 2010; Fall and Nasir, 2010; Kesimal et al., 2005; Fall et al., 2004a,b), whereas few studies have evaluated the environmental performance of CPB by investigating its geochemical reactivity (e.g. MEM, 2006; Hamberg et al., 2015). Moreover, some studies have assessed the performance of CPBs that contains sulphide-rich tailings (e.g. Cihangir et al., 2012, 2015; Ercikdi et al., 2013, 2015; Tariq and Nehdi, 2007, Hassani et al., 2001).

The reactivity of sulphidic mine wastes can be measured by using direct and indirect techniques, such as the sulphate release, pH and the oxygen gradient methods (Cihangir et al., 2012, 2015; Ercikdi et al., 2013, 2015; Ouellet et al., 2006), respectively. Among these techniques, the oxygen consumption (OC) test is most preferred because it is simple, inexpensive, fast and accurate. Also, the OC test can be used to obtain both laboratory and field measurements. The OC test was first used in Elberling et al. (1994) and Elberling and Nicholson (1996). The concept is based on measuring the rate that sulphide minerals consume oxygen in a sealed vessel during their oxidation process (Ouellet et al., 2006). This technique was used in both the laboratory and field to quantify the reactivity of various acid generating tailings and mine rocks in several studies (e.g., Martin and Davies, 2000; Mbonimpa et al., 2002; Bussière et al., 2002; Tibble and Nicholson, 1997; Elberling and Nicholson, 1996; Nicholson et al., 1995; Elberling et al., 1994, 1993). However, only a few studies have attempted to measure the reactivity of CPB by using OC testing. Ouellet et al. (2006, 2003) performed OC testing to quantify the reactivity of CPB in both the laboratory and the field. Also, Fall et al. (2004a,b) and Pokharel (2008) used the OC method on CPB samples prepared from natural and artificial tailings with different pyrite contents to investigate their reactivity. The findings of these studies indicate that the pyrite content and degree of saturation significantly influence the reactivity of the tailings and CPB. Furthermore, all of the above studies indicated that the use of cemented paste backfilling to manage sulphide bearing tailings in underground mines could reduce their environmental impacts.

However, the reactivity of CPB can be also affected by several other variables, such as the availability of oxygen, level of moisture, and range of temperature. Temperature is one of the main variables that can influence the reactivity of CPB, and CPB structures are subjected to various thermal loading conditions in the field. The temperature of CPB structures can be influenced by several different heat sources during their service life. These sources can be internal and related to CPB itself, or external and related to the mine. The main sources of internal heat include heat generated during binder hydration and the transport of paste backfill as well as oxidation sulphide minerals found in the paste backfill mixture. For example, the temperature of CPB in the stope (mine cavity) can reach 50 °C due to binder hydration as observed in many field investigations on backfill (e.g., Williams et al., 2001) or modeling studies (e.g., Wu et al., 2012; Nasir and Fall 2009). On the other hand, the external sources of heat depend on the depth of the mine and geological conditions in addition to the geographical location of the mine (Fall and Pokharel, 2010). However, our understanding of the effects of the curing and ambient (atmospheric) temperatures on the reactivity of CPB is limited. This is because the effects of temperature on the reactivity of CPB have been mostly neglected in previous studies. Therefore, in this paper, the effects of curing and mine atmospheric temperatures on the reactivity of CPB have been studied and will be discussed in detail.

2. Materials and experimental program

2.1. Materials used

2.1.1. Binder

Portland cement type I (PCI) was used as the binder in the preparation of the CPB samples because in practice, it is the most commonly used binder in making paste backfill. The effect of different types of binder (e.g., PCV, Slag, Fly Ash) on the reactivity of CPB is outside of the scope of this study. The primary physical and chemical properties of PCI are presented in Table 1.

2.1.2. Tailings

Three types of tailings are used in this study. The first type is called silica tailings (ST), which are a commercially available artificial tailings material that is made of ground silica (manufactured by U.S. Silica Co.). ST are characterized by a particle-size distribution (PSD) that is similar to the average grain size distribution of tailings from nine different mines in eastern Canada. ST also mainly consist of silica (99.8% SiO_2) particles, which are considered to be a chemically inert material (Carraro et al., 2009). The reason for using ST was to minimize and/or control the potential chemical interactions with the other ingredients (e.g. cement) in the CPB mixture, and thus reduce the impact of uncertainty on the results and their interpretation. In addition to ST, two types of natural tailings, including gold tailings (GT) and zinc tailings (ZT) obtained from Canadian hard rock mines, were used. Tables 2 and 3 show the primary physical properties and mineral composition of the tailings used, respectively. The grain size distribution of the tailings (ST, GT and ZT) is presented in Fig. 1.

2.1.3. Mixing water and pyrite

Tap water was used as the mixing water. A commercial pyrite powder (FeS_2; M.W. = 119.98) was used to synthesize the pyrite-bearing tailings (or sulphide bearing tailings). This commercial pyrite has grains with a size similar to that of pyrite minerals commonly found in the natural tailings of hard rock mines. The pyrite-bearing tailings with a pyrite content of 5%, 15% and 45% wt. were prepared by mixing ST and GT with the appropriate amounts of pyrite powder. ZT with a pyrite content of 45% wt. was also prepared by mixing ZT and the applicable amount of pyrite. The physical properties of the pyrite are presented in Table 4.