



Application of Portland cement to control acid mine drainage generation from waste rocks



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ABSTRACT

Cement has been little investigated as a control for acid mine drainage, despite having advantages over cheaper alternatives. Leaching column experiments (set up in triplicate) investigated the effect of applying Portland cement slurries with three different water/cement (w/c) ratios (0.8, 1.0, 1.2) to pyrite-bearing waste rock from Brukunga mine in southeastern Australia. After application of the cement, leachate from the cemented columns showed a reduction in acidity compared to the control columns of ~85% and 100% for w/c ratios of 0.8 and both 1.0 and 1.2 respectively. This was due to direct neutralisation of acidity by cement dissolution and encapsulation of the pyrite-bearing rock fragments by the cement (as shown by a reduction in oxygen consumption rates of up to 70%). In columns with the higher w/c ratios (1.0, 1.2), the cement slurry penetrated to the base of the columns and greatly decreased the permeability. The greater coverage of the waste rock by the cement and increased contact time between the leachate and cement meant that no acid drainage leached from these columns (pH 7–8, Fe, Al, Mn, Zn and Cu concentrations rarely above detection limits). In columns with a w/c ratio of 0.8, the cement slurry was mostly retained in the upper 30–50% of the waste rock, leaving a large fraction of the waste rock below without any cement coverage. Leachate drained relatively quickly from these columns, probably through a small number of pathways through the cement plug and carried relatively small loads of acidity and metals from uncemented waste rock beneath the cement. Thus cement may be a viable method for controlling acid mine drainage generation from waste rock dumps, and could be applied with both lower and higher w/c ratios could be used to achieve an optimal balance between deep penetration and surficial retention.

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1. Introduction

Acid mine drainage (AMD), which typically results from the oxidation of sulfide minerals in waste rock and tailings at mine sites, is an expensive environmental problem for the mining industry worldwide, as well as for governments managing historical mining landscapes (McCarthy, 2011; Harries, 1997; Nordstrom, 2011). A wide range of technologies has been developed for treating acid mine drainage (Lottermoser, 2003; Johnson and Hallberg, 2005; Blowes et al., 2003), but if the source is not effectively sealed from the atmosphere or from percolating water, then the need for treatment can remain for hundreds of years (Evangelou, 1995; Nieto et al., 2007). Controlling acid mine drainage at its source is challenging because the scale of the acid-generating waste

deposits is often huge, in the order of millions of tons, and the cost can be very high, especially for historical mining landscapes where mine planning did not take AMD prevention into account (Davies et al., 2011; Edraki et al., 2005; Nordstrom and Alpers, 1999).

A variety of techniques have been tested and/or employed to control AMD at its source, including phosphate and silicate coatings (Evangelou, 1995; Mauric and Lottermoser, 2011; Ji et al., 2012; Kang et al., 2016) and the application of limestone (Lapakko et al., 1997; Miller et al., 2003, 2009) and alkaline industrial waste products such as fly ash (Canty and Everett, 2006; Perez-Lopez et al., 2007; Guynn, 2007; Hamel et al., 2010; Skousen et al., 2012), cement kiln dust (Doye and Duchesne, 2003; Duchesne and Doye, 2005; Sahoo et al., 2013), green liquor dregs (Ragnvaldsson et al., 2014) and bauxite residues (Doye and Duchesne, 2003; Duchesne and Doye, 2005; Maddocks et al., 2004).

Portland cement is produced by the calcination of limestone with a source of aluminosilicate (typically clay) at temperatures of around 1450–1500 °C (Hewlett, 1998), and is widely used for

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geotechnical stabilisation in mining and civil engineering, as well as in the encapsulation of hazardous wastes (Heinz, 1998; Sariosseiri and Muhunthan, 2009; Kogbara et al., 2013; Sheshpari, 2015). However, it has been rarely used or tested as a means of controlling or neutralizing AMD (Ji et al., 2012; Northwest Geochem, 1996; Shabalala et al., 2017), even though it contains a similar amount of alkalinity as limestone, and (unlike limestone) forms a hard paste upon hydration with considerable impermeability (Banthia and Mindess, 1989; Claisse et al., 1999), which might be put to good effect in controlling AMD.

Furthermore, Portland cements can be applied via a range of different techniques including shotcreting, soilcreting and grout injection (Northwest Geochem, 1996; Spence, 1987), and with a wide range of water/cement ratios, which control the rheology of the slurry and the eventual distribution of cement through a rock mass (Axelsson and Gustafson, 2007; Heinz, 1998). Unlike clay cover systems, which require waste rock surfaces to be accessible to heavy vehicles, cement does not require compaction to set, and therefore could be applied to steep slopes of waste rock dumps, as well as being injected to encapsulate sulphide minerals buried deeply.

Thus there is much scope for research on the application of Portland cement to the problem of AMD. In this study, Portland cement slurries with three different w/c (water/cement) ratios were applied to sulphide bearing waste rocks from Brukunga, South Australia, to test the effectiveness of Portland cement in controlling AMD.

2. Materials and methods

2.1. Brukunga pyrite mine waste rocks

The Brukunga Pyrite Mine is located in the Adelaide Hills, 40 kms east of Adelaide in South Australia (Fig. 1). It was mined for sulfur from pyrite and pyrrhotite between 1955 and 1972 and produced around 8 million tonnes of waste rock, which remain exposed to the atmosphere at the site (Fig. 1, Taylor and Cox, 2003).

The mine was focused on the Nairne Pyrite Member within the shallow marine Cambrian Talisker Cal-siltstone; the sediments have been subjected to intermediate grade metamorphism and are now biotite-muscovite schists (Daily and Milnes, 1972) composed of quartz, feldspars (plagioclase and orthoclase) and mica (muscovite, biotite and phlogopite) (Ali, 2011). The ore consists of disseminated pyrite and pyrrhotite as well as veins of these minerals parallel to the bedding. A variety of secondary minerals (jarosite, alunite, rozenite, halotrichite, gypsum and elemental sulfur) has been identified at Brukunga (Agnew, 1994).

AMD produced by oxidation of sulphides in the waste rock dumps, quarry walls and tailings has been treated since 1980 in a lime neutralisation plant, which discharges neutral effluent from the mine to the downstream environment (Government of South Australia, Resources and Energy Group, 2014).

Approximately 90 kg of cobble-sized waste rocks were collected from three locations at the Brukunga mine on 24th June 2014: the southern waste rock dump, rubble beneath the high wall and a small pyramid-shaped dump used as a control in a previous field trial for cover techniques (Fig. 1).

2.2. Waste rock selection for leach columns

The rocks from each of the three different locations at the mine were crushed and sieved into fractions of 2–4.75 mm, 4.75–13.2 mm and 13.2–26 mm at Federation University in Ballarat, Victoria. Twelve 4.73 kg samples of waste rocks were assembled using the same proportions from each of the locations at

the mine site (57.5% from the southern waste rock dump, 21.5% from the high wall and 21% from the small dump) and the same proportions of each of the different grain size fractions (14% in the 2–4.75 mm size fraction, 69% in the 4.75–13.2 mm size fraction and 17% in the 13.2–26 mm size fraction).

2.3. Leaching columns

Twelve leach columns, 15.5 cm in diameter and 28–34 cm long, were constructed from PVC pipe. A press-on cap with a tap was used to seal the column at the base, and a screw-on cap at the top. The 4.73 kg waste rock samples were poured from zip lock plastic bags into the columns.

2.4. Leaching regime

For the first leaching event, a 1 L graduated cylinder was used to pour enough deionized water into each column to fill it up to the brim (around 4 L). The volume of water added was used as a measure of the total void space in each column. For this initial leach, the taps at the bases of the columns were initially closed, allowing water to sit in the columns for 24 h to allow for dissolution of soluble salts that had accumulated since collection of the waste rocks. After 24 h, the taps were opened to allow for collection of the leachate in 1 L sample bottles.

The columns were subsequently leached with 1 L of deionized water approximately every two weeks over around six months (twelve times), and then kept dry for around 50 days, before the columns were leached one more time with 1 L of deionized water to remove soluble salts.

Cement treatments (see section 2.5 below) were then applied to 9 of the 12 columns in 3 groups of 3 (triplicates), with 1 set of 3 columns used as a control group (Table 1). Leaching commenced one week after the application of cement slurries; the columns were then leached approximately every two weeks over the next 5 months (a further nine times), and subsequently allowed to dry for around 50 days. Leaching every two weeks then resumed (nine times over around 5 months), before the columns were again left to dry for around 50 days. Finally, the columns were leached every two weeks for six weeks (three times) (see Fig. 2).

For each leaching application, the taps of the columns were opened, so that the leachate would drain freely through the waste rocks, and water was applied with pump action spray bottles to simulate rainfall. One day was allowed for the leachate to drain through the columns, before leachate samples were collected for analysis. The first time that the columns were leached after application of cement slurries, it was noted that rates of leachate drainage through some of the cemented columns decreased, therefore on this occasion, two days were allowed for leachate drainage. After the second column leach following cement application, rates of drainage had decreased even more, and so the time allowed for leachate drainage was extended to one week for the remainder of the experiment (Fig. 2). For those columns that drained very slowly, some water was retained on top of the cemented waste rock, and after each leachate sample was collected from these columns, the water retained was emptied, and its weight calculated from the difference between the weight of the column before and after emptying.

2.5. Cement application

The cement used was Cement Australia's General Purpose Cement, composed of 64.1% CaO, 19.7% SiO₂, 5.3% Al₂O₃, 2.7% Fe₂O₃, 1.6% MgO, 2.8% SO₃, 0.7% K₂O and 0.1% Na₂O with an acid neutralizing capacity of 955 mg CaCO₃ eq./g cement (see section 2.8). For

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