Selected Papers from the Proceedings of the Fourth Geo-China International Conference

Geotechnical Special Publication No. 263

Innovative and Sustainable Use of Geomaterials and Geosystems

Edited by
Wen-chieh Cheng, Ph.D.
Jason Y. Wu, Ph.D., P.E.

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GEO-CHINA 2016

INNOVATIVE AND SUSTAINABLE USE OF GEOMATERIALS AND GEOSYSTEMS

SELECTED PAPERS FROM THE PROCEEDINGS OF THE FOURTH GEO-CHINA INTERNATIONAL CONFERENCE

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Preface

This Geotechnical Special Publication (GSP) contains 13 high quality papers that were peer-reviewed and presented at the GeoChina International Conference on Sustainable Civil Infrastructures: Innovative Technologies for Severe Weathers and Climate Changes, held in Shangdong, China on July 25-27, 2016. Major topics covered are in-situ test methods for site characterization, design and quality control of earth structures and subgrades, pavement performance evaluation & management, State-of-the-Arts and State-of-the-Practices on bridge design, construction & maintenance, tunneling in soft ground, ground conditioning & modification. The overall theme of the GSP is innovative and sustainable use of geomaterials and geosystems and all papers address engineering challenges and their countermeasures of this theme. You will have the opportunity to meet colleagues from all over the world for technical, scientific, and commercial discussions, and also to obtain knowledge regarding recent technological advances, engineering applications, and research results among scientists, researchers, and engineering practitioners.

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Application of Coal Fly Ash to Replace Lime in the Management of Reactive Mine Tailings

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Abstract: Acid mine drainage (AMD), the acidic water discharged from active, inactive, or abandoned mine sites, is the largest environmental liability facing the mining industry. Currently large quantities of lime are used for AMD control by mining companies. The manufacture of lime contributes significantly to greenhouse gas (GHG) emissions, since about 0.8 tonnes of CO_2 are generated for every tonne of lime produced. This study presents an innovative approach of using coal fly ash, a by-product from coal-fired utilities, to replace lime for AMD control in reactive mine tailings. A case study is presented to demonstrate that at on mining sites with access to high calcium coal fly ash, this approach is effective, cost efficient and presents minimum adverse environmental impacts.

INTRODUCTION

Acid mine drainage (AMD) is the largest environmental liability facing the mining industry and the public through abandoned mines, which is resulted from oxidation of sulphide minerals (Singer and Stumm 1970). Lime is the primary agent for control of acid mine drainage used by mining companies. About 0.8 tonnes of CO_2 (an important greenhouse gas) are generated for every tonne of lime produced. Laboratory studies have demonstrated that coal fly ash is effective for AMD prevention and control (Shang et al 2006, Yehysis et al. 2009). The approach may provide a significant opportunity for the mining industry to reduce the use of lime. The paper outlines the potential of using fresh and landfilled coal fly ash for the management of acid generating mine tailings, and illustrates the application via a case study.

REACTIVE MINE TAILINGS

Mine tailings are the solid waste generated from mining and mineral processing. Ores are mined, crushed, and ground to have minerals separated from the crushed rock. The remaining portion of the rock, known as tailings, is disposed directly to the nearest streams, rivers or land. Exposed to the atmosphere, the sulphur-rich minerals

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in tailings are easily oxidized, and generate acid in tailings impoundments. One of approaches to minimize oxidation of reactive tailings is using neutralization agents. Six primary chemicals have been used to treat AMD, as shown in Table 1 (Skousen et al. 2000). As shown lime products are predominant chemicals used in AMD treatment. Lime, by strict definition, is manufactured forms of lime that include quicklime and hydrated lime. Quicklime, so named because it reacts vigorously with water, is the product of calcination of limestone. The production of quicklime releases considerable amount of CO_2 gas by heating limestone in a kiln at a minimum temperature of 900°C. Approximately, 0.70 to 0.80 tonnes of CO_2 is emitted per tonne lime produced, which generates more than 1.7 Mt CO_2 annually.

Table 1. Chemicals used in AMD treatment. (Skousen et al. 2000)

Common Name	Chemical Name	Formula	Conversion Factor[1]	Neutralization Efficiency[2]	1996 Cost[3] $/ton or gallon Bulk	< Bulk
limestone	calcium carbonate	$CaCO_3$	1.00	30%	10.00	15.00
hydrated Lime	calcium hydroxide	$Ca(OH)_2$	0.74	90%	60.00	100.00
pebble quicklime	calcium oxide	CaO	0.56	90%	80.00	240.00
soda ash	sodium carbonate	Na_2CO_3	1.06	60%	200.00	320.00
caustic soda (solid)	sodium hydroxide	$NaOH$	0.80	100%	680.00	880.00
20% liquid caustic	sodium hydroxide	$NaOH$	784.00	100%	0.46	0.60
50% liquid caustic	sodium hydroxide	$NaOH$	256.00	100%	1.10	1.25
ammonia	anhydrous ammonia	NH_3	0.34	100%	300.00	680.00

[1] The conversion factor may be multiplied by the estimated tons acid/yr to get tons of chemical needed for neutralization per year. For liquid caustic, the conversion factor gives gallons needed for neutralization.
[2] Neutralization Efficiency estimates the relative effectiveness of the chemical in neutralizing AMD acidity. For example, if 100 tons of acid/yr was the amount of acid to be neutralized, then it can be estimated that 82 tons of hydrated lime would be needed to neutralize the acidity in the water (100(0.74)/0.90).
[3] Price of chemical depends on the quantity being delivered. Bulk means delivery of chemical in a large truck, whereas <Bulk means purchased in small quantities. Liquid caustic prices are for gallons. Others in tons.

Coal fly ash is fine and non-cohesive powder produced from the combustion of coal in coal-fired utilities. Coal fly ash serves two major functions in the management of reactive mine tailings, i.e. (CIRCA 2006, Baykal et al 2000):

(1) Neutralization and stabilization (precipitation). This is, to some extent, equivalent to adding lime in reactive tailings since coal fly ash typically contains significant quick lime. The neutralization capacity of coal fly ash is largely dependent on the CaO and MgO contents. Upon contact with AMD containing significant sulphate, the dissolved Ca^{2+} and Mg^{2+} ions in coal fly ash are released, which react with SO_4^{-2} ions in AMD to form calcium and magnesium sulphates (Gypsum). The pH of tailings is raised, resulting in precipitation of dissolved metals. The experimental data have shown that

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adding 10% (mass ratio) of coal fly ash in tailings has caused the pH to increased to 11. The effect is equivalent to adding approximately 5% lime. The results also showed that the pH remained stable after more than 10 pore volumes of AMD passing through compacted coal fly ash (Shang et al, 2006).

(2) Cementation. The silica and alumina, as well as quicklime in coal fly ash react with water and generate cementation, known as pozzolanic reactions. The SiO_2 content in coal fly ash is typically about 40% and Al_2O_3 about 20%, in which the fractions of reactive silica and alumina are major contributors to cementation. The reactions with AMD become more vigorous, as it contains high concentrations of dissolved solids. When coal fly ash is applied to reactive mine tailings, dissolved metals are precipitated due to increase in pH. Furthermore, secondary minerals are formed from the pozzolanic reactions. The net results are the clogged voids, which decrease the air and water permeability of the coal fly ash and/or ash-tailings mixture. It has been found that the hydraulic conductivity (permeability) of compacted coal fly ash reduced more than 3 orders of magnitude when in contact with AMD, along with the increase in the break-through hydraulic gradient up to 10 folds (Shang et al 2006). In other words, coal fly ash has formed a hydraulic barrier when in contact with AMD, which inhibits infiltration of oxygen and water from reacting with mine tailings.

A CASE STUDY

At the Musselwhite gold mine in Northern Ontario, about 19 million tonnes of tailings containing about 2% sulphur have been generated. The sign of oxidation has been observed on the Musselwhite Mine tailings disposal site after 1 to 2 years of disposal. If lime is used to treat tailings disposed on land, at least 300,000 tonnes of lime (at a mass ratio of 5%) will be required. In addition, the distance to the nearest lime production plant at Faulkner, Manitoba is more than 1000 km away from the mine site. On the other hand, the Atikokan Generating Station is located much closer, at about 400 km south of Musselwhite. Between 40,000 and 60,000 tonnes of lignite fly ash are generated every year. The coal fly ash has high CaO content (15% to 16%) with 37% to 38% SiO_2 and 18% to 19% Al_2O_3, which makes it an ideal candidate for lime replacement. Currently 80% of the fly ash is utilized in concrete cement manufacturing and other industries, whereas the remaining 20% is landfilled. In the landfill of the Atikokan Generating Station, more than 350,000 tonnes of coal fly ash is available for potential applications.

The physical, chemical and mineralogical properties of the Musselwhite tailings and Atikokan fly ash are summarized in Table 2. The major oxides in the Atikokan fly ash, including fresh and landfilled, are listed in Table 3. It was noticed from Table 3 that the fresh and landfill fly ash have basically identical SiO_2 and Al_2O_3 contents. Compared to the fresh ash, the landfill ash has slightly lower CaO content. The grain size distributions of fresh and landfill fly ashes are noticeably different, as shown in Fig. 1. The portion of fine solids (< 2 micron-meter) in the landfill ash is only 4% compared to 22% for fresh ash, which is mainly attributed to the hydration of CaO that prompted finer particles to form lumps (see the SEM images in Fig.3). Another

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noticeable difference between the fresh (FFA) and landfill (LFA) ash is that the latter (LFA) has significantly higher maximum dry density and lower optimal moisture content, as determined from compaction tests (Fig. 4). Hence the landfill ash may be better suited as a solid cover for land disposal of reactive mine tailings. The results of this study indicate that the fresh and landfill coal fly ashes from Atikokan GS have favorable physical and chemical properties for AMD control on the Musselwhite Mine tailings disposal site. Compared to the fresh fly ash, the landfill ash is slightly cemented due to some hydration from precipitation. Both fresh and landfill fly ashes demonstrated neutralization capacity. In addition, the landfill fly ash is especially suitable for applications as solid covers because of its compaction characteristics. Hece the coal fly ash may be a cost efficient and effective alternative to lime, especially considering the distance of shipping lime to the Musselwhite Mine site (more than 1000 km).

Six kinetic column permeation tests were conducted to monitor the leaching properties of the coal fly ash, and mixtures of coal fly ash and mine tailings (Yeheyis et al 2009). The results are summarized in Table 4. The pH of the effluent increased from acidic (pH 4) to alkaline (pH 8 and above). The results further indicate that concentrations of regulated elements in the leachate from the fly ash-tailings mixtures were well below the guideline set by the Ontario environmental authority.

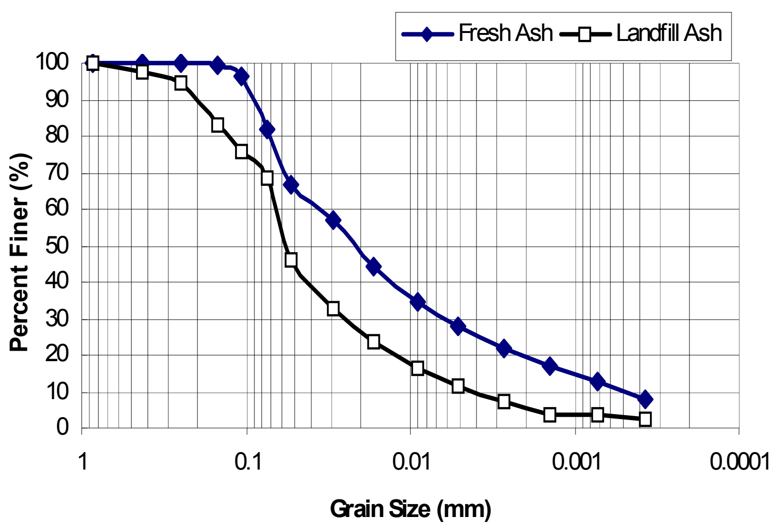

FIG. 1. Grain size distribution of Atikokan coal fly ash samples

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