In situ Mine Water Treatment of Flooded Underground Mines Using Waste Concrete: A Feasibility Study

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Abstract

This paper presents the results of a study into the use of construction and demolition waste (C&DW) in the *in situ* treatment of mine impacted water (MIW). South Africa (SA) is a developing country with the construction industry at the core of this development. The industry generates approximately 5-8 million tons of construction and demolition waste (C&DW) per annum, one of which is waste concrete (WC). The majority of the waste is landfilled with some repurposed in the same industry. In hindsight, SA is also faced with the high cost of MIW treatment due to the high cost of pumping and neutralising materials. To resolve these issues, WC slurry was evaluated at a laboratory scale for the *in situ* treatment of MIW to provide an alternative to the typical techniques that are currently used in SA. Laboratory findings of the study showed that WC may present an alternative option for MIW treatment over the conventional use of lime and limestone. The use of waste concrete would be an excellent form of waste beneficiation and a cost-effective method of managing MIW in SA.

Keywords: Construction and demolition waste, mine influenced water, *in situ* mine water treatment, waste concrete, waste concrete slurry

Introduction

For more than a century, the South African mining sector has played a significant role in the economic development of the country (Mineral Council of South Africa, 2018, formerly Chamber of Mines). However, historical mining has led to the degradation of the environment (Botha 2015; Haddaway et al. 2019; Chetty et al. 2021). The negative legacy of mine water discharge from underground mines onto the surface has left the government responsible for the management of mine water discharge in the country (Feris & Kotze 2014) which is the case in the Witwatersrand goldfields. The current techniques of mine water treatment and management in Witwatersrand, have high-cost implications due to the cost of pumping and require extensive, regular monitoring and maintenance and yet still produce high salinity effluent (Department of Water Affairs 2012). Thus, alternative mine water treatment technologies are often sought to lower the cost of the mine water treatment.

The Inter-Ministerial Committee (IMC) Report on Acid Mine Drainage published short and medium to long term strategies for managing mine influenced water (MIW) in the Witwatersrand Basin (Department of Water Affairs, 2010). In the report, *in situ* mine water treatment was identified as a medium to long term strategy for managing MIW in the region (Department of Water Affairs 2010; Vadapalli and Coetzee, 2019), consequently, laboratory scale investigations on the feasibility of *in situ* mine water treatment were commissioned and carried out at the Council for Geoscience (CGS) (Nyale *et al.* 2020; Coetzee et al. 2021). During the laboratory investigations, construction and demolition waste (C&DW),

specifically waste concrete (WC) was assessed as a neutralising material over the typical neutralising material due to its lime content. *In situ* mine water treatment also known as direct dosing offers an alternative to the traditional pump and treat method, which is temporal. Moreover, the substitution of lime with waste concrete (WC) offers a cheaper option than the use of commercial lime. On average, the cost of lime is R102.00 per 50 Kg. An estimate by Maree (2013) showed that the capital cost for MIW pump station for the three basins in the Witwatersrand to maintain the recommended Environmental Critical Level (ECL) of 150 m, 200 m and 400 m respectively for the Western, Central and Eastern Basin will amount to R211.4 Million and the electrical power cost was estimated at R57.8 million per annum.

While the overall cost of *in situ* mine water treatment has not been established, the treatment offers an alternative solution to the pump and treat method which carries exorbitant operation costs, moreover, the use of WC in mine water treatment lowers the costs associated with lime/limestone. South Africa's construction industry generates approximately 5-8 million tons of C&DW per annum (Bester et al. 2017), one of which is WC. With the rise in the construction of new cities, the production of C&DW will likely be more pronounced, providing an opportunity for reuse in mine water treatment. The cost of repurposing and handling C&DW is quite high, for example, the 2018 cost related to demolition, reduction, and reclamation of heavy concrete with a thickness greater than 750 mm per cubic metre is R1 283.62 (Ohemeng & Ekolu 2020). Measures put in place to promote recycling are necessary to achieve zero-landfill status as well as improve the status quo of the environment.

Experimental approach

laboratory trials were conducted to simulate the injection of alkaline materials into flooded mine voids. WC boulders sourced locally from demolished concrete structures were crushed to a fine powder (<75 microns) and the bulk chemical composition and mineralogy were determined using X-ray fluorescence spectroscopy (XRF) and X-ray diffraction (XRD) analysis, respectively. WC slurry made from mixes of WC and tap water at a liquid: solid ratio of 2:1 was formulated and introduced into a reaction container containing untreated mine water collected from Central Basin Acid Mine Drainage Treatment Plant in Germiston to form a slurry: mine water ratio of 13:1, mimicking the inside of flooded mine void (Figure 1).

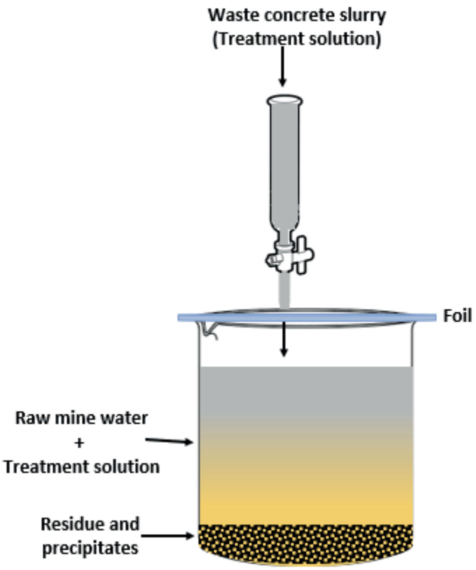

Figure 1: *Laboratory testing setup*

The pH and electrical conductivity (EC) of the raw mine water samples and treated mine water samples (after 28 days) were measured, and the chemical composition was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The laboratory simulation experiment sought to address the following:

- Determine the dosage regimen of the alkaline material i.e., the amount of treatment slurry needed for a certain volume of raw mine water;
- Determine precipitate formation time frame; and
- The quality of treated water.

Results and discussions

It was anticipated that when the mine water came into contact with the treatment slurry, a chemical reaction would take place which would raise the pH of the mine water, and subsequently trigger the precipitation of metals and other contaminants.

Feedstock characterisation

The pH and EC characterisation of raw mine water revealed a pH of 5.61, which is slightly acidic, and an EC of 4.96 mS/cm. Further analysis of the chemical composition of the mine water revealed that mine water contained a significant amount of sulfate ions (3,563 mg/L) and relative amounts of Ca (514 mg/L), Fe (504 mg/L), Mg (223 mg/L) and Na (183 mg/L). Minor concentrations of chloride ions, Mn, Si, and K were reported at 97 mg/L, 26 mg/L, 18 mg/L, and 18 mg/L respectively. Other elements reported in trace amounts included Ti, Sr, Ni, As, B, Co, Li and Zn. Al, U, and Pb were reported in negligible amounts. The negligible quantity of Al in the raw mine water is noteworthy and strongly suggests that at the pH of 5.61, almost all of the Al had already precipitated out of the raw mine water.

The bulk elemental composition of WC as determined by XRF revealed that WC was predominantly composed of SiO2 (87%) with relative amounts of CaO (5.04%) and Al2O3 (1.75%) as well as trace amounts of Fe2O3 (0.77%), MgO (0.34%) and MnO (0.067%) respectively. The mineral phase quantification of CW as determined by XRD showed that WC contained a significant amount of quartz (93%) together with calcite (7.0%). After mixes of WC with tap water to create sludge, the resulting pH was raised to 10 and EC was reduced to 0.4 mS/cm.

Mine water treatment results

A rapid increase in pH from 5.6 to 6.6 was observed within one minute upon the introduction of waste concrete slurry into the raw mine water. The pH of WC treatment increased to reach 8 on day 7 of the water treatment process. From day 7 onwards, the pH stabilised and remained relatively constant such that after 28 days, the pH was 7.8. The results generally suggest that neutralisation of the mine water improved with contact time. Likewise, the EC readings decreased from 4.96 mS/cm to 3.52 mS/cm within one minute upon the introduction of WC slurry into the reaction tank. On day seven, the EC had reached 3.50 mS/cm with a final value of 3.84 mS/cm on day 28 (Figure 2).

After 28 days of *in situ* treatment, the sulfate concentration was reduced from 3,563 mg/L to 2,479 mg/L which is similar to sulfate concentrations in the treated mine water discharged from the Central Basin Treatment Plant (2,522 mg/L). Calcium

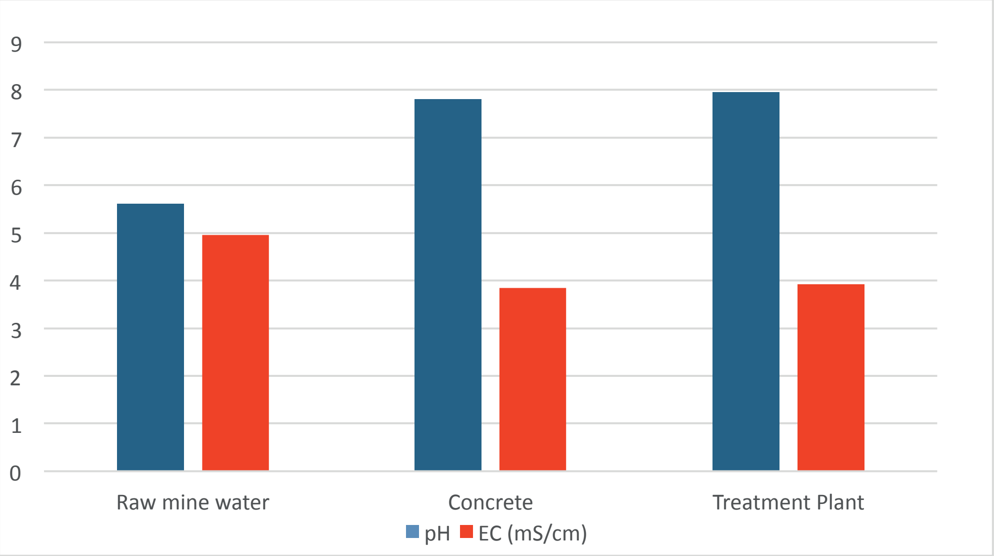

Figure 2: *pH and electrical conductivity (EC) of raw mine water vs laboratory-treated water (28 days) vs treated water from Central Basin Acid Mine Drainage Treatment Plant.*

from the waste concrete was leached into the reaction mixture with final concentrations of 670 mg/L above the initial levels in the raw mine water (5.04%). A notable percentage of Fe and Mn levels were also observed to be removed in the final treated mine water to even lower levels compared to the treated mine water discharged from the treatment plant. These results indicate that WC is as effective to mine water treatment as other typical neutralising materials (lime and limestone) in the market.

A decrease in the concentration of sodium, magnesium and chloride was noticed after 28 days of treatment by WC slurry compared to the raw mine water and discharge from the treatment plant. These results suggest that waste concrete is more effective in the reduction of salinity over lime and may present a better option for mine water treatment in the Witwatersrand Basin. Other elements analysed included titanium, strontium, nickel, arsenic, boron, cobalt, lithium, zinc, rubidium, caesium, aluminium, barium, and uranium among others. The majority of trace elements were neither detected in the raw mine water nor in the laboratory-treated water.

Conclusions and recommendations

The injection of alkaline materials into flooded mine voids presents a good option for mine water treatment in the Witwatersrand goldfields. Results from the laboratory *in situ* simulation experiment showed that waste concrete may present an alternative option for MIW treatment over the conventional use of lime and limestone. The option of *in situ* mine water treatment over the pump and treat method has a huge potential to reduce the cost of mine water treatment and may result in a direct decrease in energy demands on Eskom, a state-owned utility that operates and maintains the bulk of the generation infrastructure as well as the nation's transmission grid. Furthermore, the use of waste concrete would be an excellent form of waste beneficiation and a cost-effective

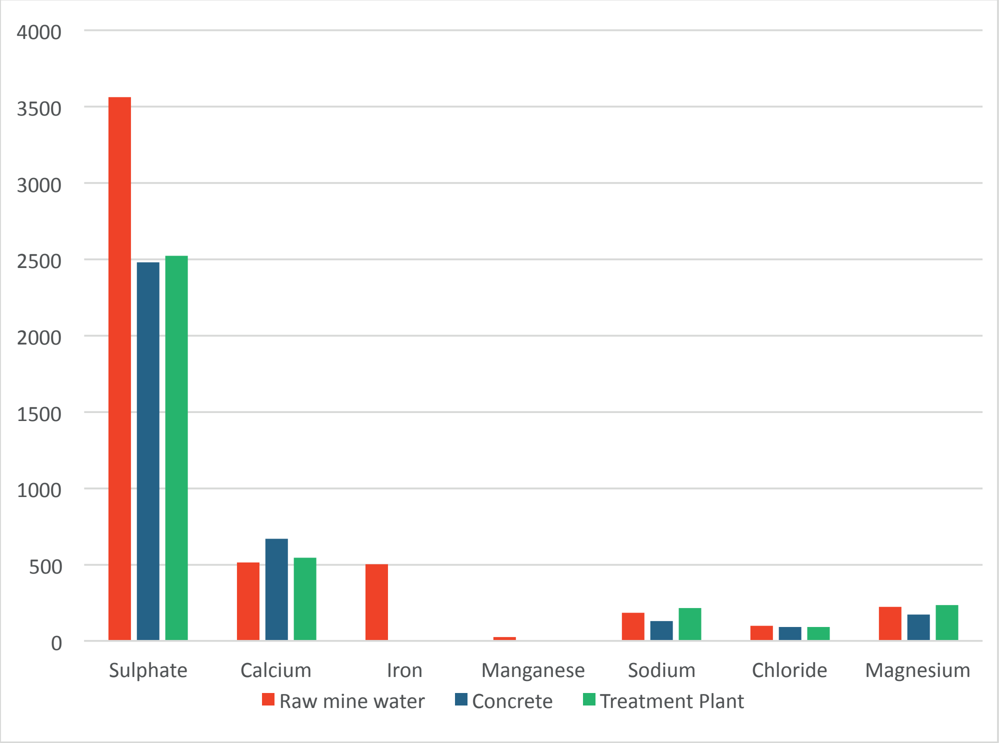

Figure 3: *Chemical composition of raw mine water Vs laboratory-treated water (28 days) vs treated water from the Central Basin Acid Mine Drainage Treatment Plant.*

method of managing MIW in South Africa over the use of traditional alkaline materials such as lime and limestone.

The following recommendations are made:

- Determination of the long term stability of precipitates formed during the *in situ* mine water treatment process;
- Assess the properties of waste concrete sludge for alternative uses;
- Investigate the cost of *in situ* mine water treatment in comparison to the active treatment options;
- Establish the application method for *in situ* mine water treatment in the Witwatersrand especially considering the underground complexities of the Witwatersrand Basin, and
- Establish a pilot site to test field application of *in situ* mine water treatment.

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