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Coal combustion products in mine backfilling

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Abstract

Fly ash and coarse ash are waste products that are generated in large quantities in South Africa from coal-based power stations. These ashes are often dumped in landfill sites, ash dams or lagoons and left to undergo chemical weathering. The growing presence of these disposal sites is creating numerous short and long-term environmental problems predominately due to the risk of element mobility, especially in the case of toxic metal release. In addition to the solid ash waste produced, a significant amount of wastewater is also produced. In an attempt to recover and reuse this water through various treatment methods, a stream containing predominately inorganic dissolved salts, known as brine, is formed. The disposal of this brine, as well as the ashes generated from coal-fired power stations, is a cause of concern due to the large quantities of waste produced which are not being utilized further in a sustainable manner. Furthermore, the disposal of brines creates an environmental risk due to the possible ingress of the inorganic salts and other trace elements into the surrounding environment.

The possibility that a potential solution exists to combat the disposal problems associated with both these wastes is worthwhile to explore. This potential solution exists through the use of mine backfilling, specifically cemented paste backfilling. Backfilling is defined as the process whereby mine tailings and other mine wastes are placed or reinserted into the void openings of underground mines in order to provide structural stability. Furthermore, the use of a cemented paste backfill is a viable option as it utilizes a mixture of different ash waste, hydraulic binders as well as brine. These constituents can be made into a thickened slurry or paste and pumped underground into the surrounding mine voids. This will reduce the current cost of disposal and simultaneously reduce the current adverse environmental impact associated with the disposal of these wastes. It is therefore important to investigate the environmental impact of both the current surface disposal methods and that of the cemented paste backfill in order to fully understand the leaching and mobility of the contaminant species and to determine the possibility of capturing salts from the brine solution into the cemented paste backfill. This study aimed to examine both these aspects through research methods which consist of a statistical analysis followed by a practical experimental verification.

Prior to examining the leachability of the cemented paste backfill, sixty-seven ash samples of different types (fly ash, coarse ash and mixed ash which consists of a mixture of the two ashes) in different states (fresh and weathered) were examined for statistically significant differences.

A two-way analysis of variance (ANOVA) was conducted in order to determine if significant differences existed between the average values of the different ash states and types with regards to the total elemental concentration and leachability or leachable fraction. This analysis aimed to determine trends in the elemental release of these different ash types following long term chemical weathering. Furthermore, this analysis provided information on the relationship between the elemental release and the total concentration in the various ash in order to predict the long term environmental suitability of alternative disposal practices. It was found that fresh ashes have a higher SiO_2 content than weathered ashes particularly due to this phase being encapsulated in the glassy matrix of the ashes and are thus not easily released. Weathered ashes have a lower SiO_2 content as most of the SiO_2 has been leached out following repeated weathering cycles. Elemental release only occurs upon weathering when this glassy matrix has been broken down leading to the release of elements such as As, Sb, G, Rb, Ce, and Li. This is also seen in the case of Si, Fe, and K whereby a linear relationship was observed between the leachable fraction and the total elemental concentration where higher leachability was observed as the concentration increased in the weathered ashes. In some instances, the elemental release was independent of the state of the ash in specifically the case of Sn, Te, Ti, Pb, Bi, and Be. On the other hand, elements that were located on the more soluble internal fraction of the ashes such as B, Ga, and Sr and are more easily released in the fresh ashes. Generally, a relatively small difference is found regarding element mobility between fresh and weathered ashes suggesting that equilibrium has been reached between the ash particles and the surrounding water and once the readily available and easily leached elements are removed, the system remains stable with time and no further release occurs. Upon analysis of the elemental percentage leached out into solution, the percentages were found to be low indicating that the risk of metal leaching is not of concern. These results indicated favourable properties for further use in cemented paste backfill applications.

It was found that fly ash (FA) and coarse ash (CA) are useful in backfill applications due to their pozzolanic reactivity. This study examined the mineralogical and chemical constituents of the ashes that enhance this reaction, thus improving the long-term strength development of the cemented paste backfill (CPB). Favourable ash properties include class F ashes with a high SiO_2 content ($SiO_2 \geq 50\%$), a low CaO content ($CaO \leq 10\%$), a low total equivalent alkalis content ($Na_2O_{eq} < 1.5\%$), a low MgO content ($MgO < 5\%$) and a low LOI ($LOI < 6\%$). If these properties are adhered to, the CPB shows favourable results in terms of both environmental and structural suitability. Environmental suitability refers to an instance whereby the CPB will not

have a detrimental impact on the surrounding environment in terms of high concentrations of contaminants leached into the environment. Structural suitability refers to a case whereby significant strength development of the CPB is achieved such that the land above the CPB can be used for other purposes and will not be subjected to collapse.

In order to further examine the environmental suitability of the use of FA, CA, MA and brine in the CPB, several leaching procedures such as the tank leach test (TLT), weathering cell test (WCT), and acid neutralization capacity (ANC) tests were employed. The structural suitability for backfilling was examined by measuring the unconfined compressive strength (UCS) at various predetermined intervals. The UCS showed that CPB mixtures containing greater proportions of FA which met the favourable characteristics stated above met the required strength limits. However, additional factors such as particle size and loss on ignition (LOI) determined the extent to which the reaction hydration products were produced and subsequent strength development. It was found that a smaller particle size drastically improved the pozzolanic reaction and strength development in comparison to samples containing ash characteristic of a larger particle size. The leaching behaviour of trace metals such as Pb, As, Cr and Ni, as well as other ionic species associated with soluble salts such as Ca, Na, Mg, K, Fe, Al, B, and Ba, were investigated to examine the potential environmental impact. Acid neutralization tests showed that leaching increased linearly as the pH of the leachant decreased for Ca, Mg and B. Leaching is found to be independent of solution pH with regards to the release of Na, K, and Ba. Cr and Pb exhibited amphoteric behaviour with higher solubility observed at the extreme ends of the pH range. Results from the TLT used to simulate flooding of the CPB showed that the leachable concentrations of soluble salts in the leachate were released in the order of Na > Ca > K > Mg. A large fraction of these soluble salts are available as they are deposited on the surface of the monoliths and thus a high release was observed initially upon contact with water. Results showed that the CPB posed a significantly lower environmental risk in comparison to surface ash disposal. The leachates contained a lower amount of soluble salts and metals in comparison to the WCT. This indicates that these elements are encapsulated within the CPB. Furthermore, the total elemental percentage leached out of the ashes in the TLT was significantly smaller than the percentage release for the WCT and the surface ash disposal. Particle size and exposed surface area have the greatest effect on the leaching behaviour of the monoliths. The addition of small proportions of CA reduces leachability as a lower elemental release is seen for Na, Mg, K, and Ba in comparison to the backfill mixtures containing only fly ash. The presence of CA improves the interparticle friction

which creates a denser CPB that exhibits lower leachability. By physically and chemically altering the FA, CA and brine interaction a more environmentally suitable option exists for the co-disposal of these wastes through the development of a CPB.

The overall findings suggest that the use of CPB technology is a potential solution for the sustainable co-disposal of ash and brines as a net environmental benefit is achieved whilst still ensuring the necessary structural and environmental properties are met.