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Fly Ash as an Alternative Liner Material in Resloving Groundwater Management Challenges in Coal Ash Dumps

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Abstract One of the key environmental challenges at electric power stations is leachate seepage from ash dumps into the underlying aquifers. Regulatory bodies generally recommend an installation of a liner system to contain toxic leachate at waste landfill sites. An attempt has been made in this study to enhance the engineering and geohydrological properties of fly ash in order for it to be used as a liner material. Varying quantities of lime and gypsum were added to fly ash in order to determine the optimum compositional ratio for the multi-layer liner system analysis. Addition of lime and gypsum increases the strength of fly ash. However this increase in strength was reduced when lime was used in excess. Addition of lime and gypsum decreases the hydraulic conductivity of fly ash. A hydraulic conductivity of 2.27×10^{-9} m/s was determined for an admixture of fly ash mixed with 3% lime and 3% gypsum. Mneralogical investigations revealed formation of secondary minerals in fly ash specimens that contained additives of lime and gypsum. These secondary minerals possibly reduced the effective porosity by clogging water pathways in the material. A water balance of the multi-layer liner system showed that 95% of leachate was contained by a fly ash admixture layer. Leachate analysed revealed that stabilization of fly ash with additives lowered concentration levels of some trace elements including chromium.
Keywords fly ash, hydrogeochemistry, groundwater management, liner systems

Introduction

Minimal reuse of fly ash is currently taking place in South Africa with the bulk being disposed in ash dumps/dams. Leachate from ash landfills has been of environmental concern with some trace elements concentrations found to be above the regulatory thresholds. Liner systems are used to contain leachate from contaminating the ground soil and consequently groundwater however, liner material is usually expensive and sometimes not easily accessible to power stations. The challenge is to use materials that are readily available to power stations hence reducing the cost of lining.

Low hydraulic conductivity is an essential component of waste disposal liner material. One material that has the potential to be used in lining construction is fly ash. The use of fly ash as a liner material has been studied extensively (Sivapullaiah and Baig 2011, Palmer et al. 2000, Nhan et al. 1996). In the current paper an attempt has been made to study the enhancement of engineering properties of fly ash by additives.

Methodology

This study used fly ash that is classified under the product name Dura-Pozz fly ash by Ash Resources (Pty) Ltd. Fly ash from a landfill at Tutuka Power Station in Mpumalanga Province was also incorporated into the study as a reference material. Calcium hydroxide $Ca(OH)_2$ (lime) and calcium sulphate dihydrate $CaSO_4{\cdot}2H_2O$ (gypsum) were used as additives. The samples name and compositional information is collated in Table 1.

Unconfined compression strength (UCS) test was carried out on specimens according to the standard methods of testing road construction materials (TMH1-A14, 1986). The indirect tensile strength (ITS) of stabilised material was determined by measuring the resistance to failure of the cylindrical prepared specimen when a load was applied to the curved sides of the specimen (TMH1-A16T, 1986).

The constant head method was used to determine the hydraulic conductivity on compacted specimens while leaching with demineralized water. Darcy's equation was used to determine the hydraulic conductivity K (m/s) from the volumetric flow rate: $K = (VL)/(Ath)$. Where: V = volume, A = cross-sectional area of the sample, L = length of sample, h = constant head, t = time.

***Table 1** Optimum moisture content (Opmc) and maximum dry densities (MDD) of samples.*

Sample	Fly ash	Lime[a]	Gypsum[a]	Opmc[a]	MDD[b]
LSM1	Dura-Pozz	0	0	28.4	1355
LSM2	Dura-Pozz	1	1	12.6	1428
LSM3	Dura-Pozz	3	1	10.7	1488
LSM4	Dura-Pozz	6	1	11.9	1474
LSM5	Dura-Pozz	10	1	12.0	1474
LSM6	Dura-Pozz	1	3	13.8	1396
LSM7	Dura-Pozz	3	3	10.7	1464
LSM8	Dura-Pozz	6	3	10.9	1460
LSM9	Dura-Pozz	10	3	10.8	1458
LSM 10	Tutuka	0	0	21.4	1278

a = wt %, b = kg/m^3, Opmc = optimum moisture content, MDD = maximum dry density

Strength tests

South African fly ash is classified as class F and therefore needs an addition of a cementing agent in order to undertake hydration reactions that produce binding material. This is evident in that fly ash samples without additives (table. 1, LSM 1 and LSM 10) were unable to attain cohesive strength to stand unsupported by the molds and hence UCS test were not performed of these specimens (fig. 1).

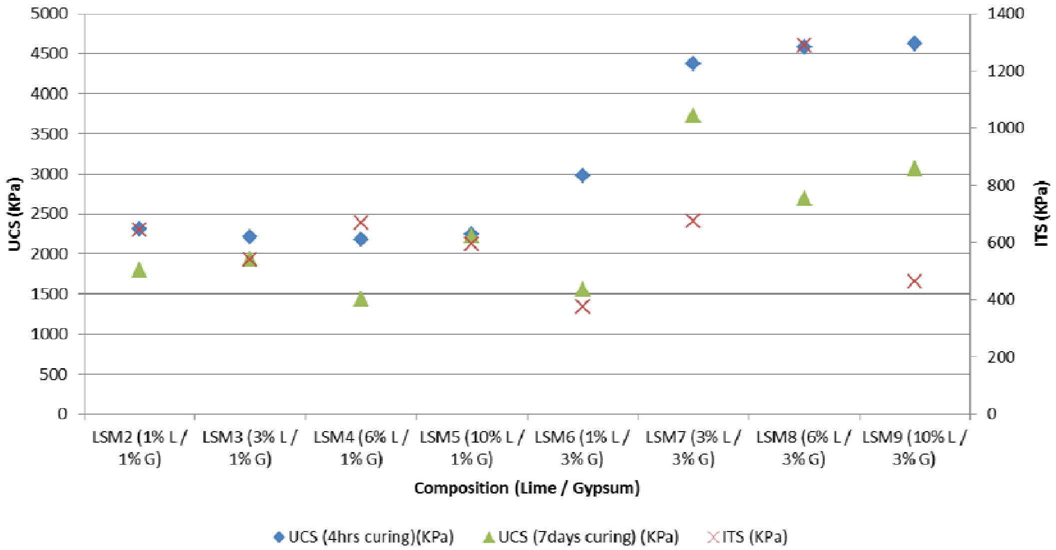

***Fig. 1** UCS (4 hours and 7 days curing) and ITS values for different samples.*

Specimens exhibit almost constant ITS and UCS values when only 1% of gypsum is added over a range of lime percentages (LSM 2 to LSM 5). This may suggests that gypsum has more influence on strength than lime as a sharp increase in UCS values is observed once the gypsum percentage is increased to 3%. In 1% gypsum admixture specimens cured for 4 hours there is a decline in the UCS values as more lime was added, as seen in LSM 8 and LSM 9. This decline was not observed in LSM7 and therefore the admixture composition of LSM 7 (3% lime and 3% gypsum) represents the most optimal composition from an additive and costing perspective. A different trend is observed for specimens cured for 7 day as the UCS values increased with increase in lime content in 3% gypsum admixtures. The hydration reaction in fly ash involves the pozzolans (AlO_3, SiO_2, Fe_2O_3) reacting with lime (CaO) in the presence of water and producing cementitious compounds that are capable of infusing inert substances (Bin-Shafique et al. 2003). Therefore the 4 hour curing period may not have been sufficient for some of the hydration reactions to take place leaving lower UCS values as compared to the extended 7 days curing period.

Hydraulic conductivity

The hydraulic conductivity results over a 7 days period (1% gypsum, fig. 2) indicate a general decreasing trend with addition of lime. However, this declining trend cannot be entirely attributed to presence of additives as LSM 1 exhibit similar hydraulic conductivity. Addition of lime and gypsum will increase the rate of hydration and the formation of calcium silicate and calcium aluminate gel.

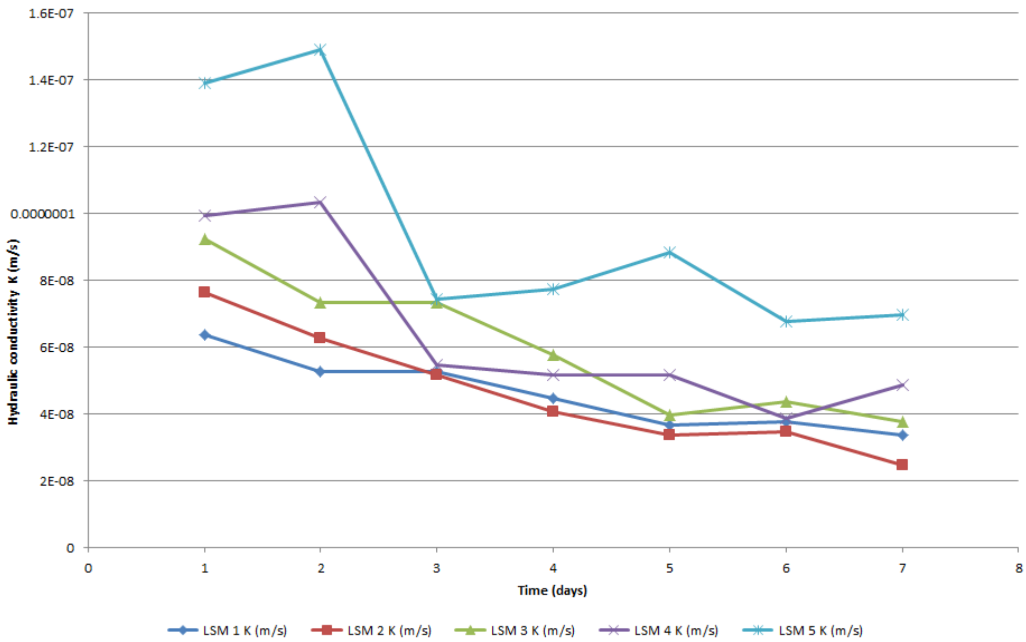

Fig. 2 *Hydraulic conductivity (m/s) changes over time for admixtures with 1% gypsum.*

The changes in hydraulic conductivity over a 7 day period (3% gypsum) indicate similar trends (fig. 3). The average hydraulic conductivity after 7 days of 1% gypsum admixtures (LSM 2 to LSM 5) was 4.52×10^{-8} m/s and that of specimens containing 3% gypsum (LSM 6 to LSM 9) was 1.27×10^{-8} m/s. Gypsum had more influence in reducing hydraulic conductivity, as LSM 7 had the lowest hydraulic conductivity value of 8.95×10^{-9} m/s after 7 days. Secondary minerals, such as ettringite, form in fly ash containing sulphate and calcium aluminate. These secondary phases precipitate and reduce the permeability of the tested samples thereby reducing the effective porosity in the material. A hydraulic conductivity of 1×10^{-9} m/s is the acceptable limit used for most hazardous liner materials.

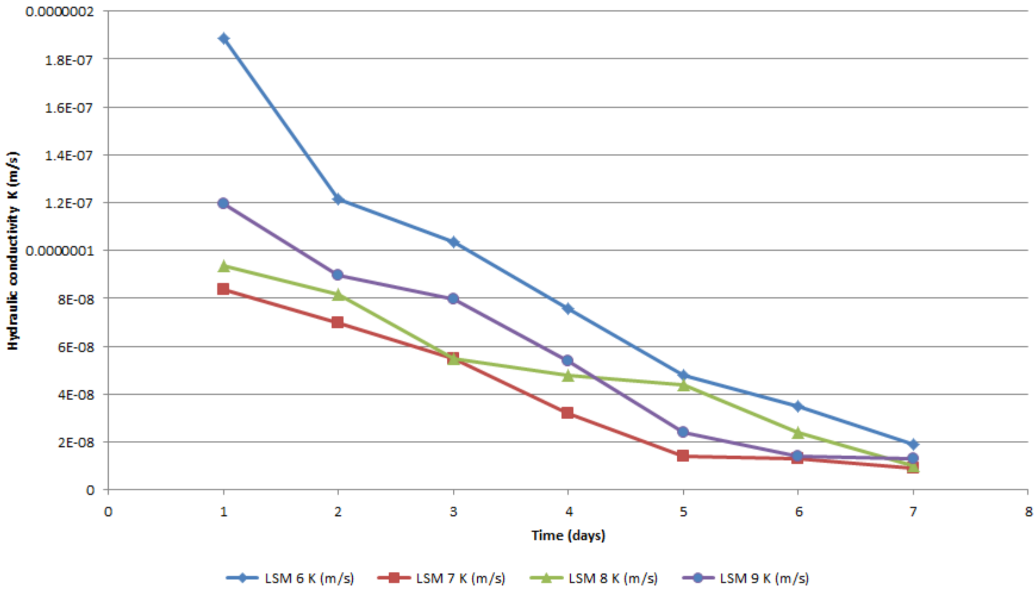

Fig. 3 *Hydraulic conductivity (m/s) changes over time for admixtures with 3% gypsum.*

Brine water is used for dust suppression in ash disposal sites and hence demineralized water does not represent real-life field conditions. Two additional constant head tests were subsequently carried using both brine and demineralized water. The results after 60 days indicated a hydraulic conductivity of 2.27×10^{-9} m/s for an admixture of Dura-Pozz fly ash mixed with 3% lime and 3% gypsum. Even though demineralized water also had an overall decreasing effect on the hydraulic conductivity with time, the hydraulic conductivity value on day 60 was 7.56×10^{-9} m/s. Brine water is effluent water rich in salts, and the lower hydraulic conductivity obtained when using brine water could be due to brine/fly ash interactions leading to formation of secondary minerals that would block the pore voids thereby reducing the effective porosity of the material.

Leachate from the seven day constant head test on LSM 7 indicated certain trace elements (B, Cr, Se, Pb, Mo) were above the regulatory threshold, this was specifically observed for the initial flush from the samples (Day 1). However the concentration were reduced with time and the leachate was classified as inert by Day 7 measurements.

Conclusions

There is a noticeable improvement in the engineering and chemical properties of fly ash with the addition of lime and gypsum. The strength of the fly ash material is increased but once lime was introduced in excess a decrease was observed. Furthermore, the addition of lime and gypsum reduced the optimum water content at which the maximum dry density is obtained for the fly ash. This would indicate that the addition of additives has a lubrication effect on fly ash therefore improving its durability in the liner system. Finally, additives decreased the hydraulic conductivity of fly ash. The reduction in hydraulic conductivity depends to a greater extend on gypsum addition than on lime content. A hydraulic conductivity of 2.27 $\times10^{-9}$ m/s was determined for an admixture of Dura-Pozz fly ash mixed with 3% lime and 3% gypsum.

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