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Evaluation of engineering properties for the use of leached brown coal ash in soil covers

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Abstract

The need to engineer cover systems for the successful rehabilitation or remediation of a wide variety of solid wastes is increasing. Some common applications include landfills, hazardous waste repositories, or mine tailings dams and waste rock/overburden dumps. The brown coal industry of the Latrobe Valley region of Victoria, Australia, produces significant quantities of coal ash and overburden annually. There are some site-specific acid mine drainage (AMD) issues associated with overburden material. This needs to be addressed both during the operational phase of a project and during rehabilitation. An innovative approach was taken to investigate the potential to use leached brown coal ash in engineered soil covers on this overburden dump. The basis for this is two-fold: first, the ash has favourable physical characteristics for use in cover systems (such as high storage capacity/porosity, moderately low permeability, and an ability to act as a capillary break layer generating minimal leachate or seepage); and second, the leachate from the ash is mildly alkaline (which can help to mitigate and reduce the risk of AMD). This paper will review the engineering issues involved in using leached brown coal ash in designing soil covers for potentially acid-forming overburden dumps. It presents the results of laboratory work investigating the technical feasibility of using leached brown coal ash in engineered solid waste cover systems.

Keywords: Soil covers; Coal ash leaching; Unsaturated flow; Waste disposal; Co-disposal

1. Introduction

The Latrobe Valley region of eastern Victoria, Australia, contains major brown coal resources which are used to provide base-load electricity from large-scale mining-power station complexes. At present there are three major open cut mining centres supplying four power stations totalling about 6500 MW electrical generation capacity, namely the Hazelwood, Yallourn and Loy Yang complexes. About 65 Mt of brown coal and 15 Mm^3 overburden are mined annually [1]. A principal waste product of these operations is coal ash, usually <2% of coal mass, containing salts and trace elements [2].

The significant quantity of ash and overburden requires effective engineering designs for disposal to ensure long-term environmental performance. A common risk with both wastes is the production of leachate, which could contain a combination of acidity, salinity and/or heavy metals. If this leachate migrates into an undesirable segment of the environment, there may be impacts on groundwater or surface water quality which are unacceptable to all concerned. Recent research has highlighted the alkaline nature and low leachable metal content of ash excavated from the ash disposal pond (called leached ash) [3] as well as the favourable unsaturated hydraulic properties of the ash for use as a cover material [4].

This paper presents the results of a study assessing and quantifying the utilisation of the ash as a special cover layer in managing potential areas of the overburden dump that could produce acid mine drainage. A review of the unsaturated hydraulic characteristics of leached ash based on laboratory testing with respect to soil cover design is presented, followed by the potential for benefits from the alkaline nature of the leached ash. The testing data is new and contributes to a little studied and published facet of waste management. Overall, the research points

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Table 1
Geotechnical index properties of Latrobe Valley leached ash samples

USCS soil texture	G_s	n (%)	PI (%)	LL (%)	LS (%)	Compaction MDD (kg/m^3)/OMC (%)[a]	CVC (m_v) (m^2/MN)	CC (c_v) (m^2/yr)	K (10^{-6} m/s)
Silty sand (SM)	2.56	46	5.6	42	1.9	1305/33	0.18	5231	1.46
Elastic silt (MH)	2.47	75	15.2	73.9	3.2	690/94	0.09	1422	0.26
Ash (mostly char)	1.64	–	24.1	100	2.4	485/136	0.36	9040	1.01

G_s, specific gravity; n, porosity; PI, plasticity index; LL, liquid limit; LS, linear shrinkage; MDD, maximum dry density; OMC, optimum moisture content; CVC, coefficient of volume compressibility; CC, coefficient of consolidation (m^2/yr); K, saturated hydraulic conductivity.
[a] Reduced standard Proctor test.

to a valuable approach in co-disposal of the two major streams of solid wastes in brown coal mining and utilisation.

2. Approach and methodology

2.1. Review of ideal properties for engineered soil covers

The technical design of engineered soil covers for waste containment will depend on numerous factors, including climate (e.g. arid, temperate, tropical), unsaturated soil hydraulic properties, waste characteristics (e.g. acid-forming, hazardous), as well as site-specific environmental regulatory requirements. Further detail on the design of such covers is presented by Khire et al. [5], Manassero et al. [6], Hauser et al. [7], Zornberg et al. [8] and others.

For potentially acid-forming mine wastes a common approach is to design a soil cover with a capillary break layer to temporarily store and then release any infiltration through soil evaporation and vegetative transpiration. The ideal geotechnical properties for such an engineered cover are low shrink–swell potential (e.g. low reactive clay content), low compressibility, moderate permeability, low pozzolanic (cementitious) potential and, perhaps most critically, a high storage capacity (porosity).

2.2. Laboratory testing and characterisation

A total of 23 leached ash samples were collected for detailed geotechnical testing. The index properties tested were specific gravity (and porosity), Atterberg limits, linear shrinkage, compaction densities, coefficient of volume compressibility, coefficient of consolidation and saturated hydraulic conductivity. The soil water characteristic curve (SWCC), or soil moisture retention curve, was also tested to a suction range approaching 106 kPa. The SWCC was tested using a series of equipment; a Tempe Cell was used up to 250 kPa suction, a pressure plate apparatus up to 1000 kPa suction and a salt solution dessicator beyond 1000 kPa suction (e.g. [9]).

In addition, two large-scale field lysimeters and laboratory leaching columns have been undertaken, as reported in Mudd and Kodikara [3] and Mudd et al. [10]. In brief, these experiments were designed and operated to quantify the water and solute balance as well as the geochemistry of the resulting leachate (see [2]).

3. Results

3.1. Geotechnical index properties of leached ash

In general, leached ash can be described as having a fine silty texture with minimal clay content as it consists predominantly of fine sand and silts with some unburnt coal and residues. On this basis, applying the Unified Soil Classification System (USCS), leached ash can range from silty sand (SM) to elastic silt (MH). The USCS defines silty sand as a non-reactive material having more than 50% sand sized particles (<4.75 mm) and varying amounts of fines (<75 μm) and gravel (<76.2 mm). Elastic silt, on the other hand, is defined as having more than 50% fines and varying amounts of sand. In general, Latrobe Valley leached ash does not undergo significant pozzolanic (or cementitious) reactions. The values for the coefficient of volume compressibility (m_v) and coefficient of consolidation (c_v) are calculated based on initial saturated porosity (in general, porosity changes little without loading). The results are summarised in Table 1.

3.2. Soil water characteristic curve (SWCC)

The results of the SWCC testing for the 23 leached ash samples from the Loy Yang complex is shown in Fig. 1. As noted for the index properties, there are generally two groupings of leached ash material—a silty sand (SM) or elastic silt (MH) (a minor proportion is also pre-dominantly char or unburnt coal).

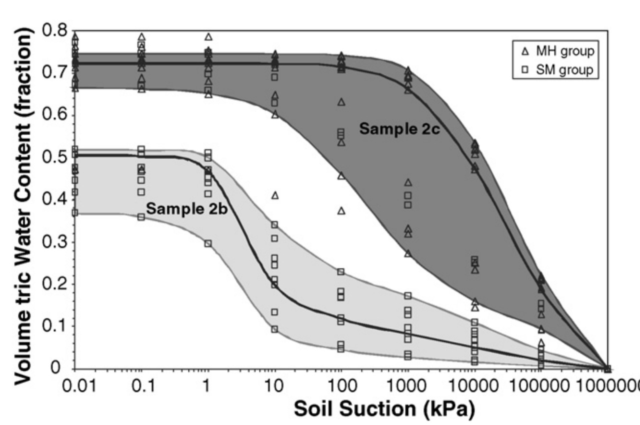

Fig. 1. General range for soil water characteristic curves of Loy Yang leached ash samples.

3.3. Leaching geochemistry

The full results of the field and laboratory testing is given by Mudd [2], Mudd and Kodikara [3] and Mudd et al. [10] and is shown below for completeness. The overall leaching of salinity from the various tests of leached ash and the pH versus pore volume is shown in Fig. 2. The salinity concentration has been normalised relative to the average during initial wash-off, when salinity was mostly constant (with some minor variation) [2]. The use of pore volumes allows direct comparison between the laboratory and field experimental studies and thereby overall leaching dynamics.

4. Discussion

The principal classifications of leached ash, from a geotechnical or soils perspective, are silty sand (SM) and elastic silt (MH).

For the elastic silt, with a fines content >50% and a low plasticity index (PI), this points to significant advantages as a cover material since it has high storage capacity but without the common shrink–swell problems associated with some clays (which have fines >50% but a high PI). The hydraulic conductivity is relatively high for a standard cover, although this property also facilitates evapotranspiration thereby minimising the potential leachate generation. The coefficients of consolidation (c_v) and compressibility (m_v) also suggest that the elastic silty ash is suitable for covers since any surcharge load leads to immediate consolidation with compressibility low to medium. The shrink–swell capacity is also low, based on the PI and linear shrinkage values. Additionally, based on the SWCC tests, elastic silty ash has an air entry value of about 30 kPa with a wilting point of about 2000 kPa. For use as a cover material, this gives an effective storage capacity of 600 mm/m of cover [4].

The silty sand, while exhibiting many similar properties to the elastic silt, has a lower storage capacity but also a higher hydraulic conductivity.

The alkaline nature of the ash is apparent in Fig. 2, a feature of leachate quality that appears to be maintained for a significant amount of pore volumes. This is primarily derived from alkaline minerals contained in the ash, such as calcium and magnesium oxides (e.g. lime). The Loy Yang complex generally has a lower content of these alkaline minerals compared to the Yallourn and Hazelwood complexes, although it is sufficient to maintain an alkaline leachate environment in the leached ash. The alkaline content is an additional benefit from the use of the leached ash as an alternate cover material, as this can help to offset any acidity formed in the underlying overburden wastes which any ash leachate would migrate into. Thus, leached ash should also help to mitigate the acid mine drainage, though further testing is required to ascertain the extent of this benefit.

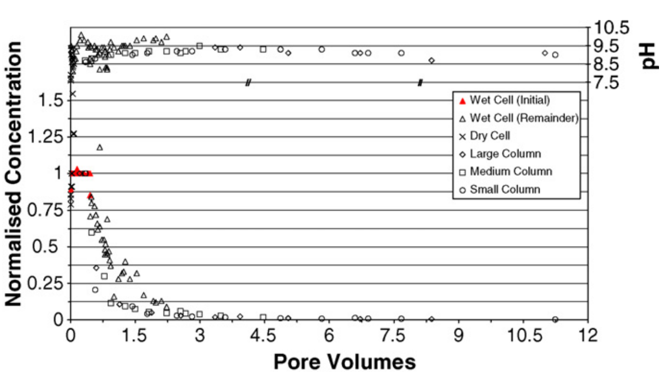

Fig. 2. Leached ash—normalised salinity and pH vs. pore volumes [9].

5. Conclusions

The unique geotechnical and geochemical properties of leached ash from the Latrobe Valley suggest it is a favourable cover material. This is due to the relatively high porosity of the ash giving it a considerable capacity for interim storage and later evapotranspiration, leading to minimal leachate generation and migration. The alkaline character of leachate could also be beneficial in managing any acid mine drainage issues. It is critical that the geotechnical and geochemical properties of potential cover materials be well studied and thoroughly tested prior to their application in the field. It is intended that future research work will model various cover scenarios with different combinations of ash materials and underlying materials to predict long-term cover performance as well as further quantify the extent of geochemical benefits for minimising acidic drainage formation. Overall, it is considered that leached ash from the Latrobe Valley region of Australia is well suited for applications in store/release soil cover systems.

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