

Acid Resistance of Novel Blended Cement Concrete for Use as Barriers to Pollution Migration

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Background

Current waste management practice relies largely on high density polythene membranes as the principal barrier by which landfill leachate is contained within a disposal site. Although this technology is well established, it is relatively expensive, and somewhat vulnerable to damage, especially during installation and the early phases of waste emplacement. To protect the polymer membrane, it is encased within layers of sand (or a sand-bentonite mixture) over which is placed a geotextile drainage blanket. The whole construction, often further protected by a drainage layer of loose aggregate, is typically over two metres in thickness. This has a direct impact on both the economics and environmental cost of waste disposal, in as much as space occupied by materials protecting the barrier is unavailable for waste containment. Additionally, conventional barriers are first covered by a graded waste layer (from which sharp and potentially damaging objects have been removed) as rupture of the membrane is likely to result in catastrophic release of leachate into the environment.

The relatively short service lives of landfill liners (typically around a hundred years) are designed to contain leachate throughout their operation and often, little attention is given to the late post-closure performance of these barriers.

By comparison, the nuclear sector of the waste industry applies a different design philosophy, recognising that all barriers will eventually fail and attempts to engineer barriers, which fail in a benign and predictable way. This is achieved by the use of sacrificial materials such as cement and concrete, which condition the local ground water and hence dominate its chemistry close to the waste. In this way, dissolution of the actinides is limited by maintaining an alkaline chemical environment.

The legislative framework in the UK permits alternative barrier construction, for example, Waste Management Paper 26^[1] describes mineral barriers containing fly ash and other inorganic materials, yet these have rarely been adopted for containment of domestic waste. This project attempts to transfer technology from the nuclear to the landfill sectors of the waste management industry and in doing so, seeks to extend the useful life of materials which are considered by their primary producers to be wastes.

The Mineral Barrier

The design concept is to provide a multi-layer barrier comprising concrete-clay-concrete layers, as shown in figure 1. The role of the base layer is to provide a strong foundation which will support the hydraulic barrier but will also contribute to the chemical conditioning of leachate which will percolate through the structure

in the late stages of the post-closure period. The middle layer consists of locally won, non-swelling clay, compacted to provide a hydraulic barrier which will prevent leachate migration for some hundreds of years. In addition to its role as a hydraulic barrier, the clay will serve as an ion-exchange medium (retaining dissolved metal ions) and as an ultra-filtration blanket (mediating transport of large organic species). On top of this, lies an upper layer of concrete which fulfils two functions; in the operational phase of the landfill, it will support vehicles allowing them to drive directly on to the liner but after closure, will contribute to the physical containment of the leachate. Moreover, late in the post-closure period, it will provide a reserve of alkalinity, which will chemically condition the leachate, neutralising organic acids and precipitating heavy metals. This approach offers distinct operational and environmental advantages over current liner technology:

◆ **Economic advantages-** Mineral barriers are relatively inexpensive; offering an estimated saving of the order of 40% of construction costs in comparison with conventional liner systems.

◆ **Environmental advantages-** The mineral barrier is thinner than conventional liner systems, as it does not require the protection of a sand-bentonite over-pack. Consequently, more air space is available for waste containment, allowing more waste to be emplaced per unit area of land surface. In addition, many of the construction materials used in the barrier were destined to be wastes and are therefore removed from the waste inventory (with commensurate tax implications).

◆ **Operational advantages-** Removing the need for a graded waste layer above the liner limits the amount of waste handling necessary at the disposal site. In addition, as the mineral barrier is physically strong, refuse vehicles may be unloaded at the point of disposal. This reduction in waste handling offers potential time and cost savings to the operator whilst minimising the likelihood of waste dispersal by wind and vermin.

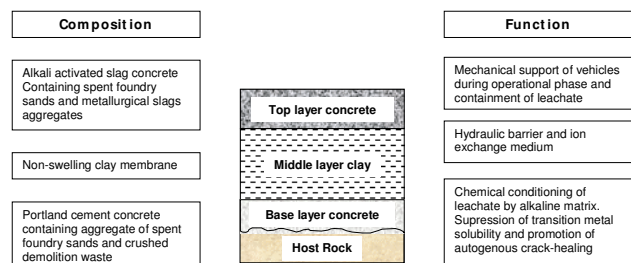


Figure 1 Schematic section of composite

The study reported here has examined the resistance of a range of barrier materials to dissolution by organic acids, such as would be found in landfill leachates during the early, acetogenic phase of landfill operation.

¹ Landfilling wastes / Department of the Environment.
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Liner Materials

A range of industrial processing wastes has been considered, including potential aggregates, such as metalliferous slags, glassy waste and spent foundry sands and a number of binder materials including alkali activated slags and ashes and a novel binder made from a borate slag. This part of the study has considered the following binders:

- Granulated blast furnace slag (unground)
- Lagoon ash
- Fly ash classification rejects and unclassified ash
- Borate slag (borax-zinc oxide)
- Cement Kiln Dust (CKD)
- Sodium sulphate/thiosulphate solution (pozzolanic activator)

These have been used to bind concrete containing aggregates comprising chrome-alumina slag, a range of ferrosilicate slags, two spent foundry sands and a burned oil shale residue.

Experimental Methods

Seven pastes or mortars were examined in the study, of which only one is reported in this text to illustrate the methods used. By mass:

Ferrosilicate slag (58.7%) CKD (16.1%) Lagoon Ash (10.6%) Water (14.6%)
 -which is equivalent to-
 40.2 parts aggregate : 1.82 parts binder : 1 part water
 (N.B. the slag is very dense!) giving a water:binder ratio of 0.55

The mixes were prepared by hand, cast into cylinders (55mm dia x 75mm long), and wet cured for 28 days. The cylinders were painted with epoxy-bitumen on all sides but one, the exposed face being cleaned with a razor blade prior to the start of the leaching experiment.

Static leaching was carried out for ten months, each specimen being submerged in approximately 1 litre of a synthetic leachate adjusted to pH 5.1 containing the following components:

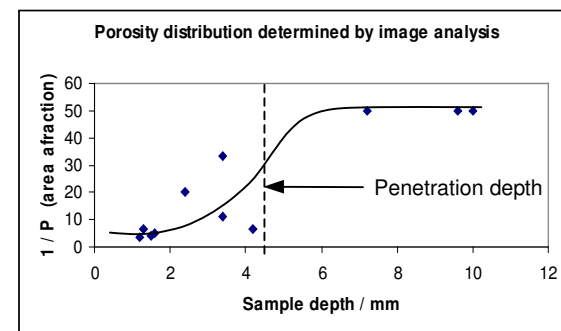
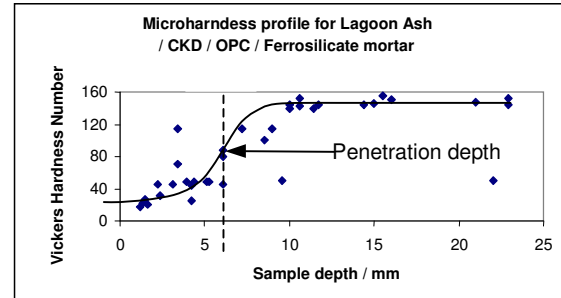
2.043g	Concentrated Sulphuric acid
4.48g	Acetic acid
1.897g	Potassium chloride
7.755g	Calcium acetate
1.186g	Ammonium chloride
0.91g	Sodium chloride
2.588g	Sodium hydroxide

This is representative of the most aggressive leachate likely to be produced in a landfill, during the early, oxygenated phase of its evolution.

Each cylinder was removed from its solution at a specified time and placed in a desiccator, in order to draw the pore fluids in the reverse direction; back towards the exposed face. In this way, examination of the specimen would reveal the (conservative) depth of penetration of the leachate during exposure. The samples so dried, were dry-cut by hand and divided into sub-samples for analysis. Specimens were polished for micro-hardness determination using a Leitz 8423 microscope. A further sample of each material was resin-impregnated, cut and polished for both optical thin section and back scattered electron microscope examination, with qualitative EDX to aid phase identification.. Using grey-scale segmentation of the backscattered image, porosity determination was made on both the leached and un-leached regions of the sample, using a PGT "IMIX" system for image analysis. Fractured surfaces were examined by optical and secondary electron SEM microscopy.

Results

As might be expected, each sample showed a region where dissolution of the cementitious binder had occurred, close to the exposed face. This ranges from four to sixteen millimetres, depending on the binder type. Comparing the apparent depth of penetration as determined by both micro-hardness profiling and porosity determination by SEM and image analysis, we see the estimates vary consistently.

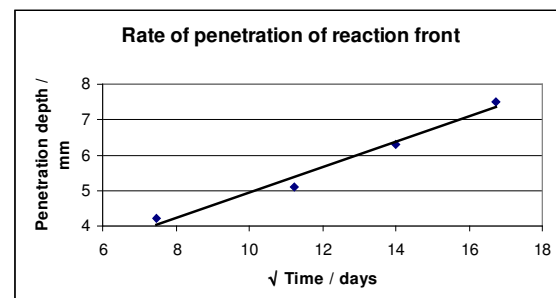


Cross-correlation of these results suggests that for each material, the difference between penetration depth determined by apparent porosity change D_p , is related to that suggested by the microhardness value D_H thus:

$$D_p = 0.7 \pm 0.2 D_H + 1 \pm 0.3 \text{mm}$$

In effect, an increase in porosity of 2 to 3% has negligible effect on the strength of the paste as determined by microhardness profiling. This allows a rapid, automated estimate of the hardness profile to be made during microscopy.

Considering next, the rate of penetration of the reaction front as a function of time, we predict that the dissolution process obeys first order reaction kinetics. For the mortar described above:



From these results, we are able to make an estimate of the likely service life of a 50cm thick layer in our composite barrier:

Material	Predicted service life / years assuming-	
	Zeroth order kinetics (linear)	First order kinetics (diffusion control)
CKD/ L.Ash / Fe-Si / OPC / Water	167 years	Thousands of years
Borate slag (ZnO in Na ₂ B ₄ O ₇ glass)	146 years	Thousands of years