

Novel Composite Landfill Liners

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ABSTRACT: This paper presents results of a study into alternative landfill liner technology, in which a large proportion of the materials used in construction are considered to be wastes by their primary producers.

A composite barrier comprising concrete-clay-concrete layers is described, in which two concretes have been developed using waste materials. These include an alkali activated blast furnace slag and a novel binder based on a zinc oxide-sodium borate slag. The aggregates used in these concretes are either slags from the metals processing industry (such as ferrosilicates or chrome alumina) or spent foundry sands. Studies of the leaching properties of many of these materials show them to be relatively unreactive in both landfill leachates and in the chemical environment prevailing in cement pore solutions. Accelerated leach testing of these materials, using high pressure flow cells, suggests that they are mutually compatible with each other and with the clay hydraulic barrier in the liner system.

1 INTRODUCTION

As the cost of waste disposal increases alongside the legislative requirement to minimize waste arisings, there has been renewed interest in using waste materials in construction. Many materials are excluded from such applications as they contain toxic metals, which although bound in chemically stable compounds, are unacceptable within current legislative constraints on building materials. Their use as mineral barriers to pollution migration offers a means by which their useful life may be extended, removing them from the waste inventory disposed of to landfill.

2 BACKGROUND TO STUDY

This project explores the transfer of technology from the nuclear to non-nuclear waste industries. The design philosophy of nuclear waste containment is to recognize that all barriers will eventually fail and to design such barriers to fail in a predictable way and with benign consequences. This is achieved by the use of sacrificial materials such as cement and concrete, which condition the migrating 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. By comparison, the short service lives of landfill liners (typically up to a few 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.

This work attempts to engineer a barrier from mineral wastes in such a way that its long-term performance is predictable, sacrificial and able to chemically condition the leachate permeating through the barrier. The 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 also to contribute to the chemical conditioning of leachate which will percolate through the structure in the final 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 provide an ion-exchange medium (for retention of dissolved ions) and 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 and in the post closure phase, will contribute to the physical containment of the leachate but more importantly, chemically condition the leachate, neutralising organic acids and precipitating heavy metals. Two further benefits of this design over conventional liners is that they may be made around 20% thinner than hitherto, as they do not require a

protective sand/bentonite over pack, nor is there the necessity to emplace a graded waste layer on their surface as they are not susceptible to puncture by sharp objects. As a result, more volume is available for waste disposal than for a conventional polyethylene liner system.

physical and chemical compatibility with the matrix and the resulting concretes tested for development of strength and permeability.

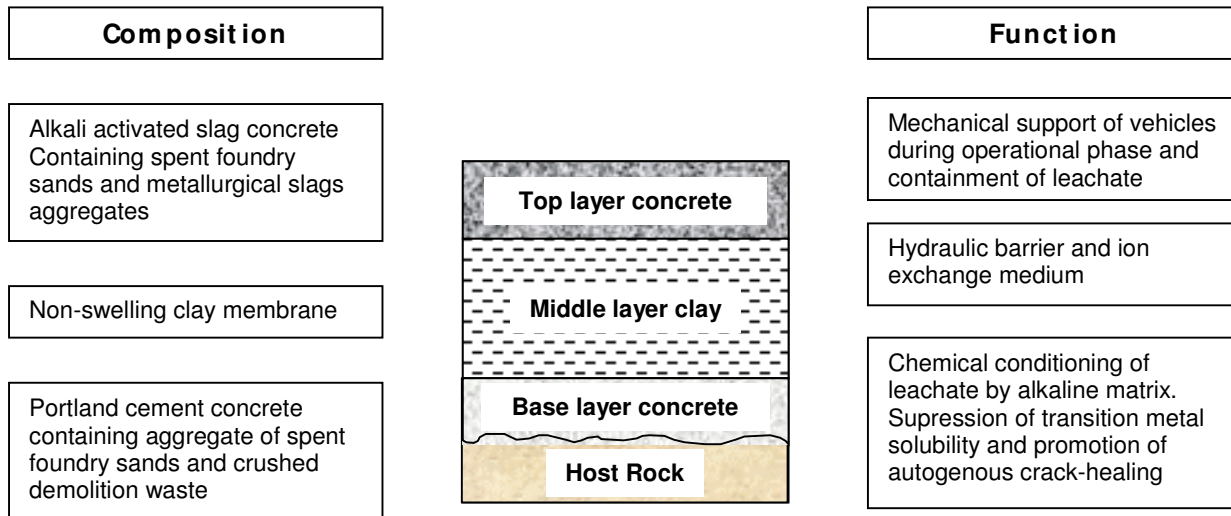


Figure 1 Schematic section of composite

3 WORK PROGRAMME

This three-year study has involved laboratory analysis and screening of materials, prior to development of experimental and numerical models of barrier performance. Owing to the limited time available for study, accelerated test methods have been developed using high-pressure elution of leachates through the barrier materials, in isolation and in combination. Thermodynamic modelling of the long-term consequence of the likely reactions of these materials has been used to optimise the selection of materials for use in a series of field trials. The first of three trial cells has been constructed (late 1999) and two more are planned for summer 2000.

4 MATERIALS

A range of materials from the metals processing and casting industries have been examined and these fall into two major groups; potential aggregate materials, which exhibit physical and chemical stability in the presence of cementitious binders and potential binder materials. The former group includes metal processing slags such as ferrosilicates, blast furnace slag, chrome alumina and spent foundry sands. These have been cast in a range of cementitious binders and assessed for their

The binder materials include alkali activated blast furnace slag, a range of gypsum and calcite filter cakes and reactive slags, such as sulphate and borax slags produced during metal refining.

4.1 Binders and Activators

Conventionally, blast furnace slag (BFS) is activated by blending with ordinary Portland cement (OPC) which provides a source of alkalinity, able to dissolve the BFS glass, resulting in the precipitation of hydration products. As the hydration kinetics of OPC are somewhat faster than BFS, it is common practice to grind the latter to a finer particle size than OPC to ensure that both will hydrate at a similar rate. Alternative sources of alkalinity may be used to activate BFS such as soluble silicates, hydroxides alkaline sulphates, carbonates and so forth. These materials are known as alkali activated slags (AAS). As a result of their particle size, AAS concretes exhibit excellent past-aggregate bond strengths, owing to the ability of BFS grains to pack into surface pores of the aggregates. In addition, the porosity of AAS pastes is very low in comparison to other cementitious media and as a result, they were chosen for inclusion in this study. A search through a wide range of industrial organizations revealed that although many processes result in the generation of soluble waste alkalis, most are used in

acid neutralization by their primary producers. A source of alkaline sodium sulphate/thiosulphate solution (~11% equivalent sodium sulphate) was identified, which is a by-product of lead refining in the UK. This was examined as a potential activator for BFS and has proved to produce excellent concrete, exhibiting compressive strengths around 13MPa and permeability around 10^{-13} ms^{-1} .

During the search for suitable activator for production of AAS concrete, a metal processing slag was identified as producing an alkaline leachate. Leach testing of the ground material showed that it is naturally hydraulic, setting as a cement on contact with water and maintaining its structural integrity on re-wetting. Further investigations showed that the

hydrated product has a higher resistance to attack by the organic acids present in leachate than do conventional cements. The unhydrated slag is shown in figure 2 and the hydrated and leached cement formed from it in figure 3. The hydration mechanism of this material remains unclear; its hydration product being a low-density borate gel. The formation of the gel appears to close the connective porosity of the powdered slag, thus preventing further ingress of the acidic leachate. In order to maximise the time available to study this material in the field experiments, it was included in the first trial cell, despite its mechanism of hydration remaining elusive.

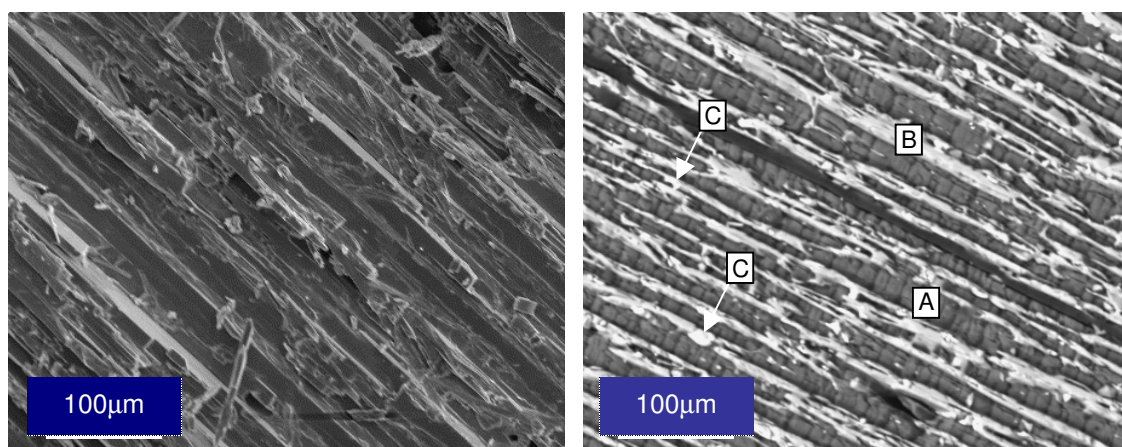


Figure 2 Unhydrated borax slag binder The borax, substituted with iron and zinc is a poorly crystalline phase and appears in a back scattered electron image as a dark grey matrix (A) with extensive cooling cracks perpendicular to its longest axis. This alternates with a relatively pure zinc oxide (bright phase, B) containing iron-rich domains (brightest phase, C). (Left: fracture surface secondary electron image, right polished surface, back scattered electron image).

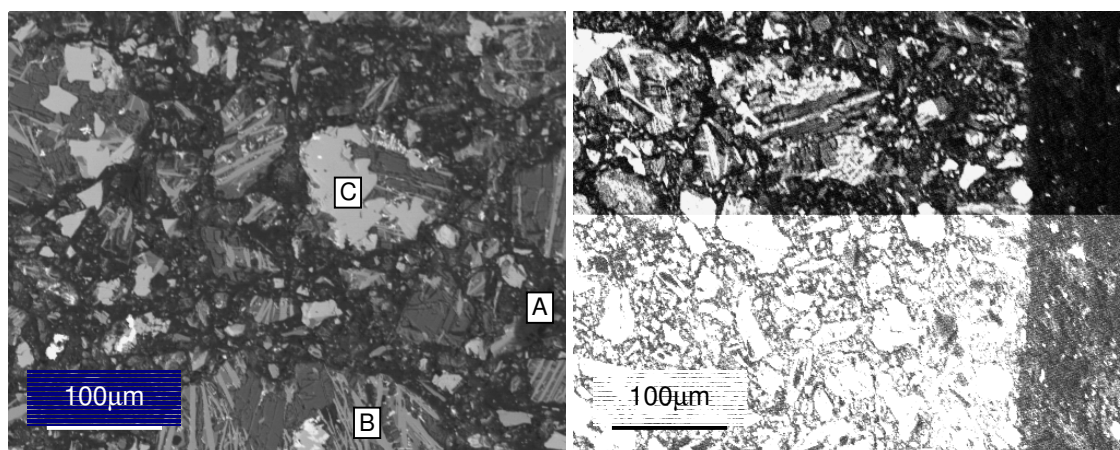


Figure 3 Hydrated borax slag binder Left: Polished surface, back scattered electron image, showing dark hydration product (A) unhydrated slag fragments (B) and ferrosilicate aggregate particle (C). Right: Polished surface, back scattered electron image. The sample has been leached by 0.1M acetic acid from the right. Above; high contrast showing detail of matrix, below, low contrast showing detail in the reaction product.

In addition to these binder types, work continues on supersulphated slag cements, which are reported to have a high resistance to organic acids [Evans *et. al.* 1960]. These materials contain BFS interground with hemihydrate, which provides the source of alkalinity necessary for slag hydration. Although preliminary studies of these materials using by-product gypsum show moderate strength concretes may be produced by this route, these investigations are at an early stage and will be reported elsewhere.

4.2 Aggregates

The use of mineral wastes as aggregates in concrete is well established, yet many are considered to be of limited interest to the construction industry. A range of metal processing slags and spent foundry sands have been examined in this study and a number of ferrosilicates and a chrome alumina have proved suitable for use in concrete liner production.

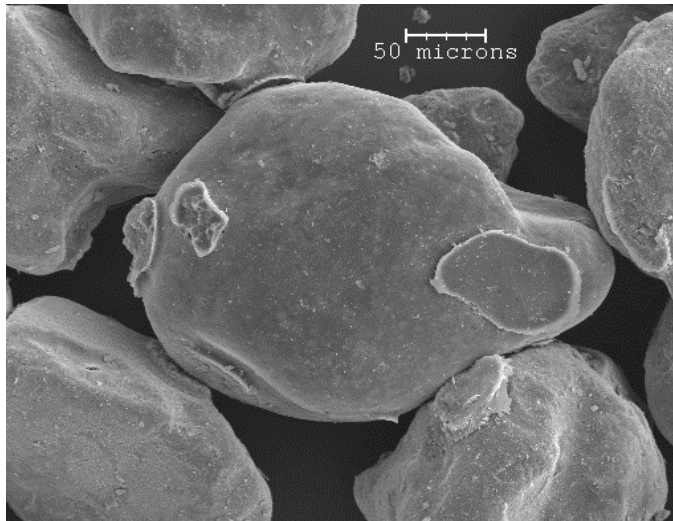


Figure 4 Spent shell sand. SEM secondary electron image. (SEI)_

Figure 4 shows a spent foundry sand, a material which is normally disposed of to landfill owing to the fused binder on its surface limiting the past-aggregate bond strength. Use of this material in concrete liners does not require the high compressive strengths attained in structural concrete and Figure 5 shows an optical thin section of a concrete containing this aggregate, the dark, intergranular regions showing hydrated alkali activated slag cement binder.

Similarly, coarse aggregates have been examined, such as chrome alumina (figure 6) and ferrosilicates (figure 7). Their chemical stability in a range of cement matrices has been monitored for approximately 1 year and they appear to be stable.

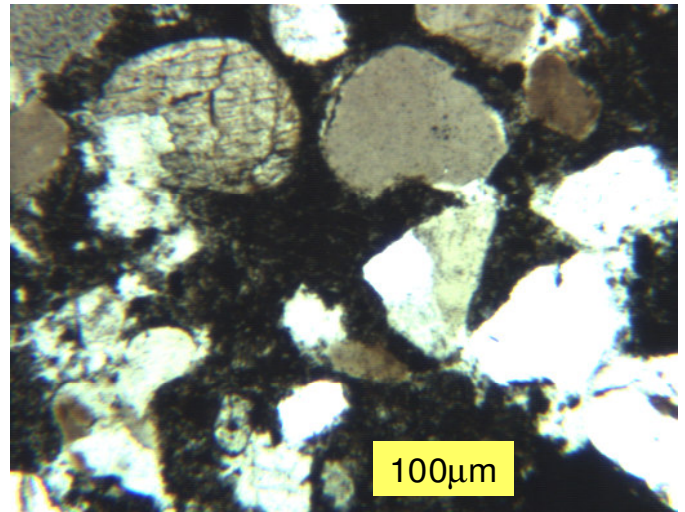


Figure 5 Spent foundry sand in sodium sulphate activated AAS concrete. Optical thin section

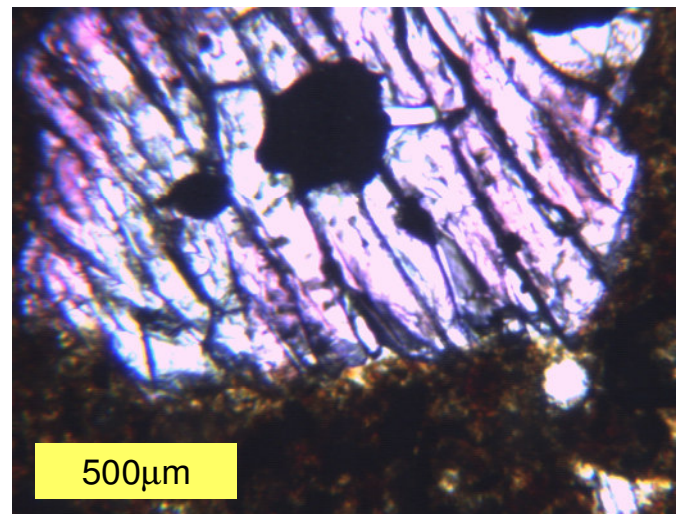


Figure 6 Chrome alumina aggregate grain in sodium sulphate activated AAS concrete. Optical section



Figure 7 Ferrosilicate slag particles, as supplied. SEM secondary electron image

In order to examine the reactions of landfill leachates with concretes incorporating these materials, an accelerated test method has been developed [Claisse & Unsworth, 1995]. The principle is that of high pressure elution of a test solution through these porous media, which enables both measurements of the permeability evolution and analysis of the effluent chemistry to be made. Figure 8 shows the apparatus schematically.

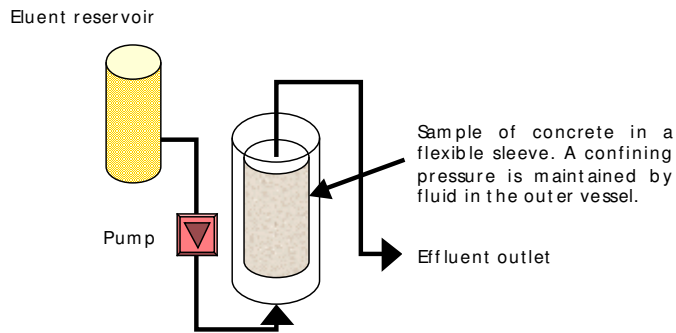


Figure 8 The confined Leach cell apparatus

In combination with strength development measurements and microstructural examination of the hydrating concretes, a range of formulations have been chosen for inclusion in a set of trial cells, constructed in Risley, Cheshire, UK.

The composition of these layers is as follows:

Top Layer (0.2m thick)

Borax-ZnO slag	450 kg.m ⁻³ concrete
Ferrosilicate sand	895 kg.m ⁻³ concrete
Limestone (20mm)	1085 kg.m ⁻³ concrete
Water	210 kg.m ⁻³ concrete

Permeability	~	5x10 ⁻¹⁰ ms ⁻¹
Compressive strength	~	5 MPa (at 28 days)

Middle layer - (0.5m thick) locally won, non-swelling clay; roller compacted. Plasticity index ~ 11% moisture Mineralogy is Illite, smectite, kandite, quartz, calcite chlorite (XRD, order of abundance)

Bottom Layer (0.3 m thick)

BFS ("Cemsave" TM)	180 kg.m ⁻³ concrete
OPC	20 kg.m ⁻³ concrete
Chrome alumina (40mm)	1085 kg.m ⁻³ concrete
Spent foundry sand	645 kg.m ⁻³ concrete
Na ₂ SO ₄ (11% aq)	295 kg.m ⁻³ concrete

Permeability	~	2x10 ⁻¹² ms ⁻¹
Compressive strength	~	13 MPa (at 28 days)

5 SITE TRIAL

The materials described above have been used to produce a trial cell at a licensed waste disposal site in Risley, Cheshire in the north of England. This site offers the opportunity to construct a number of experimental cells in which the long-term performance of these mineral barriers may be monitored.

Mixing and batching of the concrete was undertaken by a commercial ready mix concrete contractor and delivery to site was by conventional mixer. Emplacement of concrete was by excavator bucket, although the rheology of the mix was designed to enable pumping of the concrete in a larger construction. Sample lines were emplaced throughout the construction which is shown schematically in figure 9, below:

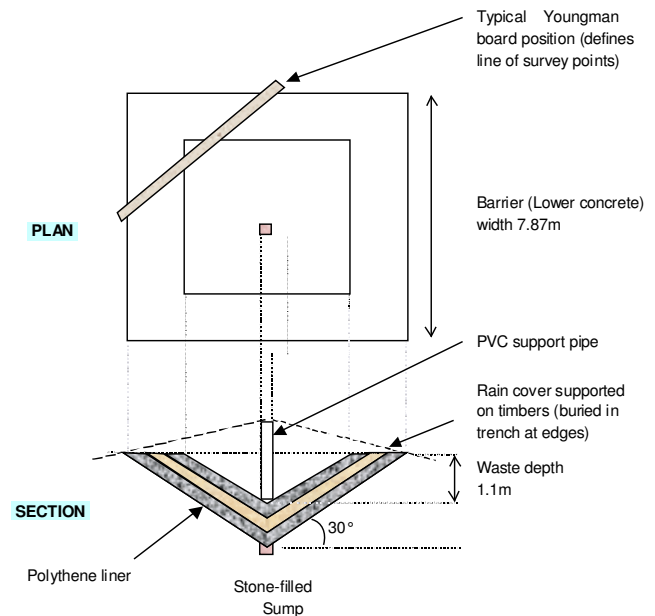


Figure 9 Schematic drawing of experimental liner

Following excavation of the cell, the lower concrete was emplaced and allowed to cure for 28 days. It attained a compressive strength of 11MPa within 7 days and 13 MPa after curing. Compaction of the clay layer was effected by the excavator blade, although compaction using a drag-roller is envisaged in larger constructions.

The top layer concrete was also emplaced using an excavator and allowed to cure for a further 28 days before the cell was filled with domestic waste, flooded with leachate and capped with a rain cover, supported clear of the waste by a wooden framework. Construction of the trial barrier is shown in figures 10 and 11



Figure 10 Compaction of the clay on the surface of the lower concrete layer.



Figure 11 The completed experimental liner system, prior to filling and covering

6 RESULTS.

The site is monitored each month although after six months, no solutions have been extracted from the sample lines in the barrier. Those placed beneath the lower concrete show that its interface with the sub-soil is saturated with local groundwater. This is close to saturation with calcite and it is expected that carbonation of the lower concrete will be seen when the materials are cored at the end of the study.

The properties of the materials used in this construction are summarised below and compared with a range of conventional barrier materials examined in the study.

7 DISCUSSION

Comparison of the permeabilities below with those of conventional liner materials show that mineral barriers offer a viable and low cost alternative to conventional polymeric liner systems. Although most of the materials used in construction of these experimental barriers are considered by their producers to be wastes, their re-use within the waste industry will potentially extend their useful life.. This not only adds value to a material which is currently a financial liability, but reduces the total waste arisings from their primary production process. Whilst it is recognised that concretes such as these are unlikely to be used in structural engineering, their use in waste management seems

Materials & percentage by mass	Compressive Strength		Eluent	Permeability	Effluent pH	
	Units	Days Age				MPa
CONCRETE				(m.s ⁻¹)		
Coarse Chrome Alumina (64.2%) Green Sand (27.3%) GGBFS (7.6%) OPC (0.9%) Na ₂ SO ₄ / Na ₂ S ₂ O ₃ solution		7	11	Water	0	
		28	13	Leachate	2.0 x 10 ⁻¹³	8.5
Coarse Limestone (44.7%) Ferrosilicate sand (36.8%) Spent Borax slag (18.5%)		7	5	Water	1.6 x 10 ⁻⁹	10
		28	4.5	Water	1.9 x 10 ⁻⁹	10

Estimation of the permeability of the clay layer has not been possible using the confined leach cell. The permeability is somewhat less than 10⁻¹⁴ ms⁻¹, yet as the clay remains plastic, increasing the head of effluent causes the sample to deform in the cell. An attempt to use a drained triaxial cell to repeat this experiment is in progress.

attractive.

From the perspective of the waste operators, increased waste volume is generated through decreased barrier thickness, which has obvious economic implications. Moreover, removing the need to grade waste prior to emplacement has environmental benefits in limiting dispersal by wind

Material	Hydraulic Conductivity (m.s ⁻¹)	Typical thickness (m)	Permittivity (m ³ s ⁻¹ m ⁻² m ⁻¹)
Compacted Clay	1×10 ⁻⁹	0.9	1.1×10 ⁻⁹
Soil-Bentonite	1×10 ⁻⁹	0.5 – 1.5	0.7-2×10 ⁻⁹
Cement-Bentonite	1×10 ⁻⁸	0.5 – 1.5	0.7-2×10 ⁻⁸
Soil Mixed	1×10 ⁻⁹	1.0 – 2.0	0.5-1×10 ⁻⁹
Grout Barrier	1×10 ⁻⁸	1.0 – 2.0	0.5-1×10 ⁻⁸
Geomembrane	1×10 ⁻¹⁴	0.001 – 0.002	0.5-1×10 ⁻¹¹
Geosynthetic clay layer	1×10 ⁻¹² - 1×10 ⁻¹⁰	0.012	8×10 ⁻¹¹ - 8×10 ⁻⁹

Comparison of transport properties of barrier materials

and vermin. This is associated with a reduction in the operators' costs in waste sorting and handling.

In conclusion, this project seeks to develop alternative barrier materials from industrial wastes and goes some way to demonstrating their use as landfill liners.

8 FUTURE WORK

Two additional cells will be constructed shortly and additional materials are sought for inclusion in the study. Of particular importance is the demonstration of the applicability of experimental and numerical models of barrier performance beyond the spatial and temporal constraints of a three year study.

9 REFERENCES

Claisse., P.A. & Unsworth., H.P. (1995) "The engineering of a cementitious barrier," Geotechnical Society, Special Publication No.11

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