Novel Composite Landfill Liners

An BIFFAWARD supported project managed by MIRO

Background

Current waste management practice largely relies 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 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.

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.

[1] Landfilling wastes / Department of the Environment. HMSO, London, 1986 ISBN: 0117518913

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 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.

- **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.

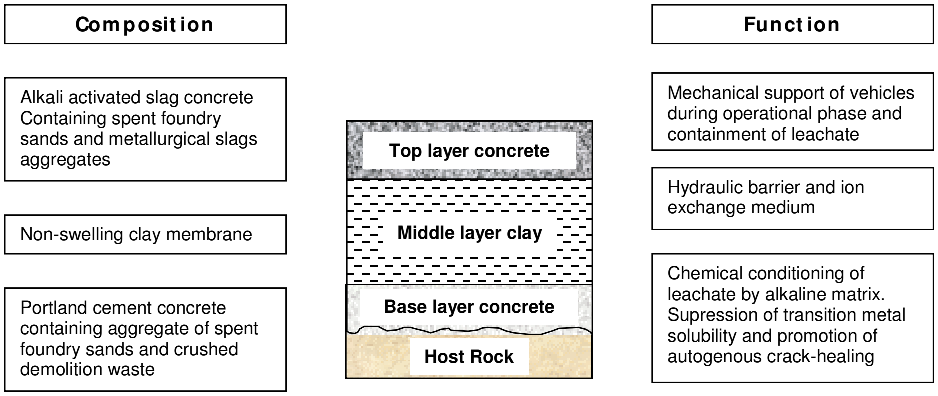
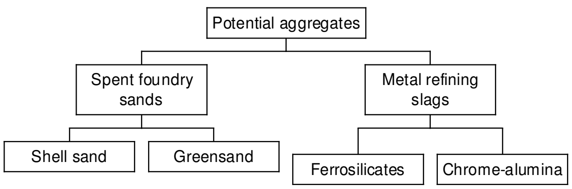


Figure 1 Schematic section of composite

Liner Materials

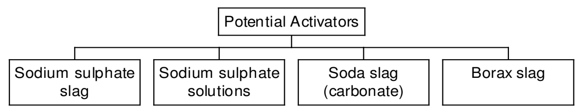


A range of materials from the metals processing and casting industries have been examined and these fall into two major groups; potential aggregate materials, which exhibit physical and chemical stability in the presence of cementitious binders and potential binder materials. The former group includes 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 physical and chemical compatibility with the matrix and the resulting concretes tested for development of strength and permeability.

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

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 paste-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 with other cementitious media and as a result, they were chosen for inclusion in this study.



A search through a wide range of industrial organisations 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 is 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.

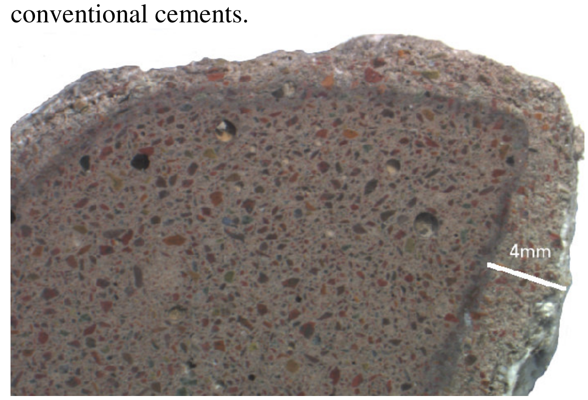


Figure 2 Borax slag cement paste after three months reaction with synthetic leachate

The hydration of this material appears to produce a low-density borate gel. The formation of the gel closes 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 it was included in the first trial cell, acting as the binder in the top layer.

Materials selection

From the wide range of materials examined, a selection of materials was chosen for inclusion in three field trials, held at an operational landfill site near Risley, Cheshire. In order to select the most suitable combination of materials, a method of accelerated testing was developed in which a leachate is eluted under pressure through a porous sample. In this way, the method allows dynamic measurement of permeability evolution along with an opportunity to examine the changes in solution chemistry and the microstructure of the reacted sample.

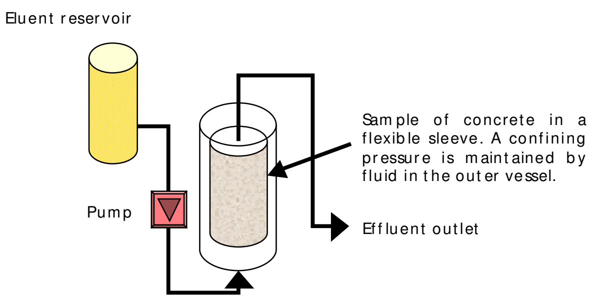


Figure 3 The Confined Leach Cell apparatus

In combination with strength measurements, a range of concretes was developed with permeabilities less than 10^{-9} ms^{-1} and compressive strengths in excess of 5 MPa; easily sufficient to support the weight of a vehicle. It was intended that the permeability of the composite barrier would be measured using the confined leach cell, however, the permeability of the clays examined proved to be so low ($<10^{-11}$ ms^{-1}) that no solution could be eluted through them. It is sufficient to say that they are fit for their intended purpose as hydraulic barriers.

Field Trials

Six concrete formulations were developed with which to demonstrate the technology in three experimental cells. 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.

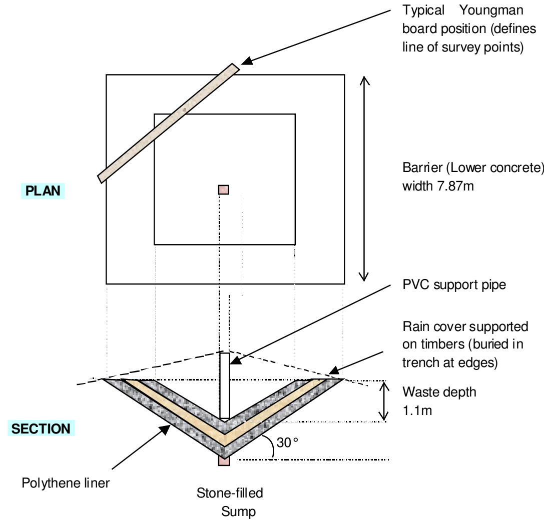


Figure 4 Experimental Liner; Schematic

Following excavation of the cell, the lower concrete was emplaced and allowed to cure for 28 days. Each formulation attained a compressive strength between 2 and 10 MPa within 28 days, rising somewhat 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 concretes were 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 moveable framework. A completed cell is shown below.

Figure 5 Completed experimental liner system prior to filling and fitting of the rain cover

Sample lines and thermocouples were placed within each layer and at each interface, allowing periodic monitoring of each cell's evolution. Monitoring will continue for as long as possible (possibly up to 5 years) after which time the materials will be excavated and examined to determine their condition.

Key Findings

Alkali activated blast furnace slag cement provides a strong, low permeability binder at a slightly lower cost per tonne than conventional Portland cement. Securing a supply of waste alkali activator proved to be more difficult than expected as the majority of alkaline waste arisings in the UK are used by their primary producers. One of the viable sources identified (a soda slag produced in non-ferrous metallurgy) demonstrated one of the inherent risks of using waste materials; that of supply variability. It is essential that any waste materials used in subsequent processes are monitored for consistency before use.

Blending of other pozzolanic binders such as fly ash with BFS and waste alkalis considerably reduces the cost of the binder without unacceptable losses in strength, permeability or setting times. This area cannot be fully investigated within the remit of this project, but it is identified as a key variable in the production of low cost concretes for a range of applications.

As the cost of waste disposal increases alongside the legislative requirement to minimise 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. This project has looked principally at metals processing slags and spent foundry sands (which reflect the interests of the partners in the study) but has identified a much larger range of potential aggregates suitable for use in liner construction.

Of the aggregates examined in this work, all but one appear to be chemically and dimensionally stable in the range of cementitious binders examined. This has commercial implications beyond the interests of this project.

The performance of the liner concrete is tolerant of minor changes in batch composition. Although the concrete formulations have been optimised to specified strengths, permeabilities, workability, setting time and cost, slight variations at the mixing stage do not appear to be of critical significance. This is a very important result, as production of unfamiliar concrete mixes by unskilled staff may result in mixes far different to those specified.

The reaction between the clay and concrete is not rapid. Concern is occasionally expressed that as these two materials cannot reach thermodynamic equilibrium with a common pore solution, their reaction may be disastrous. Thousand of years of construction in clay foundations shows that at modest temperatures, the reaction kinetics are slow. Examination of the cement-clay interface of laboratory samples suggests a reaction depth of around a micron after one year's reaction.

The use of the confined leach cell, allows relatively rapid determination of permeability using up to 10MPa pressure differential. Elution of reactive (acetogenic) leachate through cements increases their porosity during the test suggesting that the leachate will react with the binder in the upper concrete.

Future work

In the short term, it is important to ensure that access to the existing field site is maintained for as long as possible. Continued monitoring of the existing experimental cells will increase our understanding of the behaviour of the liner materials and demonstrate the viability of mineral barriers as a means of leachate containment. Eventually, these experimental liners will be cored and subject to detailed microanalysis but an extended reaction time will maximise their potential value.

A considerable number of waste materials have been identified during this project, which were not considered at the proposal stage. It would be particularly valuable to investigate glassy wastes in order to determine their pozzolanic reactivity. A substantial quantity of coloured glass is disposed of in the UK each year and a range of other glass wastes have been identified as having potential for use as cement replacement materials. Included in this group are mineral dressings and polishing residues which have great potential in producing cementitious binders.

Recycled demolition waste fines are currently landfilled as they contain leachable gypsum plaster which precludes their use as trench-fill or road-base. Bound with alkali activated BFS, this material has potential use as a construction material both for landfill liners and roads at the sites to which it is delivered. Steel converter slags are materials which have little subsequent use, owing largely to their very high density and hence transport costs. They are landfilled close to their site of production, but are subject to the same taxation as any other waste. Their potential as aggregates for use at (or close to) the disposal site has not been fully investigated and as a result, these materials should be considered in future studies.