EQual Incinerator bottom ash aggregate (IBAA) field trial

Summary report

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EQual programme

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Introduction

The EQual LIFE+ programme aims to promote the re-use and recycling of waste materials whilst protecting human health and the environment. Deriving value from waste materials by turning them back into safe, high quality products is an essential element in the move towards a more circular economy. As part of the EQual programme, field trial was carried out to improve understanding of the behaviour of four waste-derived materials in the environment. Incinerator bottom ash aggregate (IBAA) was one of the materials studied.

The Environment Agency led the programme with six partners: Rijkswaterstaat (the Netherlands' Ministry of Infrastructure and the Environment), the Chartered Institution of Wastes management, Organics Recycling Group, Environmental Services Association, Northern Ireland Environment Agency and Energy UK.

As part of the EQual programme, field trials were carried out for four waste derived materials, to improve understanding of the behaviour of these materials in the environment. The evidence base obtained from the trials will support the appropriate use of these materials in place of non-waste materials. Two of the field trials focus on the construction industry - pulverised fuel ash (PFA) and incinerator bottom ash aggregate (IBAA), and two on agricultural use - poultry litter ash and paper sludge. This report summarises the incinerator bottom ash aggregate field trial.

The trial was carried out by a consortium of TRL, the ACS Group of companies and the Geomechanics Research Group at the University of Southampton, with technical support provided by Bone Environmental Consultant. Construction of the trial was undertaken during April 2013 and monitoring commenced in May 2013. The trial was monitored until mid-September 2014.

Aims

Incinerator bottom ash aggregate (IBAA) is widely used in construction applications. A generic Quantitative Risk Assessment (QRA) was carried out as part of the EQual programme, based on extensive laboratory analysis of samples from IBAA processing plants across England. However, the hydrological and geochemical conditions which occur on site cannot be replicated fully in the laboratory; leading to uncertainties with respect to how well a QRA based on laboratory results reflects the environmental risks.

A field trial was carried out to improve the understanding of water movement and leachate production and quality within incinerator bottom ash aggregate (IBAA) under UK weather conditions and assess how the laboratory results transfer to real world applications.

The trial was designed to:

- determine the water balance within and out of the test structure;
- develop an understanding of the production, movement and quality of leachate arising from the use of IBAA in construction; and
- provide robust data to assess how laboratory results for IBAA reflect realistic use* conditions and inform assessment of environmental risk.

*albeit without a low permeability cover to gain results within available timescales.

Methodology

A contained trial section approximately 5 m x 5m was designed and constructed, with a collection system to monitor the quantity and quality of leachate draining from the structure. The section represented common usage of IBAA in road subbase; but with a layer of free-draining gravel in place of the asphalt layer that would normally overlie IBAA subbase with a layer of free-draining gravel. This allowed a reasonable amount of leaching of the IBAA to take place, whilst providing cover to prevent wind blow of IBAA dust, and to provide protection from extremes of temperature.

The IBAA was underlain by a sand blanket over an HDPE impermeable liner, to prevent any leachate infiltrating into groundwater or watercourses. The design was produced in accordance with the Specification for Highway Works, Design Manual for Roads and Bridges[1] and relevant standards. The design was finalised in consultation and agreement with the IBAA Steering Group. The completed test pad is shown in Figure 1.

Figure 1 Completed test pad

Physical analyses were carried out on samples of the IBAA and drainage/cover gravel. The materials were analysed for grading, particle density, the relation between moisture content and dry density, and hydraulic conductivity. The IBAA was a well-graded material that compacted well and appeared to be typical of material that is used as Type 1 unbound subbase in the UK.

Instrumentation was installed in the test pad to measure the input via rainfall, the movement of water through the test pad, and the output of water via drainage. Measurements of climate parameters were made to enable the evaporation from the pad to be calculated. Facilities were installed to enable samples of the pore water and drainage flows to be obtained.

Samples of pore water within the test pad, and leachate draining from the test pad were collected for chemical analysis. Samples were taken weekly from September to December 2013, then monthly from January to September 2014. Samples of precipitation at the site were also taken for analysis, to provide 'background' concentrations.

[1] Highways Agency, Transport Scotland, Welsh Assembly Government and Department for Roads in Northern Ireland. (2014). Specification for Highway Works – Manual of Contract Documents for Highway Works, Volume 1, available at http://dft.gov.uk/ha/standards/index.htm.

Results: Water balance calculation

The water balance of the test pad was calculated using the results of on-site monitoring. Rainfall was measured at the site from 15 May 2013 to 16 September 2014. Over the period of the trial the monthly totals at the site were 130% of the Long Term Average (LTA) for a nearby weather station. Values for individual months ranged from 52% of the LTA in August 2013 to 232% in January 2014.

Evaporation from the surface of the IBAA pad was estimated using air temperature, relative humidity, wind speed, and net solar radiation measured on site. The daily version of the Penman-Monteith equation was used to estimate reference potential evapotranspiration[2]. The amount of stored water in the IBAA pad was estimated from the measurements of water content by instrumentation within the IBAA. Pore water pressure (or tension) was measured at two depths in the IBAA test pad, and used to indicate the likely direction of fluid flow.

The outflow from the IBAA pad was measured using the tipping bucket flow gauge installed within the instrumentation container. To determine the outflow in mm, the total measured outflow in litres was divided through by the plan area of the test pad, taking into account the protrusion of the liner beyond the gravel zone, which increases the total area of the pad that catches rainfall.

For a given time period, the water balance of the pad may be defined as:

$$R \approx ET + \Delta S + OU \qquad \text{Equation 1}$$

where R is rainfall, ET is evaporation, ΔS is the change in stored water, and OU is outflow from the base of the IBAA layer.

The overall water balance was calculated for the period 15 May 2013 to 15 September 2014, a period of 489 days (the discrepancy of 1mm is due to rounding):

- Rainfall: 1287 mm
- Outflow : 1057 mm
- Change in stored water: -53 mm
- Potential evapotranspiration (calculated): 1014 mm
- Actual evapotranspiration (estimated): 284 mm

There was very little absorption of water by the IBAA. Drainage was observed from the start of the trial, and there was no significant time lag between rainfall and outflow as leachate. Calculations of permeability based on the grading of the IBAA indicated a free-draining material; this was confirmed by the measured data.

Liquid to solid ratio

The liquid to solid ratio (L/S) is a key parameter for comparing laboratory and field data. It is used to represent time, enabling a direct comparison to be made between field and laboratory column test leaching data, as used for the QRA. The L/S was calculated from the volume of leachate outflow and the mass of IBAA. The liquid to solid ratio (L/S) achieved 2.3l/kg over the duration of the field trial. This was sufficient for comparison with laboratory leaching tests over a good range of L/S values.

[2] Allen, R. K., Smith, M., Perrier, A. & Pereira, L. S. (1994). An update for the calculation of reference evapotranspiration. ICID Bulletin. 43, (2), 35–92.

Results: chemical analysis

The field trial collected a comprehensive set of data to improve understanding of leaching of key substances from IBAA under UK weather conditions and to assess how the laboratory results, using the column test, transfer to real use applications.

Analysis of material samples, pore water and leachate were carried out, enabling comparison of:

- Leached mass from field trial (FT) IBAA EQual samples with leached mass from QRA samples; and:
- Concentrations in FT pore water and leachate with QRA column test eluate concentrations used as the basis of the QRA risk assessment.

Leached mass was analysed using 2-stage batch tests (BS EN 12457-3). The tests extract substances using distilled water, or water of similar purity in the pH range of 5.0 – 7.5, to provide an estimate of leached mass (in mg/kg) over a reasonably long timescale (corresponding to a liquid to solid ratio = 10l/kg). The results can be used to compare the leaching behaviour of different materials/samples under standard conditions, and so assess whether observed differences in leachate concentrations are due to the material properties rather than environmental conditions.

The QRA column test concentrations show the concentrations leaching from the material in water in the laboratory under dynamic flow conditions. FT pore water shows the concentration of water within the IBAA, extracted under suction. FT leachate results show the concentrations in leachate draining from the test pad following infiltration of rainwater and movement through the test pad, including the drainage bed.

Leached mass (batch test) and leachate comparisons

Concentrations in FT leachate are generally very consistent with QRA concentrations; both laboratory and FT leachate concentrations tend to reflect the leached mass in batch tests on the respective material samples.

For example, leached mass of calcium (Figure 2) is high in FT IBAA relative to the laboratory (QRA) samples; this is reflected in the high leachate concentrations (Figure 3). Conversely, leached mass of zinc (Figure 4) in the FT IBAA is low compared to QRA samples; also reflected in the relatively low concentrations in FT leachate (Figure 5**Error! Reference source not found.**) compared to laboratory samples.

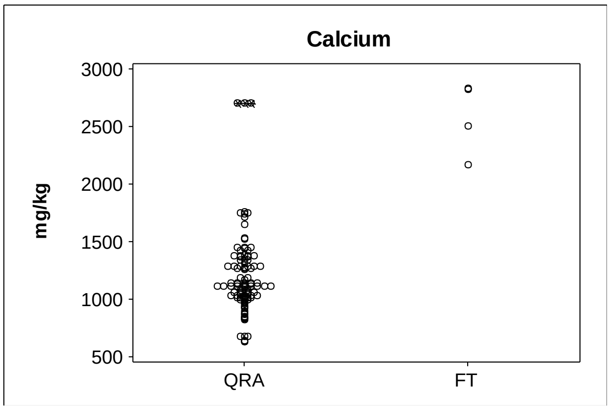

Figure 2 Leached mass Ca

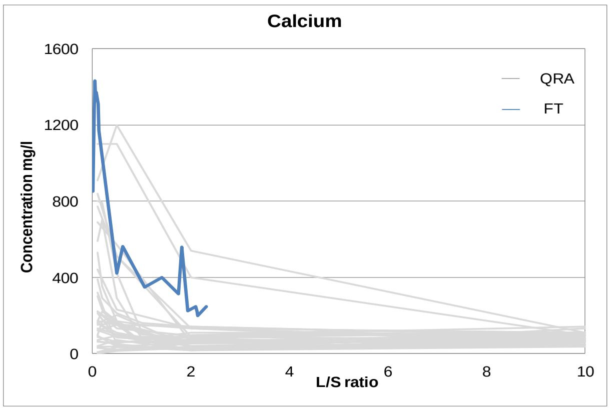

Figure 3 Leachate Ca

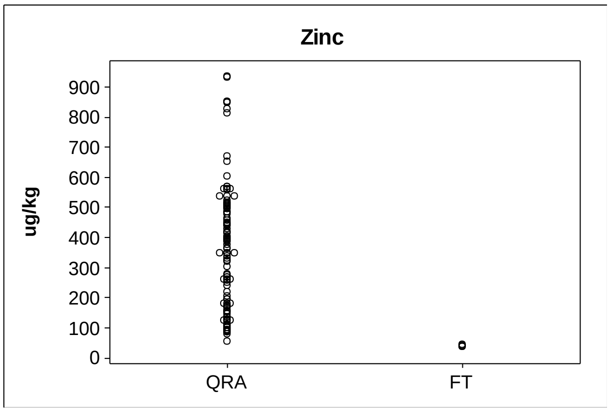

Figure 4 Leached mass Zn

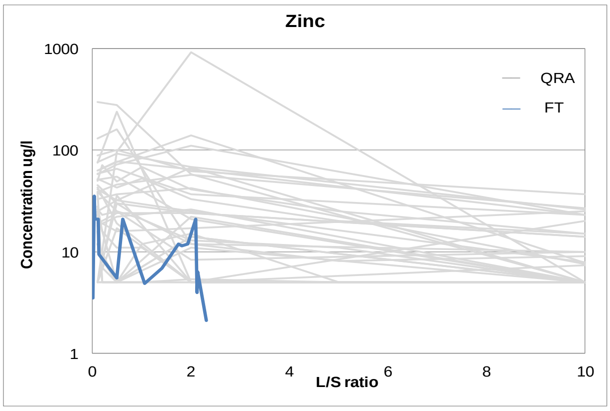

Figure 5 Leachate Zn

Chromium release

The leached mass of Cr(total) in FT IBAA was very low compared to the QRA data set (Figure 6). Concentrations in FT leachate were around the low end of the range of concentrations in QRA leachate, but show an increasing concentration with L/S, relative to the QRA column test behaviour (Figure 7). Field trial CrVI concentrations were also below the reporting limit (Figure 8); in this case the reporting limit was higher than that for the QRA batch tests (different laboratories). One interesting difference in behaviour between column test and FT is the lack of a decline in the leachate concentrations from the start of the trial to L/S = 2. Both Cr(total) and CrVI can be better described as constant or even increasing.

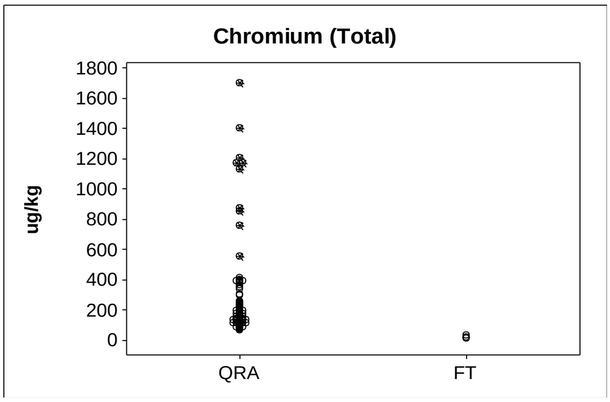

Figure 6 Leached mass Cr(total)

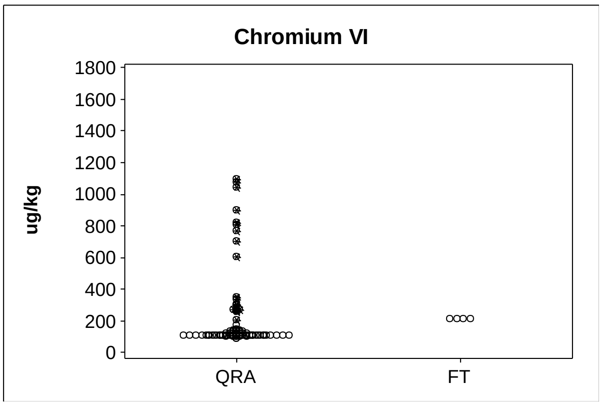

Figure 7 Leached mass CrVI

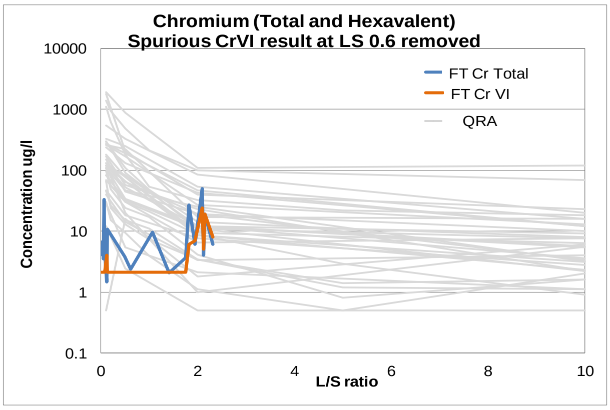

Figure 8 Leachate Cr(total)& CrVI

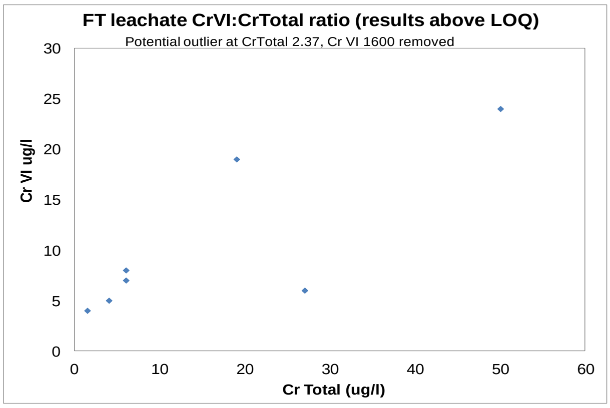

Figure 9 FT leachate CrVI vs Cr(total)

Where FT leachate concentrations were above the reporting limit, there was a fairly strong correlation between CrVI and Cr(total) concentrations (Figure 9).

The results of the FT batch tests show a higher release of chromium from the flint gravel (top cover) than from IBAA; therefore, the concentration of chromium in both the pore water and leachate may therefore overestimate release from the IBAA alone. However, the FT IBAA has a much low chromium content compared to the QRA IBAA; hence the apparent high proportion of chromium accounted for by the cover gravel in the field trial.

Pore water and leachate comparison

Pore water samples extracted using the two soil water samplers within the IBAA test section were compared to each other and to the leachate draining out of the test section.
Pore water concentrations for most substances were generally higher than the leachate concentrations in the early part of the trial, after which the concentrations become similar; as demonstrated for potassium (Figure 10).

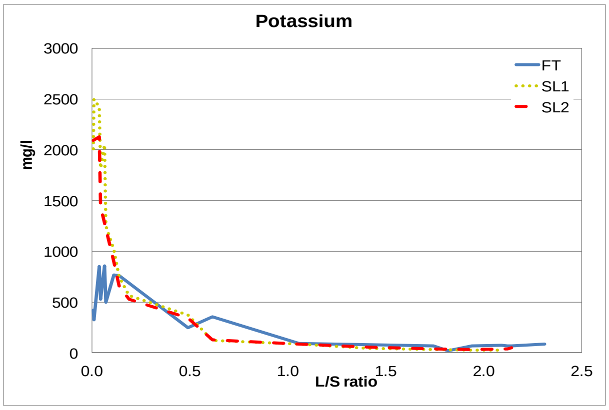

Figure 10 Leachate and pore water K

The comparison of leaching behaviour of pore water and leachate can be divided into broad categories:

Evidence of conservative behaviour: Conservative behaviour is where a substance will leach from IBAA and pass through the drainage system without attenuation. Conservative behaviour may be indicated by the lack of significant difference in concentration between leachate and PW at the same L/S. Conservative behaviour is predicted for substances with little or no attenuation capacity (for example by sorption or cation exchange). Conservative behaviour is shown by ammoniacal nitrogen, cobalt, fluoride, magnesium (discounting one high leachate value) and strontium. Boron may also behave conservatively.

Possible evidence of attenuation: Attenuation of inorganic substances in the drainage layer may take place by adsorption of a dissolved substance to particle surfaces (such as clay minerals, iron oxides or organic carbon), cation exchange (with corresponding increase in concentration of the exchanged cation), transformation to a less soluble form (for example hexavalent to trivalent chromium), complexation and/or precipitation. For some substances such processes may be controlled by changes in pH or ORP. Possible attenuation may be indicated by:

- early PW concentrations > leachate at the same L/S, then convergence as concentrations reduce; and
- PW concentrations consistently > leachate at the same L/S.

There is some evidence of attenuation of hexavalent chromium at low L/S ratios, but there is no clear evidence to support any significant (long term) attenuation of chromium within the drainage layer. However, strong evidence of attenuation can be inferred for vanadium. Pore water concentrations show a rapid decline and a slight increase toward the end of the trial (Figure 11, note logarithmic scale). Leachate concentrations are consistently lower than pore water except for one anomalously high result. The two order of magnitude difference in concentration between leachate and pore water in the early samples provides a strong basis to support vanadium attenuation in the drainage layer.

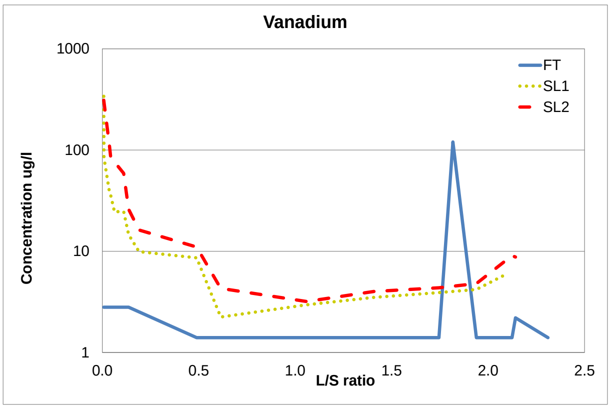

Figure 11 Leachate and pore water V

Possible evidence of release in the drainage system: substances may be released from the solid phase to leachate in the drainage layer by cation exchange, desorption from particle surfaces or dissolution. For some substances such processes may be controlled by changes in pH or ORP. Possible release may be indicated by:

- early leachate concentrations >PW at the same L/S, then convergence; and
- leachate concentrations consistently >PW at the same L/S.

Evidence of release in the drainage area can only be attributed to aluminium; but it is unclear why aluminium is consistently higher in leachate.

Evidence of little or no substance release: A substance may be effectively immobile under the pH and ORP conditions prevalent during the trial. There was evidence of little or no substance release for beryllium, lead, orthophosphate and thallium in both pore water and leachate; Ammoniacal nitrogen, cadmium, lithium, mercury and nitrite showed an early release, followed by little or no release.

This is a subjective comparison based only on observed leaching behaviour. A number of uncertainties are difficult to resolve, such as the impact of sampling volume (zone of influence of soil water samplers vs leachate tank), flow path heterogeneity, dilution (although this is mitigated by installation of baffles to prevent side-wall pathways), and exposure of samples to air. Further evaluation, such as geochemical speciation modelling, would need to be carried out to identify potential mechanisms to explain either release or attenuation by adsorption, precipitation or transformation. This is beyond the scope of this study.

Conclusions

The IBAA field trial developed and constructed a structure providing a balance between a realistic representation of the use of IBAA in construction and the need to obtain leachate results within the timescales of the study.

During the trial the IBAA was exposed to a wide range of weather conditions. The summers of 2013 and 2014 were dominated by hot, dry weather and fairly low drainage flows. However, the flows never stopped completely during these periods and it was not necessary to irrigate the test bed. Winter 2013 was the wettest winter on record in England. Over the duration of the trial, the site received 1287mm of rainfall, representing 126% of the long-term average rainfall measured at a nearby rain gauge. There was very little absorption of water by the IBAA; the infiltrating water came straight through as drainage. The L/S ratio of 2.31 l/kg achieved was higher than anticipated at the design stage.

Rainfall, leachate flow, movement within the IBAA test pad and weather variables were measured. The trial provided a robust data set which enabled the water balance to be calculated and showed that there was very little absorption of water by the IBA, indicating a free-draining material. The field trial has improved understanding of the infiltration and movement of water within IBAA in a construction scenario.

Samples of the materials used to construct the trial were obtained and characterised to enable comparison with the samples of IBAA underpinning the QRA. Pore water within the IBAA test pad, and leachate draining from the test pad were obtained and analysed at regular intervals throughout the trial, to enable comparison with the QRA data and evaluation of leaching and attenuation under field conditions.

The field trial has provided a robust dataset which has improved understanding of the production, movement and quality of leachate within and from the IBAA test bed and enabled assessment of how well the laboratory analysis used to inform the QRA represented field conditions. The trial demonstrated that the QRA laboratory tests generally represent field conditions well, with a few exceptions. The field trial results will be used to review the QRA for unbound IBAA, reducing uncertainties in the QRA model and giving greater confidence in the assessment of the environmental risks.

Overall the trial has been very successful and has clearly achieved its objectives to:

- determine the water balance within and out of the test structure;
- develop an understanding of the production, movement and quality of leachate arising from the use of IBAA in construction; and
- provide robust data to assess how laboratory results for IBAA reflect realistic use conditions and inform assessment of environmental risk.