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Environmental impacts of sewage sludge ash in construction: Leaching assessment

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ABSTRACT

Sewage sludge ash is a residue left behind after the incineration of sewage sludge, a wastewater treatment by-product. Sustainable use of ash as a construction material must be predicted on ensuring that potentially harmful environmental impacts arising from its heavy metals fraction are avoided. This paper assesses the globally available experimental results on the leaching of SSA and when used in cement clinker production, lightweight aggregate production, mortar, concrete, blocks, road pavements, geotechnics and ceramics. The data analysis indicates that although the material itself is not classified as inert, the mobility of the heavy metals can be heavily restricted in many of these construction products. This can be attributed to solidification/stabilisation effects of Portland cement, supplementary cementing materials or clay, whilst high temperature treatments involved in lightweight aggregate and ceramics production are also beneficial. Restrictions on the use of SSA are also endorsed to avoid strongly unfavourable conditions, such as high rainfall-high seepage areas and severely acidic environments.

1. Introduction

Sewage sludge is a by-product of wastewater treatment. Past practices to manage the residue have included disposal at sea, spreading on agricultural lands and landfilling. The first option has been forced to stop since 1998 (European Community, 1991), a more restrictive approach has been adopted with its agricultural use, and tightening targets have been set to reduce landfilling (European Community, 1999). As a response, the quantity of sewage sludge being incinerated is increasing. In the 28 European countries, 36% of the total sludge was incinerated in 2014 (calculated from Eurostat, 2017). This treatment uses the sludge as a fuel for energy recovery and also reduces its mass and volume by 70% and 90%, respectively, leaving the residual sewage sludge ash (SSA).

With aspirations of moving towards a sustainable society, there is a desire to develop uses for all materials as resources, including SSA. Research has explored the ash use in various construction applications; however, any use must be predicted on ensuring that impacts on the surrounding environment are acceptable. Differing from natural materials used in construction, the ash contains a significant fraction of heavy metals. As such, the major question regarding the potential leaching of these elements must be addressed.

This paper deals with the environmental impacts arising from the use of SSA, focusing specifically on leaching, based on the analysis and evaluation of collected global data on the subject. Relevant characteristics of SSA are covered first, including the material leaching properties, followed by an assessment of the ash use in cement clinker manufacturing, lightweight aggregate production, mortar and concrete, blocks, road pavements, geotechnical applications and ceramics.

2. Sewage sludge ash characteristics

Sewage sludge ash consists of predominantly silt and fine sand size particles, with curves similar to filler or fine aggregate at times (See Fig. 1). The ash has a mean density comparable to that of light sand. The material has a porous microstructure with high water absorption properties. Ash particles are irregularly shaped with rough surface textures. The main oxides present are SiO_2, P_2O_5 Al_2O_3, CaO and Fe_2O_3, whilst a small organic fraction also remains in SSA after its combustion. The most abundant mineral present is quartz, whilst calcite and hematite are also frequently found. Trace amounts of heavy metals are present in SSA and indeed, for this paper on the environmental assessment, this aspect is of primary interest, based on the potential for leaching into nearby sensitive receptors. More detailed information on other general properties of SSA can be found in Lynn et al. (2015, 2016a).

An initial analysis of the total contents, focusing on the more toxic elements in the ash, is given in Table 1. Of particular interest are the

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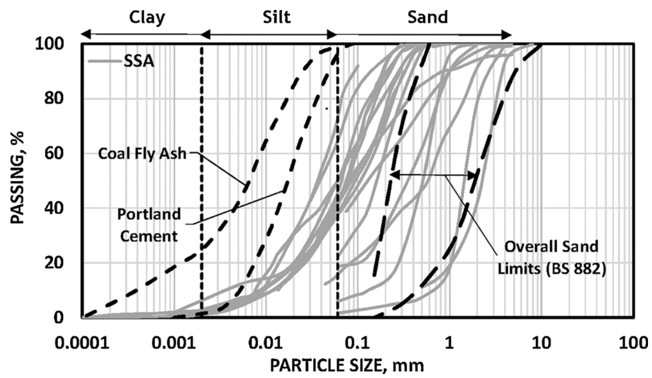

Fig. 1. Particle size distribution curves for SSA samples.
Data for SSA samples from: Al-Sharif and Attom (2014), Alcocel et al. (2006), Anderson and Skerratt (2003), Bhatty and Reid (1989), Cheeseman and Virdi (2005), Donatello et al. (2010a), Environmental & Water Technology Centre of Innovation, Ngee Ann Polytechnic (2012), Franz (2008), Garcés et al. (2008), Hu et al. (2012), Khanbilvardi and Afshari-Tork (1995), Khanbilvardi and Afshari-Tork (2002a), Kosior-Kazberuk (2011), Krejcirikova (2015), Maozhe et al. (2013), Petavratzi (2007).

Table 1
Analysis of the total contents of the toxic trace elements in SSA.

ELEMENT	NO. OF SAMPLES	MEAN, mg/kg	ST DEV, mg/kg	CV, %	LAGA LIMITS, mg/kg
Fe	48	79578	55333	70	–
Al	45	48253	27668	57	–
Cl	31	1241	3043	245	–
Zn	103	2964	3257	110	10000
Cu	117	1673	2713	162	7000
Pb	115	321	402	125	6000
Ba	27	1663	1174	71	–
Cr	106	477	928	195	2000
Sr	12	441	173	39	–
Sb	11	33	24	73	–
Ni	96	198	325	164	500
V	30	135	129	96	–
Se	11	57	154	270	–
As	47	30	52	173	–
Co	17	137	172	126	–
Mo	36	29	30	101	–
Cd	84	17	57	328	20
Hg	44	2.2	3.3	148	–

significant contents of heavy metals such as As, Cd, Cr, Cu, Ni, Pb and Zn. On this aspect, there was a very large amount of data sources available, totalling 105 publications, dating back to 1972, produced in 24 countries. However, many of these references were used solely for the total SSA heavy metal content data used to formulate Table 1, and as such, to avoid overly bloating the paper length, these publications were not included in the reference list.

Heavy metals are generally not present in harmful quantities in traditional construction materials and most standards do not consider these issues. As such, it is not straightforward to evaluate the status of SSA. Referring to landfilling, classification limits have been established for inert, non-hazardous and hazardous materials, though these are based on leached concentrations, rather than the material's total contents. Total contents, by themselves, do not accurately predict the leached contents. Only a fraction is available for leaching, depending on pH, complexing components, mineralogical reactions and rainfall infiltration rate (Lynn et al., 2016b).

The German Länderarbeitsgemeinschaft Abfall document (LAGA, 1994), on the valorisation of residues, gives total content limits prior to more extensive leaching testing. These guidance limits, presented in Table 1, provide some useful context for the SSA results. Mean contents of each of the elements in SSA are below these limits, though this should be interpreted cautiously as an initial check.

Coefficient of variations in Table 1 indicate high variability in the element contents of worldwide SSA samples. Contributing factors include differences in the waste and wastewater composition, processing, incineration conditions and in the method used to determine the element contents. Focusing on the changeability of SSA produced within a single country, where there would be some harmonisation of the above factors, and taking Germany as an example, variation was found to decrease somewhat for many elements including as Pb, Cd, Cr, Cu, Zn, Ni and Hg.

On the leaching of SSA, a number of different test procedures have been adopted, influenced by both the lack of harmonisation of the standards and the challenge in replicating the full range of in-use conditions in a laboratory setting. A brief description of the methods used and how many times each has been applied with SSA, is presented in Table 2.

The types of procedures included batch leaching, pH-dependent and column leaching tests. Batch leaching involves insertion of the test specimen into the leachant solution or adding the leachant to the specimen, followed by agitation and analysis of the final liquid. The TCLP, which follows this methodology, has been by far the most commonly adopted method with SSA (17 studies). An additional dynamic column test, in which the leachant passes through the SSA sample, provided information on the leaching kinetics. Acid neutralisation capacity tests

Table 2
Description of leaching tests adopted with SSA.

LEACHING TEST	DESCRIPTION	NO. OF SSA STUDIES
American TCLP (USEPA, 1992)	Particles < 9.5 mm, L/S 20, pH controlled at 5, agitated for 18 ± 2 h	18
European Batch Leaching (EN 12457-2, 2002; EN 12457-3, 2002)	Particles < 4 mm, L/S 2 & 8,or 10, Agitated for 6 and 18 h or 24 h	4
British Aggregate Leaching (BS EN 1744-3, 2002BS EN 1744-3, 2002)	Tank filled with mass of leachant 10 x dry mass of test sample. Stirred for 24 h.	1
Acid Neutralisation Capacity (ANC) Test	2.5 g sample, L/S 6 with HNO_3 increasing from 0 to 4 meq/g in different 11 tubes. Leaching vs pH behaviour.	2
Brazilian Solubilisation (NBR 10005, 1987)	Particles < 9 mm, 5 g sample, 96.5 ml of deionized water. For target pH, add 3.5 m L of 1 N HCL or acetic acid	1
Brazilian Leaching (NBR 10006, 1987)	Particles < 9.5 mm, 250 g sample, 1000 mL of deionized water added, 5 mins shaking.	1
Japanese Batch Leaching (JTL46)	Particles < 2 mm, L/S 10, 6 h contact time, 0.45 µm membrane filtration	2
European Bureau of Reference Sequential Extraction	Evaluates 4 fractions of metals: mobile, prone to reduction, prone to oxidation and immobile	1
Saikia et al. (2006) Dynamic Column Leaching Setup	1 g sample, 2 cm long column. Leachant volumes of 300 ml & 675 ml, with pHs of 1 & 6. Leaching time 3 mins.	1
Cheeseman et al. (2003) Batch Leaching Setup	Ground 5 g samples, 30 ml of nitric acid solution, mixed for 48 h	1