

Variability of Environmental Properties of MSWI Bottom Ash as Alternative Aggregates in Road Construction

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ABSTRACT

The use of industrial by-products as alternative resource of aggregates in road construction could improve the sustainability of this industrial activity. However the chemical composition of these materials, in reference to organic material and heavy metals contents, is very different from that of the natural aggregates.

In order to comply with the technical and environmental regulations, the characterisation of alternative aggregates is required if they have to be used in road construction.

The main objective of the work presented in this paper has been to study the seasonal variability of the Municipal Solid Waste Incinerator Bottom Ash environmental characteristics. Fresh MSWIBA generated for three months in a Spanish plant were sampled. Chemical and leaching properties with legislative relevance were analyzed. The main results are discussed.

INTRODUCTION

Authorities recognise the inherent tensions in reconciling the goal of sustainability with activities that initially present limited opportunities for sustainability. Infrastructure agencies are seeking opportunities to incorporate sustainability principles in projects [Moss 2009]. Water savings and reuse or recycling of waste are among key innovations achieved by infrastructure agencies, resulting in successful environmental management and sustainability.

In order for human industrial systems to be sustainable, they need to be modelled after natural systems, in which waste is all reusable. Industrial symbiosis is directly related to industrial ecology and is concerned with the flow of energy and materials through regional economies; collaboration opportunities offered by geographic proximity is important and allows the user to avoid the high costs and impacts of transportation [Chertow 2000].

Incorporating roadways into the industrial ecology of a region requires shifting it from an open loop system that utilizes virgin resources and then disposes of them at the end of their life cycle, to one that utilizes secondary materials for maintenance and reconstruction. In road construction and maintenance, some use of virgin resources may be always necessary, but the aim should be to minimize the amount required, and the impact from their use. Utilization of industrial by products (IBPs) helps to minimize impacts from mining and processing of virgin materials and disposal of IBPs. Additionally, as industry is generally located in urban regions, by-products are closely located to areas with higher roadway infrastructure needs and transportation of building materials can be minimized. There does not appear to be any data to indicate that the use of IBP in roadway structures reduces the longevity of the structures [Gardner and Carpenter, 2008]. Examples of IBPs include power station ashes, blastfurnace and steel slags, minestone, slate waste, china clay sand, municipal solid waste incinerator ashes, and foundry sands. Many of these materials could be used as a substitute for primary aggregate materials in various applications and have been successfully applied to low specification applications in road construction and bulk fill [Hill et al, 2001].

The use of these alternative aggregate materials as a substitute for primary materials results in multiple environmental benefits that conduce maintaining the integrity of ecosystems through efficient management of natural resources. Policy measures need to address as directly as possible the environmental externalities in extraction, transformation, production, use and disposal. Authorities have different tools like Life Cycle Assessment (LCA) that can be used to support the decision making in the evaluation of the environmental sustainability of secondary materials.

Several studies are available that utilized LCA for building materials. Olsson et al [2006] conducted an LCA on a roadway utilizing bottom ash from municipal solid waste incinerator. MSWIBA was utilized as a replacement for aggregate in the sub-base of the roadway. Birgisdottir [2005] conducted an extensive LCA of roadways incorporating the use of MSWIBA as alternative material. Gardner and Carpenter [2008] evaluated the incorporation of roadways into a regional industrial ecosystem and compared the combined uses of recycled materials (coal ash, foundry sand and slag) and virgin aggregate alone in the construction of roadways. A spatial analysis was conducted to simulate the use of materials for projects in the closest proximity to the source and to compare the life cycle impacts as well as the transportation costs.

However, the characterisation of the behaviour of alternative aggregates is required before evaluation of the environmental sustainability of the secondary materials in road construction.

In the early 1980s, it was found that the lack of environmental hygiene parameters represented an obstacle to the reuse of secondary raw materials on or in the soil. This mainly concerned stony building materials as building material, impact these building materials had on the soil and surface water, including soil below surface water. Authorities have to lay down environmental hygiene parameters for the use of primary and secondary building materials on or in the soil or in surface water. Consideration of the actual risks associated with use of building materials have to be advocated. The rules also have to provide clarity about the scope for the reuse of waste as building material or as soil and have to provide a balance between, the protection of human health and the maintenance of the soil functional characteristics and the provision of scope for social activities on the soil [Soil Quality Decree, 2007].

Over last years, research at the Spanish Centre of Studies and Public Works Experimentation (CEDEX) has investigated both mechanical and environmental behaviour of MSWIBA from Spanish plants. The project is supporting by Spanish Environmental Ministry. Research has focused on assessing the suitability of MSWIBA as alternative material for road construction. The temporal variability of the MSWIBA environmental characteristics is reported here.

METHODS

The aim of this paper is to evaluate the environmental features of the municipal solid waste incinerator bottom ash (MSWIBA) at a Spanish plant. The incineration plant burns municipal waste that has not been separated for recycling purposes, as well as the rejected material from packaging waste plants, composting plants, methanation plants, and construction and demolition waste treatment plants. The plant uses a roller grate combustion chamber for combustion. Bottom ash is removed using an ash remover after the ash is cooled with water.

The bottom ash is stored in the incineration plant for a week until it reaches the right humidity so it can be processed at the bottom ash treatment plant.

The bottom ash treatment plant eliminates the metal, ferrous and non-ferrous material. Material with a grain size of 0/35 mm is sorted into two fractions: very fine (grain size: 0/8 mm) and fine (grain size: 8/35 mm). The former is used as a mineral material by cement companies and the latter is used to cover non-hazardous waste at landfill.

The temporal variability of the environmental characteristics of both fractions was evaluated. The results on the fine group are discussed in this presentation.

Sampling Procedure

To draw up the sampling plan, the directives defined in EN 14899 standard [CEN, 2005] were used, along with the CEN Technical Reports [CEN/TR 15310, 2006a, 2006b, 2006c].

The sampling plan was executed in the summer months, which coincided with a waste-processing peak. Because the plant is located in a tourist area, the production of municipal solid waste was greater than normal. The results therefore reflect the composition of the mineral fraction of bottom ash under less favourable conditions.

Number of Samples and Frequency of Sampling

Of the two fractions, fine and very fine, **10 composite samples** were extracted from the bottom ash generated over a period of three months of plant operation, as indicated in the following time distribution:

“For one week (Monday to Friday), consecutive sampling was carried out and 5 samples were obtained. Each daily sample was a composite sample obtained over the 7-hour operating period at intervals of 45 minutes. Each of the 8 increments had an approximate mass of 1.5 kg of bottom ash and was loaded into a polyethylene bag. At the end of the day, the 12 kg bag was closed and the air was eliminated manually. The bags were labelled and stored in a closed waste drum. After the samples were obtained, they were sent to the laboratory for analysis.

“On the eleventh day after finishing the weekly sampling (without counting Saturdays or Sundays), fortnightly sampling began, which was carried out as described in the previous procedure. The other five 12 kg composite samples were obtained in this way. After each of these fortnightly samples was obtained, it was sent to the laboratory for analysis.”

Location of Sampling Point

A cross-sectional sample was taken by dipping a bucket into the discharge of the tripper conveyor (see Figure 1) and following this procedure:

“The sampler goes to the top part of the stockpile with a sampling bucket in his/her hand. The bucket is held so it forms a 90° angle under the centre of the flow from the tripper conveyor while ensuring that the complete cross-section is sampled. About 6 kg of bottom ash is extracted from the flow.

“Once this amount is obtained, the bucket is removed from the flow and the sampler gets down from the stockpile. The contents of the bucket is then dumped onto a piece of tarp and divided up manually so a 1.5 kg sub-sample can be extracted.

“At the same time the contents is divided up to obtain a sub-sample of about 250 ml for the incineration plant.

“The sub-sample is transferred to a bag. The outside of the bag is cleaned and the bag is labelled after the last dump takes place, as specified in the Sampling Plan.”

Procedure for Receiving and Preparing Samples

When the samples reached the laboratory, they were registered and subjected to the division process as described in EN 932-2 standard [CEN, 1999]. Figure 2 shows the general division method for environmental characterization of the samples.

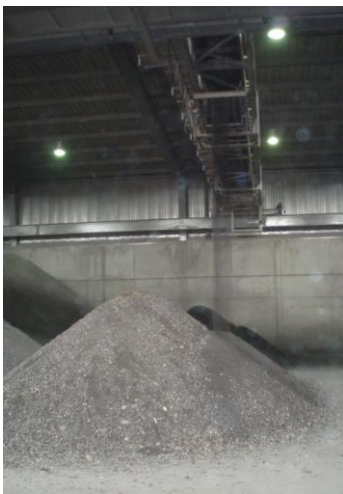


Fig. 1. Location of the sampling point.

The fractions were obtained as indicated in Figure 2 and broken down as follows:

Fraction I (A and B): Lab sample for studying leaching behaviour in accordance with EN 12457-4 standard [CEN, 2002].

Fraction II: Sample used to characterize the bottom ash components.

Fraction III (A and B): Sample divided up into sub-samples and then pulverized in a planetary mill with grinding bowl and tungsten carbide balls (FRITSCH Pulverisette 6). Aliquots were taken then from the pulverized sample for chemical characterization analysis.

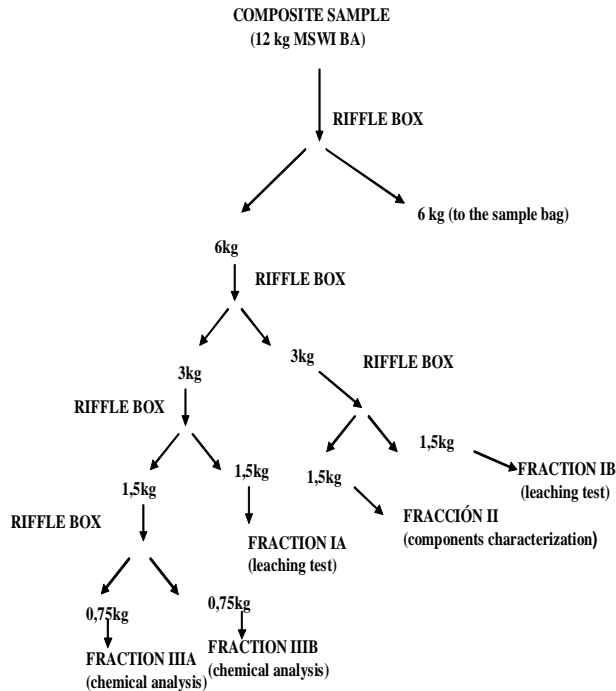


Fig. 2. Riffling sub-sampling procedure.

Environmental Characterization of the Fine Mineral Fraction of Bottom Ash

All of the 20 samples were analysed, bearing in mind the requirements of the Council Decision of 19 December 2002 for accepting waste at landfills [EC, 2003], given that this bottom ash is considered waste until it is actually used.

To obtain leachate, the procedure described in EN 12457, part 4 [CEN, 2002] was followed, given that the waste was granular. The concentrations of the following elements of environmental interest were measured in the leachate: arsenic, barium, cadmium, total chrome, copper, mercury, molybdenum, nickel, lead, antimony, selenium, chloride, fluoride and sulphate. The content of anions was determined by means of Ion Chromatography (IC). It was performed in a Methrom 850-Professional IC instrument with 858 IC Sample Processor system for automatic sampling. The composition of anionic eluent was Na_2CO_3 3.6 mM. Packing of the anionic column was composed of Polyvinyl alcohol with quaternary ammonium groups. The eluent flow was 0.8 ml/min and chemical suppression water system was used to increase experimental signals intensity. Heavy metal content, was determined by simultaneous Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) in a Varian Vistapro instrument.

The bottom ash was analysed to measure the content of total organic carbon (TOC) and extractable organohalogen compounds (EOX). EOX and TOC levels were found to be extraordinarily low, so it was not considered relevant to measure the presence of PCB, BTEX, mineral oil, dioxins or furans.

The procedure described in EN 13137 standard [CEN, 2001] was followed to measure the TOC content. The samples underwent combustion and an infrared detector was used for quantification. The samples were analysed by the Atomic Spectrometry Centre at the Universidad Complutense de Madrid (CEA/UCM) in a TOC-V CSH unit from Shimadzu with the SSM-5000A solid sampling module.

The EOX content was measured using a modified USEPA9023 procedure [USEPA, 1996]. About 16 g of the sample was placed in a Soxhlet extractor for 24 hours with a hexane/acetone extract (1:1). The chlorine content of the extract was measured by microcoulometry at the CEA/UCM facilities in an ECS 1200 system from a Thermo Fisher Scientific instrument.

All the composite samples were analysed in duplicate in accordance with the sample-division procedure indicated in Figure 2.

RESULTS AND DISCUSSION

After completing the sampling plan, 10 samples each of the fine and very fine mineral fractions were obtained, 5 of which were extracted on five consecutive days of operation of the bottom-ash treatment plant (which corresponded to the weekly production of bottom ash (Monday to Sunday) at the incinerator.

The other 5 samples were taken one day a week (Monday to Friday), distributed over a three-month period. One sample was taken every 15 days, with the first taken on Monday, the second on Tuesday, and so on. In this case, the aim was to analyse the environmental characteristics of the bottom ash obtained in the first and second weeks and determine if there were any statistically significant differences.

When recording the samples, **FMFS1** was used to refer to the results of the first week and **FMFS2** to those of the second week. In both cases, they were treated as a whole. The **STATGRAPHICS 5.1 Plus** program was used for statistical analysis of the results.

Evolution over time of TOC and EOX concentrations in the mineral fraction of bottom ash

Tables 1 and 2 show the statistical analysis of the results obtained for TOC, expressed as a percentage of dry matter, and EOX, as the amount of chlorine (mg) per kg of dry bottom ash.

Regarding the temporal variability of the concentration of the organic fraction of bottom ash, expressed by means of TOC and EOX, analysed in the mineral fraction of bottom ash, the following is worth noting:

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Table 1. Statistical analysis for the TOC content.

COMPONENT SAMPLE	STATISTICAL ANALYSIS	
TOC (%) FMFS1	Maximun value	0,59
	Mean*	0,50
	Variance	0,004
	Standard deviation*	0,066
	95%confidence interval for mean	±0,11
TOC (%) FMFS2	Maximun value	0,66
	Mean*	0,40
	Variance	0,04
	Standard deviation*	0,20
	95%confidence interval for mean	±0,10
* denotes no a statistically significant difference		

- ◆ No statistically significant differences were observed in the organic chemical concentration of the mineral fractions extracted in the first week, compared to those extracted in the second week, regardless of the parameter in question.
- ◆ For the parameters analysed on the samples of the fine mineral fraction, the differences between the mean values, medians and standard deviations of the samples analysed from the two weeks were not statistically significant. The distribution of values around the mean was similar in both weeks.
- ◆ In terms of the variability of the results, evaluated in terms of variance, there was no clear behavioural pattern that established the variability of the first week as being lower or higher than the second, given that the dispersion of results depended on the parameter analysed.
- ◆ The EOX content was used as a parameter to indicate different families of organic chemical compounds. Given that the levels in the samples of the fine mineral fraction were found to be below the limit value imposed by the Dutch authorities (0.8 mg Cl/kg), which is the most restrictive of all those consulted [Soil Quality Decree, 2007], it was considered irrelevant to proceed with EOX characterization.

Evolution over time of leachate composition

Table 3 shows the statistical analysis of the concentration of different elements of environmental interest that were present in the leachates obtained, in accordance with the procedure described in standard EN 12457-4 [CEN, 2002] of the samples taken during the three-month sampling period.

Table 2. Statistical analysis for the EOX content.

COMPONENT SAMPLE	STATISTICAL ANALYSIS	
EOX (mgCl/kg) FMFS1	Maximun value	0,29
	Mean*	0,14
	Variance	0,02
	Standard deviation*	0,13
	95%confidence interval for mean	±0,07
EOX(mgCl/kg) FMFS2	Maximun value	0,21
	Mean*	0,14
	Variance	0,005
	Standard deviation*	0,07
	95%confidence interval for mean	±0,07
* denotes no a statistically significant difference		

It should be pointed out that it was not possible to evaluate the temporal variability of the concentrations of arsenic, cadmium, mercury, nickel, antimony or selenium, given that they were found to be below the equipment's detection limit in both weeks. With regard to these elements, the real concentration was below the values indicated in mg/kg: arsenic (<0.162), cadmium (<0.01), mercury (<0.06), nickel (<0,06), antimony (<0.149) and selenium (<0.184).

Regarding the temporal variability of the chemical composition of the leachate obtained from the fine mineral fraction of bottom ash, the following is worth noting:

- ◆ For most of the elements analysed, no statistically significant differences were observed in the chemical composition of the leachate obtained from the samples of the fine mineral fraction extracted in the first week compared to the second.
- ◆ For elements such as molybdenum, barium and chrome, the differences between the mean values and medians of the samples analysed in both weeks were not statistically significant. However, the differences between the standard deviations were statistically significant. This could invalidate the statistical analysis carried out for the concentrations of these elements. The dispersion of values in one week was significantly lower than the other.
- ◆ The concentration of sulphate was found to be just the opposite: no statistically significant differences were observed in the standard deviations of the concentrations corresponding to the two weeks, but the differences between the mean values and medians were statistically significant. In these cases, the distributions of the samples were similar, but they were around values whose difference was statistically significant.
- ◆ No statistically significant differences were observed between the mean values and the standard deviations in the concentration of copper in the samples extracted in one week or the other, but the difference between medians was statistically significant. The values were distributed similarly around the mean value, but the difference in the centrality was statistically significant.

Table 3. Statistical analysis for leachate composition.

COMPONENT (mg/kg)		STATISTICAL ANALYSIS				
		Maximum value	Mean	Variance	Standard deviation	95% confidence interval for mean
Fluoride	FMFS1	14.4	8,8*	14.3	3.8*	€2.7
	FMFS2	12.3	7.3*	11.3	3.4*	
Sulphate	FMFS1	45.9	34.7*	89.8	9.5**	€5.1
	FMFS2	14.9	12.0*	10.1	3.2**	
Chloride	FMFS1	1546	1085*	82025	286*	€210
	FMFS2	1602	1312*	85147	292*	
Zinc	FMFS1	1.6	0.8*	0.4	0.6*	€0.7
	FMFS2	2.9	1.5*	1.5	1.2*	
Copper	FMFS1	1.63	1.12*	0.18	0.43*	€0.53
	FMFS2	3.73	2.13*	0.86	0.93*	
Lead	FMFS1	12.2	3.91*	23.8	4.9*	€4.49
	FMFS2	17.5	4.6*	52.3	7.2*	
Barium	FMFS1	8.9	4.1*	8.1	2.9**	€4.9
	FMFS2	27	12.4*	84.5	9.2**	
Chromium	FMFS1	0.23	0.07*	0.008	0.09**	€0.05
	FMFS2	0.07	0.04*	0.0005	0.02**	
Molybdenum	FMFS1	0.37	0.26*	0.008	0.09**	€0.05
	FMFS2	0.23	0.20*	0.0007	0.03**	
* denotes no a statistically significant difference						
** denotes a statistically significant difference						

- ◆ When the variability of the results was evaluated in terms of variance, there was no clear behavioural pattern that established the variability of the first week as being lower or higher than the second, given that the dispersion of results depended on the parameter analysed.
- ◆ When the pollutant loads observed in the leachates (Table 3) were compared to the limit values that must be satisfied for waste to be considered inert in accordance with the Council Decision of 19 December 2002 [EC, 2003], it was found that the concentration of chloride, lead and barium exceeded those limit values. Therefore, this material could not be classified as inert waste.

CONCLUSIONS

After analysing the results obtained in the characterization of the fine mineral fraction of the bottom ash, a number of conclusions were made regarding the different points considered in this study.

- The characteristics of municipal solid waste incinerator bottom ash depend on the combustion technology and conditions, and the kind of municipal solid waste being processed. However, the influence of these variables must be considered over the long term, given that the results obtained in three months of plant operation provide material whose environmental properties were stable over time.
- For most of the parameters analysed, no statistically significant differences were found between the mean values of one week or the other.
- The temporal homogeneity of the material's environmental characteristics should be taken into account when considering the use of the material.
- When defining final use of the fine mineral fraction of the bottom ash, special attention should be placed with regard to lead, barium and chloride, since the concentrations of both elements exceed the threshold values imposed for this fraction to be accepted at a landfill for inert waste.
- To this end, the material can be subjected to more in-depth treatments, i.e. reducing chloride levels in the leachate by including a washing stage in the bottom-ash processing line, or enlarging weathering stage in order to reduce lead values.

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