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A Study on the Classification of a Mirror Entry in the European List of Waste: Incineration Bottom Ash from Municipal Solid Waste

Beatriz S. Bandarra [1,*], Sónia Silva [2], Joana L. Pereira [3], Rui C. Martins [1] and Margarida J. Quina [1]

[1] CIEPQPF, Department of Chemical Engineering, University of Coimbra, Rua Sílvio Lima, Pólo II—Pinhal de Marrocos, 3030-790 Coimbra, Portugal
[2] Teramb-Empresa Municipal de Gestão e Valorização Ambiental da Ilha da Terceira, EM, Central de Tratamento e Valorização de Resíduos da Ilha Terceira, Canada do Cidral n°55, São Bento, 9700-135 Angra do Heroísmo, Portugal
[3] CESAM—Centre for Environmental and Marine Studies, Department of Biology, University of Aveiro, 3810-193 Aveiro, Portugal
* Correspondence: bsbandarra@eq.uc.pt

Abstract: In the European Union (EU), waste is classified according to the List of Waste (LoW) and relying on the assessment of 15 hazardous properties (HPs). Incineration bottom ash (IBA) from municipal solid waste is a mirror entry in the LoW, which leads to extremely different management options within the EU. IBA has shown potential for different applications under a circular economy perspective, contributing both to avoiding waste landfilling and the consumption of natural resources, such as sand and gravel. In this context, IBA evaluation and classification play a significant role in understanding which protection measures should be taken. This work aims to present an assessment of the 15 HPs and the consequent classification of IBA using data from the industry. Each HP is assessed based on knowledge of waste, chemical composition considering concentration limits for hazardous substances, and/or through tests (chemical, physical, or biological). According to the criteria followed, 5 out of 6 samples from a Portuguese Waste-to-Energy plant were considered non-hazardous. Only one sample was classified as hazardous due to the assignment of HP 10, which resulted from Pb content (0.36%) above the concentration limit established for this property (0.3%). Nonetheless, although most hazardous entries in the LoW have this classification based on HP 14, the results obtained for the samples of this work seem to indicate IBA from this study is non-ecotoxic. Moreover, it has been suggested that IBA could possibly achieve the End-of-Waste status according to the Waste Framework Directive. For such purpose, clear criteria should be laid down to safely use the material, and testing is a crucial step.

Keywords: waste classification; mirror entry; incineration bottom ash; hazardous properties

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1. Introduction

The total waste generation rate in the European Union (EU) is massive, amounting to about 2.62 Gt in 2018 for the EU-28 [1]. The classification of hazardousness of waste is vital for its sustainable management, favoring safe recycling and preventing the spreading of contaminants [2]. In the EU, the classification of waste is conducted according to the List of Waste (LoW; EU Decision 2014/955/EU) and the 15 hazardous properties defined in Commission Regulation (EU) No 1357/2014. In the last few years, there has been an attempt to link waste regulation to chemical regulation, and for such purpose Regulation (EC) No 1272/2008 on classification, labeling, and packaging of substances and mixtures (CLP) has been present in waste classification. The LoW contains absolute (hazardous and non-hazardous) entries and mirror entries. The latter refers to waste that may be classified as hazardous or non-hazardous, depending on the results of an assessment of the 15 hazardous properties (Commission Regulation (EU) No 1357/2014) and persistent organic pollutants (POP) content (Regulation (EU) 2019/1021). This assessment comprises physical, health, and environmental hazard properties. For such purpose, expert judgment, chemical composition with calculations, and experimental tests can be applied. From the range of hazardous properties defined, the assessment of HP 14 ("ecotoxic") is the most challenging one and the approach to it is still widely debated in the scientific community. Most hazardous entries in the List of Waste owe this classification to HP 14 [3,4]. Different approaches have been suggested by different EU Member States, but no definite and harmonized decision has been provided by the European Commission based on chemical and ecotoxicological tests for HP 14 assessment. Despite the method based on the chemical composition recommended in the EU Council Regulation 2017/997, different authors have recognized the advantages of biotests since they consider the effect of all substances, their interactions, and bioavailability, especially considering that wastes are complex matrixes with limitedly known composition [5–8]. Currently, the EU Member States follow different approaches regarding HP 14. While some of them carry out chemical evaluation using calculation formulas (following EU Council Regulation 2017/997), others perform biotests, yet testing batteries differ among countries [5].

Incineration bottom ash (IBA) from municipal solid waste (MSW), excluding the fraction of the ferrous material, is a mirror entry in the LoW (codes 19 01 11* and 19 01 12). Nonetheless, this waste has been generally classified as non-hazardous [5,9,10]. IBA corresponds to the incombustible material left following the incineration of MSW and it is a residue largely generated in Europe. In 2018, around 19 Mt of IBA were generated in the EU-28, accounting for nearly 20 wt.% of total incinerated MSW [11]. The "mirror" classification results in drastically different management approaches across EU Member States, e.g., some countries recycle the generated IBA in full, while some choose to landfill all of it [12,13]. Generally, IBA undergoes a treatment, and the selection depends on the future application. Natural weathering/aging/carbonation is the most usually employed method to obtain a more stable material by storing IBA outdoors exposed to ambient conditions for 6 to 20 weeks [11,14]. In this process, carbonation and oxidation reactions occur leading to the neoformation and hydration of the mineral phases and a pH reduction from 10–13 to 8–10 [12,14–16]. There are various potential applications for this material, mainly due to the wide particle size distribution and composition in glass, ceramics, stone, brick, concrete, ash, and melting products [17]. IBA has been mainly used as a secondary aggregate in the construction sector alternatively to natural materials such as gravel and sand [11,12]. In fact, the most widely employed and authorized application in the EU has been in road construction, namely, road beds [11,13,18,19]. In Italy, a case study was conducted which consisted of a road pavement full-scale test track containing stabilized IBA [20]. IBA was analyzed in mixtures of granular materials for foundations, cement-treated materials for subbases, and asphalt concretes for base and binder courses. From a technical point of view, the results indicated that IBA can be used as road material with the procedures currently used for road construction. Nonetheless, a careful definition of compaction procedures for bituminous layers should be considered for an optimization of volumetric and mechanical performance. Regarding the environmental analysis, the mixtures complied with the concentration limits for leaching behavior from the Italian regulation. Other applications for IBA at the EU level are related to noise barriers, embankments, cement and concrete products, foundations for buildings, and recovery in landfill sites [11–13,18,19,21,22]. For example, the BSB plant in Nocento (Italy) produces concrete containing treated IBA, according to EN 12620. Regarding the treatment process, aging occurs, ferrous and non-ferrous metals are separated, and bottom ash is washed. Treated IBA (30%) is mixed with other inerts (70%) producing a product known as Ecocal®, which is then used (10% to 40%) to produce concrete. This concrete is certified and is chiefly used to produce precast electrical substations and interlocking blocks for dry-stone walls. The Regional Environmental Protection Agency (ARPA) evaluates the leaching behavior of the material twice a year [23]. Furthermore, other construction-related products have been addressed, including ceramics, glass-ceramics, glass, bricks, and tiles resulting from the sintering of IBA at high temperatures (over 1000 °C) [9,24–30]. Monteiro et al. [9,29] studied the feasibility of using IBA in the production of glass. Full vitrification was reached through the melting of IBA at 1400 °C for 2 h. The produced glass showed good thermal stability and the hardness and fracture strength values were equivalent to commercially available glass. Good chemical stability against leaching in water and in alkaline solution was observed. IBA has also been studied in other fields of application, such as secondary raw material in soil stabilization in peatlands, as an adsorbent for the treatment of wastewaters and the purification of gases from landfills, and more recently as a precursor of geopolymers [14,30–34].

The application of IBA under a circular economy framework seems to be an opportunity for green building by using waste as raw materials for construction. Furthermore, it allows us to minimize landfilling and linked environmental impacts (extensive use of land space, emissions of greenhouse gases, e.g., CO_2 and CH_4, pollution of soil and groundwater), and contributes to saving natural resources, avoiding—in parallel—the environmental consequences related to their extraction and transportation (e.g., on water and biodiversity). Indeed, the proper management of waste and, in particular, safe valorization, contribute overall to the protection of environmental and human health. Thus, the application of this material is rather attractive. Considering the substantially different management and related legal regulation for IBA across the EU [12,13,35], its classification plays a key role for use in a wide variety of applications because the classification as non-hazardous facilitates the recovery of materials under a circular economy framework. To the best of our knowledge, there is no comprehensive study in the literature on the properties related to the hazardousness of this material covering industrial data. Thus, this work aims to fill this gap by presenting an assessment of the 15 hazardous properties of IBA with data from the industry and its consequent classification.

2. Materials and Methods

2.1. Materials

Most of the data presented in this study were provided by a Portuguese Waste-to-Energy (WtE) plant located on Terceira Island in the Azores, and refer to IBA samples after the removal of ferrous metals. This WtE plant has a nominal capacity of 40,000 t/year and uses moving grate technology. The plant analyzed 6 samples of IBA (hereafter A1–A6). Samples A1, A2, and A6 were sieved to a particle size under 20 mm, while the remaining were not sieved. Sampling took place in two different periods (with a 2-year gap): A1–A3 were sampled and analyzed in the first phase, and A4–A6 in the second phase. Sample A1 refers to IBA aged less than 3 months; A2 to a sample of 3-month weathered IBA; A3 to a sample of IBA aged more than 3 months; A4 represents a sample of IBA with more than 3-month weathering; A5 is a fresh sample of IBA (1 day); and A6 is a sample of IBA with more than 3-month weathering. The weathering process was carried out at the WtE plant after the sorting of ferrous metals by storing IBA outdoors exposed to ambient conditions in contact with air and rainwater.

2.2. Physical and Chemical Characterization

The physical and chemical parameters were analyzed according to the standards and methods presented in Table 1.

The parameters defined in Table 1 were determined in the solid matrix of IBA, except for pH which was determined in the leachate obtained from IBA with water. Leachates from IBA were also used in biotests. The pH and the electrical conductivity (EC) measured in these leachates can be found in the Supplementary Information (Table S1). Leachates were obtained following the European standard EN 12457-2. This leaching test involves a reduction in particle size to below 4 mm and agitation with distilled water at a liquid to solid (L/S) ratio of 10 L/kg for 24 h at room temperature (around 20 °C). The leachate was separated through filtration using a 0.45 μm membrane.

Table 1. Methods used for the physical and chemical characterization of the IBA samples.

	A1–A3		A4–A6	
Parameter	**Standard**	**Method**	**Standard**	**Method**
pH	EPA 9045D	Electrometry	EPA 9045D	Electrometry
Moisture	EN 14346:2007	Gravimetry	EN 14346:2007	Gravimetry
TOC [a]	-	-	EN 15936:2012 (Method B)	-
As, Be, Cd, Co, Cu, Cr, Mo, Ni, Pb, Sb, Se, Sn, Te, Tl, Zn	EN 13656, EPA 200.7	ICP-OES	EN 13656, EPA 200.7	ICP-OES
Hg	EN ISO 17852	Atomic fluorescence spectrometry	EN ISO 17852	Atomic fluorescence spectrometry
PAHs [b]	EN 15527:2008	Gas chromatography	EN 15527:2008	Gas chromatography
Reactive cyanides	EPA SW-846 Chapter 7	Colorimetry	EPA SW-846 Chapter 7	Colorimetry
Reactive sulfides	SM 4500-S2 D	Colorimetry	SM 4500-S2 D	Colorimetry

[a] Total organic carbon. [b] Polycyclic aromatic hydrocarbons.

2.3. Methodology for the Assessment of Hazardous Properties

Each hazardous property was assessed through an evaluation of chemical characterization according to Commission Regulation (EU) No 1357/2014 as well as Regulation (EC) No 1272/2008 (CLP), considering concentration limit values, and/or using experimental tests in some cases, according to the related regulation (detailed in Section 2.3.1). Furthermore, knowledge of the waste under study was also considered. In fact, the LoW indicates that the results of experimental tests should be prioritized over calculation formulas using chemical composition. Therefore, the methodologies followed for each hazardous property are summarized in Table 2.

Table 2. Summary of the methodologies followed for each hazardous property.

Hazardous Property	Methodology	Hazard Statement Code/Hazard Class and Category Codes	Cut-Off Values	Calculation Methods and Concentration Limit
HP 1—Explosive	Expert judgment	H200, H201, H202, H203, H204, H240, H241	-	-
HP 2—Oxidizing	Expert judgment	H270, H271, H272	-	-
HP 3—Flammable	Expert judgment; Flammability potential test (samples A1–A3)	H220, H221, H222, H223, H224, H225 H226, H228, H242, H250, H251, H252, H260, H261	-	-
HP 4—Irritant: skin irritation and eye damage	Commission Regulation (EU) No 1357/2014; Annex I of CLP (irritating if pH $\leq$ 2 or pH $\geq$ 11.5); Dermal irritation/corrosion test with albino rabbits (samples A1–A3)	H314 Skin corr. 1A, H315 Skin irrit. 2, H318 Eye dam. 1, H319 Eye irrit. 2	1%	Σ H314 1A $\geq$ 1% or Σ H318 $\geq$ 10% or Σ H315 $\geq$20% or Σ H 319 $\geq$ 20%
HP 5—Specific target organ toxicity (STOT)/aspiration toxicity	Commission Regulation (EU) No 1357/2014	H370 STOT SE 1, H371 STOT SE 2, H335 STOT SE 3, H372 STOT RE 1, H373 STOT RE 2, H304 Asp. Tox. 1	-	max(H370) $\geq$ 1% or max(H371) $\geq$ 10% or max(H335) $\geq$ 20% or max(H372) $\geq$ 1% or max(H373) $\geq$ 10% or max(H304) $\geq$ 10% or Σ H304 $\geq$ 10% and overall kinematic viscosity at 40 °C < 20.5 mm^2/s
HP 6—Acute toxicity	Dermal irritation/corrosion test (samples A1–A3); Acute oral toxicity test with albino rats (samples A1–A3); Commission Regulation (EU) No 1357/2014 (samples A4–A6)	H300 Acute Tox. 1 (Oral) H300 Ac. Tox. 2 (Oral) H301 Ac. Tox. 3 (Oral) H302 Ac. Tox. 4 (Oral) H310 Ac. Tox. 1 (Derm.) H310 Ac. Tox. 2 (Derm.) H311 Ac. Tox. 3 (Derm.) H312 Ac. Tox. 4 (Derm.) H330 Ac. Tox. 1 (Inhal.) H330 Ac. Tox. 2 (Inhal.) H331 Ac. Tox. 3 (Inhal.) H332 Ac. Tox. 4 (Inhal.)	Cat. 1, 2 or 3: 0.1% Cat. 4: 1%	Σ H300 1 $\geq$ 0.1% or Σ H300 2 $\geq$ 0.25% or Σ H301 $\geq$ 5% or Σ H302 $\geq$ 25% or Σ H310 1 $\geq$ 0.25% or Σ H310 2 $\geq$ 2.5% or Σ H311 $\geq$ 15% or Σ H312 $\geq$ 55% or Σ H330 1 $\geq$ 0.1% or Σ H330 2 $\geq$ 0.5% or Σ H331 $\geq$ 3.5% or Σ H332 $\geq$ 22.5%
HP 7—Carcinogenic	Commission Regulation (EU) No 1357/2014	H350 Carc. 1A and 1B H351 Carc. 2	-	max (H350) $\geq$ 0.1% or max (H351) $\geq$ 1%
HP 8—Corrosive	Commission Regulation (EU) No 1357/2014; Dermal irritation/corrosion test with albino rabbits (samples A1–A3)	H314 Skin Corr. 1A, 1B and 1C	1%	Σ H314 $\geq$ 5%
HP 9—Infectious	Expert judgment	-	-	-
HP 10—Toxic for reproduction	Commission Regulation (EU) No 1357/2014	H360 Repr. 1A and 1B H361 Repr. 2	-	max (H360) $\geq$ 0.3% or max (H361) $\geq$ 3%
HP 11—Mutagenic	Commission Regulation (EU) No 1357/2014	H340 Muta. 1A and 1B H341 Muta. 2	-	max (H340) $\geq$ 0.1% or max (H341) $\geq$ 1%
HP 12—Release of an acute toxic gas	Reactivity in contact with water test; Regulation (EC) No 1272/2008	EUH029, EUH031, EUH032	-	-

Table 2. *Cont.*

Hazardous Property	Methodology	Hazard Statement Code/Hazard Class and Category Codes	Cut-Off Values	Calculation Methods and Concentration Limit
HP 13—Sensitizing	Commission Regulation (EU) No 1357/2014	H317 Skin Sens. 1, H334 Resp. Sens. 1	-	max (H317) $\geq$ 10% or max (H334) $\geq$ 10%
HP 14—Ecotoxic	Acute toxicity test with *Daphnia magna*; Council Regulation (EU) 2017/997 (samples A4–A6)	H400 Aquatic Acute 1 H410 Aq. Chronic 1 H411 Aq. Chronic 2 H412 Aq. Chronic 3 H413 Aq. Chronic 4 H420 Ozone	H400, H410: 0.1% H411, H412, H413: 1%	Σ H400 $\geq$ 25% or Σ [(100 $\times$ H410) + (10 $\times$ H411) + (H412)] $\geq$ 25% or Σ (H410 + H411 + H412 + H413) $\geq$ 25% or max (H420) $\geq$ 0.1%
HP 15—Waste capable of exhibiting a hazardous property listed above not directly displayed by the original waste	Commission Regulation (EU) No 1357/2014	H205, EUH001, EUH019, EUH044 (may explode if heated, dried, or confined)	-	Presence of substances with H205, EUH001, EUH019, or EUH044

2.3.1. Experimental Tests

Different experimental tests were included in the evaluation of specific hazardous properties (Table 3). The flammability potential test to assess HP 3, the dermal irritation/corrosion test to assess HP 4 and HP 8, and the acute oral toxicity test to assess HP 6 were only performed with samples A1, A2, and A3. These tests were not considered necessary in the second period of testing (A4, A5, and A6) (See Section 3.2). Flammability potential was not a relevant property expected given the process of formation of IBA (combustion) and the knowledge on the waste. Therefore, this test was not carried out in the second period of testing. Testing with vertebrate organisms, namely, the dermal irritation/corrosion test with rabbits and the acute oral toxicity test with rats, was avoid given that these effects were not expected considering the process of formation of the material and the fact that the physical chemical analysis of IBA did not show the presence of hazardous substances with these properties in concentrations capable of causing these effects.

Table 3. Experimental tests used in the assessment of hazardous properties HP 3, HP 4, HP 6, HP 8, HP 12, and HP 14.

Test	Guideline	HP	Samples
Physical chemical tests			
Flammability potential	Regulation No 440/2008 method A. 10	HP 3	A1–A3
Reactivity in contact with water	Regulation No 440/2008 method A. 12	HP 12	A1–A6
Biotests			
Dermal irritation/corrosion with albino rabbit	OECD 404	HP 4 and HP 8	A1–A3
Acute oral toxicity with albino rat	OECD 423	HP 6	A1–A3
Acute (eco)toxicity with *Daphnia magna*	OECD 202	HP 14	A1–A6

In the flammability potential test, a preliminary screening was carried out following Regulation No 440/2008 method A. 10. Accordingly, the sample was shaped into an unbroken strip on a non-combustible, non-porous, and low-heat-conducting base plate. Then, a hot flame from a gas burner was placed in contact with one end of the strip and it was observed if the sample ignited and propagated combustion by burning with flame or smoldering.

To test the reactivity in contact with water according to Regulation No 440/2008 method A. 12, the sample was mixed with distilled water at 20 °C and the rate of evolution of gas was measured each hour for 7 h. The test was carried out in triplicate.

To assess dermal irritation/corrosion, three New Zealand albino rabbits weighing 2000 to 3000 g were used. The fur was previously shaved from the testing area of each animal without friction to ensure intact skin. A gauze patch with 0.5 mL of leachate was applied to each animal in an area of 6 m^2, for 4 h. The experimental room was at 20 °C (± 3 °C) with a photoperiod of 12 h light:12 h dark. The animals were fed a conventional laboratory diet. After the exposure period, residues were removed using distilled water. All animals were examined for signs of dermal effects (erythema and oedema) at 60 min, and then at 24, 48, and 72 h after patch removal. The dermal effect scores were evaluated according to the grading of skin reactions included in OECD guideline 404 (Table S2 in the Supplementary Information).

To evaluate the acute oral toxicity, a single dose of the leachate of 2000 mg/kg body weight was administered to three male and three female albino rats in two steps (three animals per step). This limit test is used when there is no information indicating that the test material is likely to be non-toxic. The test was conducted at 22 °C (±3 °C), with a photoperiod of 12 h light:12 h dark. The animals were fed a conventional laboratory diet.

The animals were observed individually during the first 30 min, periodically during the first 24 h, especially during the first 4 h, and daily thereafter for 14 days to record mortality.

Acute (eco)toxicity was assessed using the Daphtoxkit F^{TM} bioassay with the microcrustacean *Daphnia magna*. The test was carried out according to the standard operational procedure provided by the manufacturer [36]. The Daphtoxkit F^{TM} test was performed in compliance with OECD guideline 202. The toxicity was measured as the immobilization of *Daphnia magna* following exposure. For such purpose, a 30-well microplate was used, and each test vessel contained 10 mL of the test solution as well as 5 neonates aged less than 24 h. Four replicates were used and five concentrations of IBA leachate (1%, 2%, 4%, 8%, 16%) plus control were tested. Incubation occurred at 25 °C in dark conditions. After 48 h, the number of immobilized daphnids was counted.

3. Results and Discussion

3.1. Physical and Chemical Properties and Experimental Test Analysis

The results of the analysis of each sample were provided by the plant and are addressed in the following sections. Table 4 shows the results for the physical and chemical parameters analyzed for IBA, and Table 5 details the measurement of the organic components grouped as polycyclic aromatic hydrocarbons (PAHs) in the former table. The results of the chemical and physical characterization of samples A1 to A6 (Table 4) were in the same range as those found in other studies. As expected, organic compounds (PAHs) were found in rather low concentrations in all samples (Table 5). The concentration of chemical elements in mg/kg can be found in Supplementary Table S3.

Table 4. Results of the physical and chemical parameters analyzed for IBA samples (A1 to A6).

Parameters	A1 [a]	A2 [b]	A3 [c]	A4 [d]	A5 [e]	A6 [f]	Literature [g]
pH	9.7	9.2	9.0	9.8	11.6	10.4	Fresh: 10–13 [h]; Weathered: 8–10 [i]
Moisture (%)	14.2	16.5	15.8	24.4	27.4	14.0	7–30% [j]
As (%)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0012–0.019
Be (%)	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	0.00008–0.0006
Cd (%)	<0.0002	0.0003	0.00036	0.00042	0.0115	0.0003	0.00003–0.0146
Co (%)	<0.0004	0.0017	0.0008	0.0013	0.002	0.0008	0.0006–0.035
Cr (%)	0.0047	0.0049	0.004	0.0029	0.0027	0.0021	0.002–0.34
Cu (%)	0.2151	0.3267	0.0525	0.1289	0.0688	0.0019	0.019–2.5
Hg (%)	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	0.00002–0.000775
Mo (%)	<0.00004	<0.00004	<0.00004	0.0002	<0.0001	<0.0001	0.00025–0.028
Ni (%)	0.0034	0.0023	0.0028	0.0019	0.0018	0.004	0.0007–0.43
Pb (%)	0.0894	0.0433	0.0313	0.0334	0.059	0.3569	0.0075–1.4
Sb (%)	<0.001	<0.001	<0.001	<0.001	<0.001	0.0038	0.00076–0.0432
Se (%)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.000005–0.0010
Sn (%)	<0.0004	<0.0004	<0.0004	0.0054	0.0039	<0.0004	0.00002–0.096
Te (%)	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	0.0000208
Tl (%)	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	0.00000077–0.000023
Zn (%)	0.2454	0.2501	0.2213	0.2279	0.2932	0.141	0.0010–2.0000
PAHs (μg/kg)	<160	<160	<160	426	237	<160	0.0013–0.219
TOC (%)	-	-	-	2.40	0.22	0.26	<0.0001–0.0004

[a] Less than 3-month weathering (<20 mm); [b] 3-month weathered (<20 mm); [c] more than 3-month weathering; [d] more than 3-month weathering; [e] fresh IBA (1 day); [f] more than 3-month weathering (<20 mm); [g] [35,37–50]; [h] [16,51]; [i] [14,15]; [j] [19,21,52,53].

The chemical characterization (Table 4) revealed the presence of potentially toxic metals in the samples, mainly Zn, Cu, and Pb. Considering the "worst-case scenario" (worst impacting form) for the major elements determined, the chemical forms presented in Table 6 could be found in IBA.

Table 5. Concentrations of PAHs found in the IBA samples analyzed.

Parameter	Uncertainty	A1 [a]	A2 [b]	A3 [c]	A4 [d]	A5 [e]	A6 [f]
Acenaphthene (µg/kg)	±35	<10	<10	<10	10	10	<10
Acenaphthylene (µg/kg)	±35	<10	10	28	37	51	<10
Anthracene (µg/kg)	±35	<10	<10	<10	11	23	<10
Benzo-(g,h,i)-perylene (µg/kg)	±35	<10	<10	<10	<10	<10	<10
Benzo-a-anthracene (µg/kg)	±35	<10	<10	18	12	10	9
Benzo-a-pyrene (µg/kg)	±35	<10	<10	<10	<10	<10	<10
Benzo-b-fluoranthene (µg/kg)	±35	<10	<10	<10	10	21	<10
Benzo-k-fluoranthene (µg/kg)	±35	<10	<10	<10	<10	<10	<10
Chrysene (µg/kg)	±35	<10	<10	<10	8	<10	<10
Dibenzo-(a,h)-anthracene (µg/kg)	±35	<10	<10	<10	<10	<10	<10
Phenanthrene (µg/kg)	±35	15	18	35	47	80	10
Fluoranthene (µg/kg)	±35	<10	<10	13	21	44	<10
Fluorene (µg/kg)	±35	<10	<10	<10	12	31	<10
Indene-(1,2,3-c,d)-pyrene (µg/kg)	±35	<10	<10	<10	<10	<10	<10
Naphthalene (µg/kg)	±35	<10	<10	14	46	60	<10
Pyrene (µg/kg)	±35	<10	<10	14	25	84	11

[a] Less than 3-month weathering (<20 mm); [b] 3-month weathered (<20 mm); [c] more than 3-month weathering; [d] more than 3-month weathering; [e] fresh IBA (1 day); [f] more than 3-month weathering (<20 mm).

Table 6. Compounds that could be found in the samples in a "worst-case scenario", their concentrations, the hazard class/category code(s) and the hazard statement code(s), according to the list of harmonized classification and the labeling of hazardous substances (Annex VI of CLP), as well as the cut-off limits established in Regulation (EU) No 1357/2014.

Chemicals	A1 (%)	A2 (%)	A3 (%)	A4 (%)	A5 (%)	A6 (%)	HP	Hazard Class and Category Code(s)	Hazard Statement Code(s)	Cut-Off Limits
Zn (dust)	0.25	0.25	0.22	0.23	0.29	0.14	HP 3	Water-react. 1	H260	-
							HP 3	Pyr. Sol. 1	H250	-
							HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Zinc oxide (ZnO)	0.31	0.31	0.28	0.28	0.37	0.18	HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Zinc sulfate ($ZnSO_4$)	0.61	0.62	0.55	0.56	0.72	0.35	HP 6	Acute Tox. 4	H302	1%
							HP 4	Eye Dam. 1	H318	1%
							HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Zinc chloride ($ZnCl_2$)	0.51	0.52	0.46	0.48	0.61	0.29	HP 6	Acute Tox. 4	H302	1%
							HP 8	Skin Corr. 1B	H314	1%
							HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Cu	0.22	0.33	0.05	0.13	0.07	0.002	-	-	-	-
Copper(II) oxide (CuO)	0.27	0.41	0.07	0.16	0.09	0.002	HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Copper(I) oxide (Cu_2O)	0.48	0.74	0.12	0.29	0.16	0.004	HP 6	Acute Tox. 4	H332	1%
							HP 6	Acute Tox. 4	H302	1%
							HP 4	Eye Dam. 1	H318	1%
							HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%
Pb	0.09	0.04	0.03	0.03	0.06	0.36		-	-	-
Lead compounds with the exception of those specified elsewhere in Annex VI of CLP	>0.09	>0.04	>0.03	>0.03	>0.06	>0.36	HP 10	Repr. 1A	H360	-
							HP 6	Acute Tox. 4	H332	1%
							HP 6	Acute Tox. 4	H302	1%
							HP 5	STOT RE 2	H373	-
							HP 14	Aquatic Acute 1	H400	0.1%
							HP 14	Aquatic Chronic 1	H410	0.1%

Table 7 summarizes the results of the experimental physical, chemical, and biological tests performed with solid samples and leachates to assess some of the hazardous properties of IBA as displayed in Table 3. None of the samples from A1 to A3 ignited when in contact with a hot flame, and thus did not show flammability potential. Likewise, none of the samples from A1 to A3 showed significant gaseous evolution; thus, the tests did not show relevant reactivity when in contact with water.

Table 7. Results from the experimental tests used to assess specific hazardous properties.

Tests	Samples	Results	Conclusion
Physical chemical tests			
Flammability potential	A1–A3	No ignition	Negative
Reactivity in contact with water	A1–A6	Release of cyanides: <50 mg/kg Release of sulfides: <100 mg/kg	Negative
Biotests			
Dermal irritation/corrosion	A1–A3	Score = 0 (no erythema, no eschar, and no oedema)	Negative
Acute oral toxicity	A1–A3	LD_{50} > 2000 mg/kg (No mortality)	Negative
Acute (eco)toxicity	A1–A6	EC_{50} > 160,000 mg/L	Negative

The acute dermal irritation/corrosion assay for samples A1–A3 showed that no erythema, eschar, and oedema formation occurred after 1, 24, 48, and 72 h of exposure to IBA leachate for all replicates. Thus, a 0 score out of 4 was obtained for every replicate according to OECD guideline 404, which means that none of the animals displayed any skin damage throughout the test period. Therefore, IBA leachates showed a non-irritating/corrosive nature for dermal tissues.

Likewise, the administration of a single oral dose of 2000 mg/kg of IBA leachate induced neither mortality nor signs of acute toxicity in all replicates of A1–A3 during the test period of 14 days Therefore, the median lethal dose (LD_{50}) through oral administration was over 2000 mg/kg, and the samples presented low acute oral toxicity.

Finally, in the acute ecotoxicity assay with *Daphnia magna*, a rather significant variability was found in the results for the different samples, which highlights the complexity and variability of the matrix of this material. Nonetheless, the maximum effect observed in all replicates for all samples was 45% of immobilization for samples A3 and A4 (Table S4 in the Supplementary Information). For this reason, it was not possible to calculate the median effect concentration (EC_{50}), meaning the EC_{50} was higher than 16% (160,000 mg/L). Thus, the results indicate that IBA is not ecotoxic based on the limit of 100 mg/L set by Regulation (EC) No 1272/2008.

3.2. Evaluation of the Hazardous Properties and Classification of Incineration Bottom Ash

3.2.1. HP 1 "Explosive", HP 2 "Oxidizing", and HP 3 "Flammable"

HP 1 includes pyrotechnic waste, explosive organic peroxide waste, and explosive self-reactive waste. HP 2 refers to waste that causes or contributes to the combustion of other materials, generally in contact with oxygen. HP 3 includes waste that ignites in contact with air, readily combustible waste or waste that may generate fire through friction, waste that emits flammable gases in dangerous amounts in contact with water, and other flammable waste such as flammable aerosols, flammable self-heating waste, flammable organic peroxides, and flammable self-reactive waste. IBA is mainly inorganic, composed chiefly of incombustible materials since it is formed in a combustion process at a high temperature (above 1000 °C). Thus, according to Commission Regulation (EU) No 1357/2014 and Article 14 of Regulation (EC) No 1272/2008, hazardous properties HP 1, HP 2, and HP 3 were not assigned to any of the samples since these properties were not expected based on the information available on origin, characteristics, and waste composition. Nonetheless, considering that zinc dust is classified as *Pyrophoric Solid Category 1* and *Water-reactive Category 1*, the samples were assessed according to physical test methods. The flammability and reactivity tests confirmed that the waste presented neither flammability potential nor reactivity in contact with water (Table 7).

3.2.2. HP 4 "Irritant: Skin Irritation and Eye Damage" and HP 8 "Corrosive"

Considering the generation process (combustion) of IBA, hazardous properties HP 4 and HP 8 were not attributed to any of the IBA samples since the concentration of none of the substances classified as irritant or corrosive was expected to be above the limits established for waste according to Commission Regulation (EU) No 1357/2014: 1% for the sum of concentrations of substances classified as *Skin Corrosion 1A*; 5% for the sum of concentrations of substances classified as *Skin Corrosion 1A, 1B* or *1C*; 10% for the sum of the concentrations of all substances classified as *Eye Damage 1*; 20% for the sum of concentrations of substances classified as *Skin Irritant 2* and *Eye Irritant 2*. Considering the "worst-case scenario" for Zn, some of the compounds that could be found were $ZnSO_4$ classified with *Eye Damage 1* and $ZnCl_2$ classified with *Skin Corrosion 1B*. Regarding the "worst-case scenario" for Cu, one could find Cu_2O classified with serious *Eye Damage Category 1*. However, none of these compounds exceeded the limit values established for HP 4 and HP 8. In fact, they were below the cut-off limit for individual substances. In addition, according to the Commission notice on technical guidance on the classification of waste (2018/C 124/01), the pH value should be considered in this evaluation when waste is not classified as 'Irritant' due to its known substances and when some of them are still unknown. Accordingly, a waste is considered corrosive if it presents pH $\leq$ 2 or pH $\geq$ 11.5. Considering the pH values obtained, samples were not considered skin corrosive (*Skin Corrosive Category 1*) according to Annex I of Regulation No 1272/2008. Similarly, negative results were obtained in the skin irritation/corrosion test carried out to evaluate the possible combined effect of substances in the first period of tests (samples A1–A3) (Tables 7 and 8), and thus dermal or eye irritant effects are not expected due to exposure to IBA.

3.2.3. HP 5 "Specific Target Organ Toxicity (STOT)/Aspiration Toxicity"

The waste was also not classified with HP 5 based on the chemical composition of the samples, since the strictest concentration limits established by Regulation (EU) No 1357/2014 of 1% were not equaled or surpassed by substances classified as either *STOT SE 1* or *STOT RE 1*. A generic entry for lead compounds not specified elsewhere in Annex VI of CLP is classified with organ-specific toxicity *STOT RE Category 2* (H373) with a concentration limit of 10%, but the maximum concentration measured for Pb was 0.36% (A6). Furthermore, considering the information available on the waste and the analysis carried out, the HP 5 property due to aspiration hazards does not apply.

3.2.4. HP 6 "Acute Toxicity"

HP 6 was evaluated through the acute oral toxicity test with albino rats carried out according to Regulation (EC) 440/2008 for the first batch of samples (A1–A3), and a negative result for this property was obtained. For samples A4–A6, this test was not carried out since high concentrations of substances that ascribe acute toxicity were excluded given the information on the production process and the results from the physical and chemical characterization. In fact, using the "worst-case scenario", one could find $ZnSO_4$, zinc chloride, copper (I) oxide, and lead compounds not specified elsewhere in Annex VI CLP, all classified with *Acute Toxicity Category 4*. Nonetheless, the cut-off value of 1% and the concentration limit of 25% for this hazard class and category established by Regulation No 1357/2014 were not exceeded. Thus, no further biotests were performed, taking into account that enough information was available in this case to avoid it.

3.2.5. HP 7 "Carcinogenic"

Based on the chemical characterization (Tables 4 and 5), none of the samples displayed substances classified as *Carcinogenic Category 1A* or *1B*, such as some PAHs (e.g., benzo-a-anthracene, benzo-a-pyrene, benzo-k-fluoranthene, chrysene) and other elements (e.g., Be, As), in concentrations above the limit of 0.1% established in Regulation (EU) No 1357/2014. Likewise, no substances classified as *Carcinogenic Category 2*, such as Ni or naphthalene, were found in concentrations above the limit of 1%. Thus, none of the samples were classified with HP 7.

3.2.6. HP 9 "Infectious"

The property HP 9 is mainly linked to waste resulting from the provision of healthcare to humans or animals and other sources that produce bio sanitary waste containing viable microorganisms or their toxins that may cause disease in humans or other living organisms. Furthermore, IBA was formed at temperatures above 1000 °C, which also works as a sanitary treatment for MSW. Thus, HP 9 was not assigned to any of the IBA samples since the likelihood of the presence of infectious substances was very low.

3.2.7. HP 10 "Toxic for Reproduction"

Regarding property HP 10, the chemical characterization of samples A1–A5 did not show the presence of any substance classified as toxic for reproduction (*Repr. 1A or 1B*) at concentrations above the concentration limit of 0.3% established in Regulation (EU) No 1357/2014. However, sample A6 showed the potential presence of substances (Pb compounds) classified as *Toxic for Reproduction Category 1A* with a concentration above the limit since the concentration of lead was 0.36%. Thus, HP 10 was assigned to sample A6. Thus, this property must be under surveillance for IBA.

3.2.8. HP 11 "Mutagenic"

HP 11 "Mutagenic" refers to waste that may cause a mutation, i.e., a permanent alteration in the amount or structure of the genetic material in a cell. Based on the production process and considering the results from the chemical analysis, none of the samples were expected to show substances classified as mutagenic at concentrations above the limits established in Regulation (EU) No 1357/2014, i.e., 0.1% for *Mutagenic 1A* and *1B* (e.g., benzo [a] pyrene) or 1% for *Mutagenic 2* (e.g., chrysene). Thus, IBA was not classified with HP 11.

3.2.9. HP 12 "Release of an Acute Toxic Gas"

According to method A. 12. of Regulation 440/2008, HP 12 was assessed for samples A1–A3 and a negative result was obtained (Table 7). However, this method aims at setting a limit on the release of flammable gases through the reaction with water or damp air that is not directly applicable to toxic gases released by waste. Hence, the harmonized classification for each of the gases addressed was considered. According to Annex VI of CLP, hydrogen sulfide is classified with *Acute Inhalation Toxicity Category 2* with a limit value of 0.5%. The experimental tests with IBA did not show significant gaseous sulfide evolution (<0.01%). Depending on hydrocyanic acid gas, the classification could be *Acute Inhalation Toxicity Category 1 or 2*, and the most restrictive limit is 0.1%. A lower concentration (<0.005%) was released in the tests with IBA. Thus, based on this and considering that substances classified as EUH029, EUH031, or EUH032 are not foreseeable, IBA was not classified with HP 12. According to expertise and previous results, HP 12 was not assigned to samples A4–A6.

3.2.10. HP 13 "Sensitizing"

HP 13 "Sensitizing" indicates waste that contains one or more substances that induce sensitizing effects on the skin or the respiratory organs. HP 13 was not assigned to any of the IBA samples since the presence of substances classified as *Respiratory or Dermal Sensitizers* H317 (e.g., benzo [a]pyrene, Be, Co, Ni) or H334 (e.g., Co) in concentrations equal to or above the 10% limit established in Regulation (EU) No 1357/2014 was not expected, considering the information on waste characteristics and the chemical analysis.

3.2.11. HP 14 "Ecotoxic"

Council Regulation (EU) 2017/997 was followed when evaluating the ecotoxicity of IBA (samples A4–A6) from a chemical point of view. According to Annex VI of CLP, Zn dust is classified into *Aquatic Acute Toxicity Category 1* and *Aquatic Chronic Toxicity Category 1*. Considering the "worst-case scenario", some of the compounds that could be found are ZnO, $ZnSO_4$ or zinc chloride, which are all classified as *Aquatic Acute Toxicity 1* and *Aquatic Chronic Toxicity 1*. For copper, one could find CuO and copper (I) oxide, both also classified with *Aquatic Acute Toxicity 1* and *Aquatic Chronic Toxicity 1*. Lead compounds not specified elsewhere in Annex VI of CLP are also classified as *Aquatic Acute Toxicity Category 1* and *Aquatic Chronic Toxicity Category 1*. The limit value of 25% for the sum of all the substances present in IBA classified as toxic to the aquatic environment was exceeded, according to the calculation formulas from Council Regulation (EU) 2017/997. Nevertheless, Commission Decision 2014/955/UE indicates that when a hazardous property has been assessed via a test and using the concentrations of hazardous substances, the results of the test shall prevail. The possible combined effect of the substances was verified through an ecotoxicity test with *Daphnia magna*. An EC_{50} value > 160,000 mg/L was obtained via the test. Regulation (EC) 1272/2008 establishes that EC_{50} < 100 mg/L demonstrates ecotoxicity. Thus, the results of the test indicate low acute toxicity for the environment, and the waste was not classified with HP 14 for any of the samples.

3.2.12. HP 15 "Waste Capable of Exhibiting a Hazardous Property Listed above Not Directly Displayed by the Original Waste"

Finally, waste can be classified as hazardous according to HP 15 when it contains one or more substances assigned to one of the hazard statements or supplemental hazards H205, EUH001, EUH019, or EUH044, except if the waste is in such a form that it will in no case display explosive or potentially explosive properties. Therefore, considering the chemical composition and the production process of IBA, none of the samples were classified as hazardous according to HP 15.

3.2.13. Classification of Incineration Bottom Ash Samples

The assignments of each hazardous property to each sample are summarized in Table 8, which also presents the classification allocated to six samples of IBA.

Table 8. Summary of the results of the hazardous properties for the IBA samples studied and corresponding classifications.

Hazardous Property	A1	A2	A3	A4	A5	A6
HP 1—Explosive	No	No	No	No	No	No
HP 2—Oxidizing	No	No	No	No	No	No
HP 3—Flammable	No	No	No	No	No	No
HP 4—Irritant: skin irritation and eye damage	No	No	No	No	No	No
HP 5—Specific target organ toxicity (STOT)/ aspiration toxicity	No	No	No	No	No	No
HP 6—Acute toxicity	No	No	No	No	No	No
HP 7—Carcinogenic	No	No	No	No	No	No
HP 8—Corrosive	No	No	No	No	No	No
HP 9—Infectious	No	No	No	No	No	No
HP 10—Toxic for reproduction	No	No	No	No	No	Yes
HP 11—Mutagenic	No	No	No	No	No	No
HP 12—Release of an acute toxic gas	No	No	No	No	No	No
HP 13—Sensitizing	No	No	No	No	No	No
HP 14—Ecotoxic	No	No	No	No	No	No
HP 15—Waste capable of exhibiting a hazardous property listed above not directly displayed by the original waste	No	No	No	No	No	No
Classification	NH [a]	NH	NH	NH	NH	H [b]

[a] Non-hazardous; [b] hazardous.

According to the criteria established in Annex III of Commission Regulation (EU) No 1357/2014, in Regulation (CE) 1272/2008 (CLP), or in Regulation (EC) 440/2008, it was concluded that five out of six samples should be considered as non-hazardous. However, sample A6 presented the hazardous property HP 10—toxic for reproduction. This was because of Pb. Thus, the classification as mirror entry in the LoW is justified, and precaution must be used before applying IBA in the environment. In fact, when considering a circular economy approach, testing and proper protection measures are crucial to ensure the safe application of the materials.

3.3. Prospects for Classification

Klymko et al. [40] analyzed a large dataset of elemental composition covering IBA from different EU member states and used a tiered approach for hazard classification (Figure 1). In Tier 1, a general screening was carried out by assessing the relevance of the 15 hazardous properties based on knowledge of the gross characteristics and the composition of IBA. In Tier 2, the chemical composition was evaluated, assuming a worst-case assessment. Finally, Tier 3 consisted of expert judgment, information from geochemical modelling, information on leaching properties, and data from the literature. From this approach, all the hazardous properties were excluded, except HP 10 and HP 14, which were found to potentially classify IBA as hazardous. In Tier 3, it was concluded that IBA samples with total lead content below 3500 mg/kg do not display HP 10, i.e., are not toxic for reproduction. This seems to be the case in Iberian countries, for example, [54]. Some samples from the dataset were above that limit; nonetheless, the authors could not identify these critical individual samples and, consequently, the possible causes for the high Pb content, due to the absence of the original data. The samples from the present paper were in line with this conclusion. Thus, some precaution should be used in case Pb is suspected to be present in high concentrations. Furthermore, careful attention should be provided to the presence of MSW containing Pb in the input feed for incineration (e.g., batteries). By detecting specific waste contributing to the contamination of IBA with potentially toxic elements, WtE plants may divert it from the process. In addition, different treatment and protection measures have been used considering various applications [25,31,55]. For example, the thermal treatment applied to IBA (700–1500 °C) to produce ceramic materials for construction applications reduces the mobility of potentially toxic metals. Indeed, vitrification can not only separate volatile metals such as Pb, Zn, Cd, and Hg, but also encapsulate Ni, Cr, and Cu into the new glassy and crystalline phases formed in the process [25,55]. Regarding the application of IBA as a loose construction aggregate, the leaching of potentially toxic metals can be reduced, for example, by applying carbonation or size separation. Weathering and accelerated carbonation have been broadly studied and applied to enhance the properties of waste. This method is based on the carbonation of silicate minerals containing alkaline oxides, resulting in more stable phases that can encapsulate some potentially toxic metals (e.g., Pb and Zn) and, consequently, reduce their mobility. It should be noted that the total elemental content of a material is not equal to the (bio)available elemental content. Furthermore, wet or semi-dry techniques are generally used for size separation and metal removal. In fact, the chemical composition of IBA may depend on the particle size, and potentially toxic metals (e.g., Pb) are generally in higher concentrations in smaller IBA particles [17]. Wet techniques allow the dissolution of the adsorbed impurities. Moreover, a washing process using a liquid leachant (e.g., water, acid) can be useful to reduce metal content, and the most relevant factors are firstly the control of pH and then the liquid-to-solid ratio. As previously mentioned, the treatment of IBA in the BSB plant in Italy involves washing to promote the leaching of heavy metals [23].

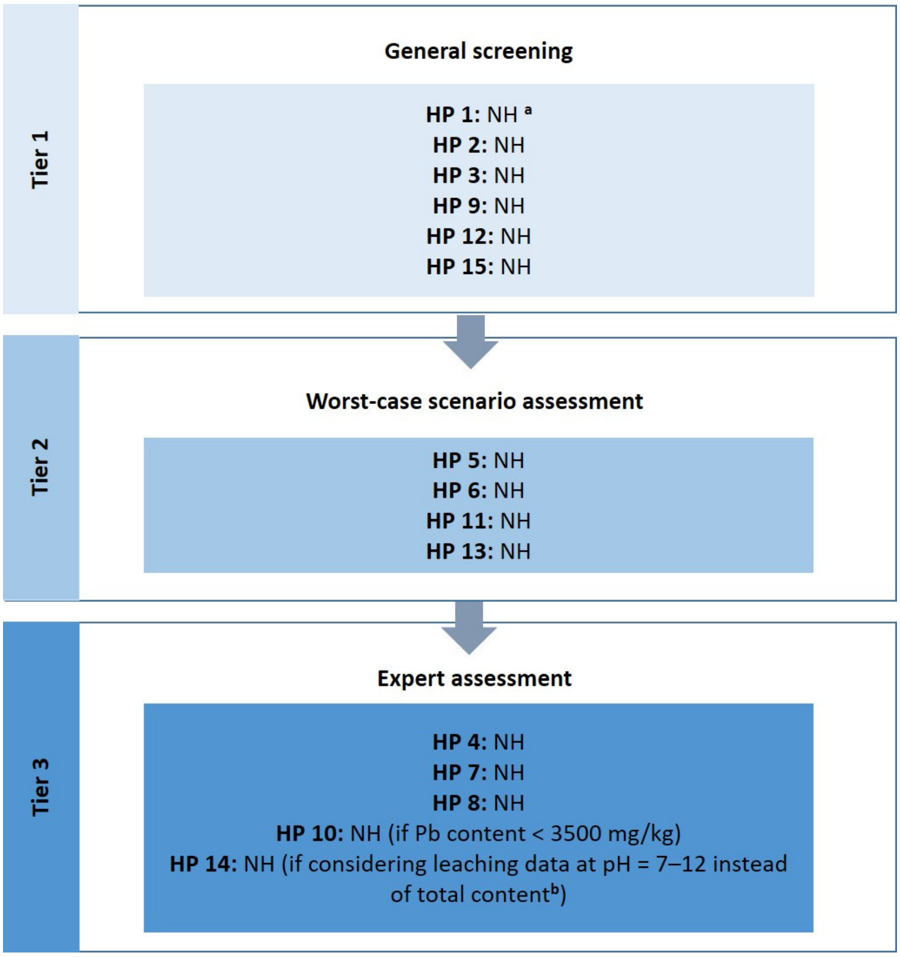

Figure 1. Hazardous properties assessed in the tiered approach used by [40] and corresponding conclusion. [a] NH: non-hazardous; [b] based on the summation method according to EU Council Regulation 2017/997. Adapted from [40].

On the other hand, the assessment of HP 14 has shown to be more complex and is still widely discussed. In Tier 3, Klymko et al. [40] found that when the total elemental concentration is used in the summation method recommended in EU Council Regulation 2017/997 for HP 14 assessment, IBA may be considered hazardous. However, this approach may not be a real hazard assessment of the waste, but rather indicate the worst outcome possible for the ecotoxicity of the waste. Klymko et al. [40] suggested replacing the total content with leaching data released at pH = 7–12 in the summation formulas. This approach led to a non-hazardous classification of IBA according to HP 14. Furthermore, other authors have recommended approaches including leaching data together with geochemical speciation modelling to determine the relevant chemical species for ecotoxicity, particularly for IBA [56–59]. Additionally, several authors have recognized the value of biotests for ecotoxicological assessment. There are no regulations in this regard at the EU level, but different studies have been carried out, involving diverse test methods, substrates, and approaches to obtain extracts from waste [6,8]. Particularly, some authors have studied the ecotoxicological effects of IBA [8,60–62]. In the EU, some Member States perform different biotests for HP 14 assessment, but different ecotoxicological test batteries and threshold values are used due to the inexistence of guidelines for this purpose [5]. It should be noted that HP 14 is actually the hazardous property that most frequently classifies waste as hazardous and this is reflected in the hazardous entries in the LoW [3,4,6,59]. Therefore, the establishment of a consensual and realistic methodology for HP 14 assessment is extremely relevant for the classification of the mirror entries in the LoW. The biotest performed for the samples of this work (immobilization with *Daphnia magna*) is one of the most broadly used and recommended ecotoxicological tests for HP 14 assessment. In fact, it is a standardized test performed in some of the EU members Member States. Thus, the results obtained for the samples of this study seem encouraging for the classification of IBA as a non-ecotoxic waste. Nonetheless, further ecotoxicological studies with different samples of IBA are necessary, using a systematic ecotoxicological test battery comprising organisms of different functional levels from both aquatic and terrestrial compartments, as well as the analysis of distinct exposure scenarios (e.g., short and long term) and types of effects (e.g., physiological and behavioral), such as it has been proposed in the literature for a more complete and reliable evaluation of the ecotoxicity of waste [6,62]. In the EU, France and Germany are currently following this approach. Studies analyzing the responses to IBA in this context would be relevant for HP 14 assessment. Moreover, threshold values of 10% for EC_{50} have frequently been proposed for biotests [3,6], which is significantly higher than the limit value considered for the samples of this work. However, the conclusion would be identical if considering this threshold value. Furthermore, a mutagenicity test should be performed (e.g., the Ames test or the umu-test with *Salmonella typhimurium*) for HP 14 or HP 11 assessment to cover interactions between individual compounds and the effects of unknown components, although they are not foreseen in the technical guidelines and mandatory procedures that follow currently enforced regulation.

Additionally, it has been suggested that IBA could possibly achieve End-of-Waste status in line with the Waste Framework Directive for increasing the valorization of the material [13]. This status can be obtained at the EU level, nationally, or case-to-case within the Member States. However, this status has not been obtained in any of these cases inside the EU-27. The discussions at the EU level have been centered on the way the conditions established in the Waste Framework Directive should be fulfilled, specifically those referring to safeguarding human health and the environment. Thus, it might be difficult to achieve this status at the EU level. In Europe, a company in Scotland [63] has achieved this status on a case-to-case basis with the Scottish Environment Protection Agency (SEPA), which has published a position statement for the use of IBA [64]. The achievement of an End-of-Waste status should be preceded by the establishment of clear criteria and their compliance. Indeed, a proper evaluation of the material is vital to assure the safety of using IBA in a considered application.

4. Conclusions

From the assessment of each of the 15 hazardous properties of waste, five out of six samples of IBA were classified as non-hazardous since none of them displayed any of the hazardous properties. Sample A6 was the only one assigned with a hazardous property (HP 10) and, consequently, considered hazardous. Thus, the classification as a mirror entry in the European List of Waste seems justified. Similar to other studies, Pb content was the main contributor to potential hazardousness and precaution must be used regarding this metal. Nonetheless, it should be noted that promising results were obtained regarding HP 14, since all samples of IBA were considered non-ecotoxic. HP 14 is responsible for most hazardous classifications in the List of Waste. Thus, it seems that if IBA is deemed non-ecotoxic through a proper assessment and Pb content is below the limit value, then IBA may be considered non-hazardous. Special attention should be given to the presence of materials composed of lead in the waste input stream of incinerators, for example, batteries. In case the major sources of potentially hazardous metals can be identified, the WtE plants may divert these materials from the process in order to minimize the contamination of IBA. The End-of-Waste status (following the Waste Framework Directive) has been discussed in the EU Member States, aiming to increase the valorization of IBA in a circular economy framework. For such purpose, clear requirements should be established and testing plays an important role in guaranteeing the safe utilization of the material in different applications. In this context, it is worth mentioning that the risks linked to waste are not necessarily related to the risks of its application as a product, since treatments and protection measures are employed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141610352/s1, Table S1: Results obtained from leachate preparation, regarding particle size as well as pH and EC of the leachates; Table S2: Grading of skin reactions (erythema and eschar formation, and oedema formation) according to OECD guideline 404; Table S3: Results of the physical and chemical parameters analyzed for IBA samples (A1 to A6). Concentration of chemical elements expressed in mg/kg; Table S4: Immobilization of *Daphnia magna* (mean ± standard deviation) after 48 h exposure to different concentrations of IBA leachates.

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