Spain 02/2019 to 04/2020

Inorganic binder system to minimize emissions, improve indoor air quality, purify and reuse of contaminated foundry sand

LIFE17 ENV/FI/173 “Green Foundry LIFE”

Action B4.1 Cleaning by composting method

Deliverable DeB4.1B composting method results inorganic, organic binder system waste foundry sands in Spain

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Content

1. Introduction

This report shows the results obtained from the analysis of six composting heaps which formed the Spanish part of the Green Foundry project. This work was subcontracted out to TECNALIA by ARABA, S.A. and took place between January 2019 to March 2020. The composition of the heaps was as follows: from February to June 2019, two heaps with inorganic waste sand (from silicate moulding process) and two heaps with organic waste sand (from washed green moulding sand*). From August 2019 to March 2020 two heaps with ecologic waste sand from cores from aluminum foundry. Note, in Spain no foundry uses ecologic sand for moulding.

*This sand was the last sand washed and supplied by Ecofond, a collaborator in the project, before they closed down as a business in 2018.

2. Cleaning of surplus foundry sand by composting process

The purpose was to evaluate the viability of cleaning various types of spent foundry sand (sand no longer fit for purpose/SFS) through the composting method, i.e. biodegradation.

Both waste sand grains and sand dust were used, and mixed in the following proportion; 75% grains to 25% dust.

Separate composting heaps (sand plus organic matter) were formed with:

- unwashed inorganic waste sand (from silicate moulding process), 2 heaps
- washed organic waste sand (from green moulding sand process), 2 heaps
- ecologic inorganic waste sand (from cores formed with ecological binder, Inotec, from moulding green sand process for aluminum foundry), 2 heaps

Each type of sand were mixed with organic material typically used in compost production (forest waste, wood chips from waste pallets, and in this particular case, horse manure) in specific proportions. The proportions of sand to organic matter were developed by Meehanite and Tecnalia according to LIFE-Foundry Sand project (LIFE13 ENV/FI/285 “Foundrysand”).

Figure 1: General view of pilot site.

The composting process was carried out by Tecnalia, in conjunction with a compost plant named Komposgune, in Ormaiztegui, in The Basque Country, northern Spain where is the location of composting tests. Komposgune was there all permits, the test heaps were managed in accordance with pertinent legislation; Law 22/2011 and Law 5/2013 on waste and contaminated soil and Government Instruction AAA/661/2013 on waste landfill.

Chemical and biological analyses were carried out by Tecnalia and Tecnalabaqua (ENAC nº1116 LE2210) and Phytotoxicity tests were by Neiker.

The weight of each test heap was approx. 20 tons, giving a total weight for the three pairs of heaps of 120 tons. This heap size was found to be the most manageable given that aeration forms an important part of engineering the composting process. A standard forklift was able to perform this process.

Figure 2: Horse manure, forest waste, branches and waste pallets constituted the organic material

Figure 3: Launch day of Green Foundry project.

Figure 4: Composting tests in Spain, 4 heaps, from initial February 2019 to June 2019.

Figure 5: Composting tests in Spain, 2 heaps, from initial August 2019 to March 2019.

In order to monitor the progress of the composting process it is necessary to measure temperature. To this end, three Wi-Fi connected thermocouples (Testo 175T3) were inserted in each heap (figure 6). This monitoring took place from March to June 2019 and from October 2019 to March 2020. (Note: the preparation of the heaps a couple of months before). In addition, manual thermometers were inserted in the heaps during sampling (every 15 days) as a second check.

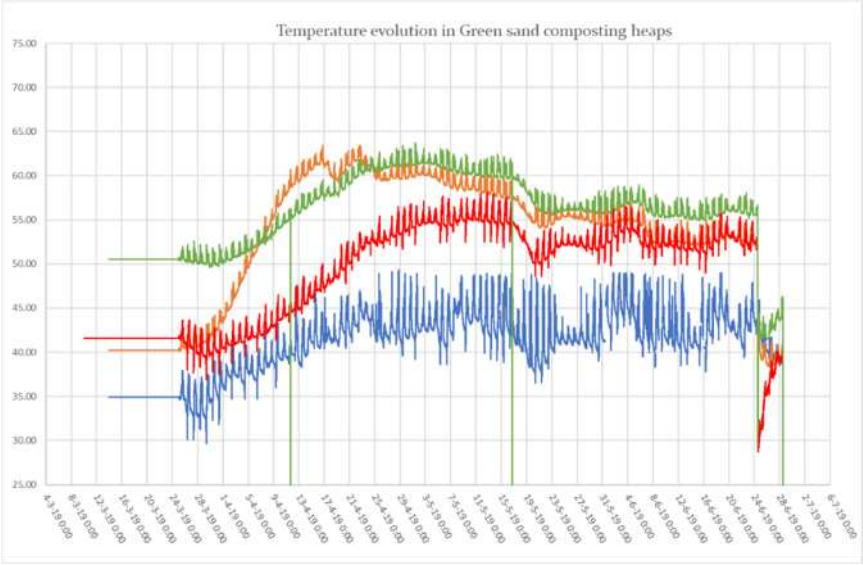
Figure 6: Heaps showing thermocouples

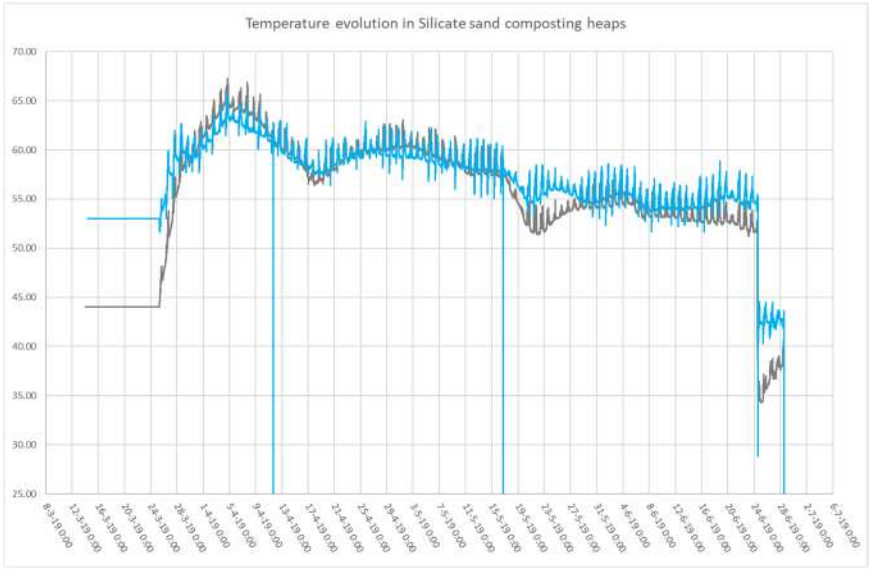
Figure 7: Thermocouple displays showing temp at stages 1-2-3.

Figure 8: Manual thermometer used during sampling

The following graphs show the changes to temperature as recorded by the monitoring equipment.

Figure 9 shows temperature change by each thermocouple inserted in the heaps – one colour represents data from one thermocouple. In the first and third graph results from two thermocouples per heap are shown. In the second (silicate sand), results from one thermocouple per heap are shown due to technical issue.





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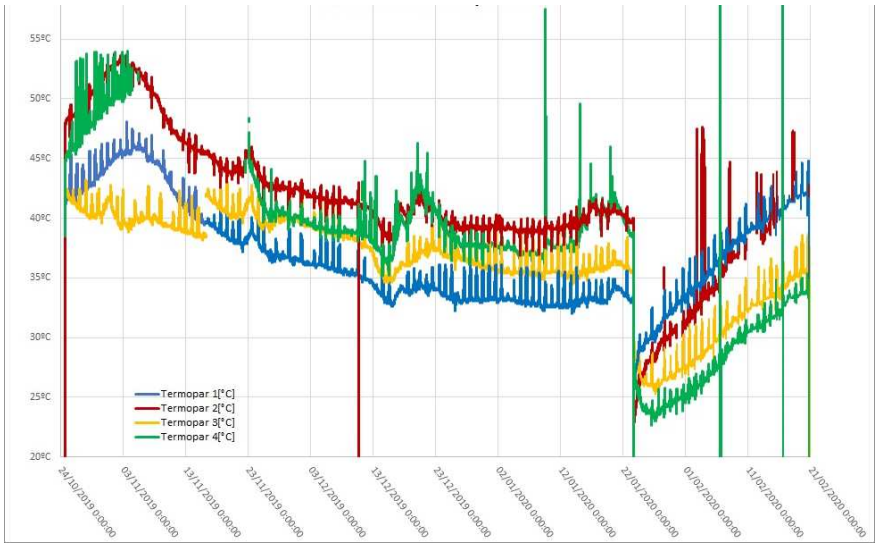

Figure 9 a, b, c: Changes in temperature detected by the thermocouples throughout the trial periods.

The natural biodegradation process follows three predictable stages (mesophilic 1, thermophilic and mesophilic 2). Engineered biodegradation follows the same pattern, but the transition from one to stage to another occurs faster as a result of optimizing material and conditions (aeration and irrigation if necessary). At stage mesophilic1, there is a transformation of the organic material driven by an increase in temperature which destroys microbial life. At stage 2, thermophilic, new life appears in the form of invertebrates (Bemisia and oniscideas) and fungi (see photo below) which continues in more abundance in stage 3 (mesophilic 2).

Sample analysis was carried out at each of the three stages of biodegradation. A minimum of eight samples of material were taken from different locations in each of the heaps. These heap samples were combined in one container to obtain representative samples of that sand type.

Figure 10: heaps following sample extraction and bottled material.

Figure 11: Invertebrate lifeforms and fungi present at stage 2 and results at stage 3.

3. National regulations and limit values for composting material

In order to comply with Ministry of Agriculture, Food and Environment as well with the Basque Country (Law 22/2011, of 28 July and Law 5/2013 on waste and contaminated soil) Government Instruction AAA/661/2013* regulating the disposal of waste by landfill for recycled foundry sand for use as compost, fertilizer or as a construction material (geothermic), the following tables must be observed. It suggests that foundry sand must comply with the limit values set for inert waste. Waste material may not endanger surface or ground water quality, may not react or cause harmful substances to dissolve from it.

Waste foundry sand composting materials at Stage 1 and Stage 2 are compared to inert waste limit values according to legislation (IA) and (IB). (IA) stablish the leachate limit values of heavy metals and other compounds and (IB) the limits for organic content.

Also limit values for nonhazardous (IIA-IIB), and hazardous waste material (IIIA-IIIB) are shown in the following tables for comparison purposes. Then in the last stage composting end-products (IV) limit values established for fertilizer are used for comparison.

(IA) Inert waste limit (leaching limit values, metal components):

Table 1: Limit value for inert waste material.

Components	**Limit value for leaching L/S = 10 l/kg (mg/kg of dry material)**	**Co (percolation test) (mg/l)**
As	0.5	0.06
Ba	20	4
Cd	0.04	0.02
Cr	0.5	0.1
Cu	2	0.6
Hg	0.01	0.002
Mo	0.5	0.2
Ni	0.4	0.12
Pb	0.5	0.15
Sb	0.06	0.01
Se	0.1	0.04
Zn	4	1.2
Chlorides	800	450
Fluorides	10	2.5
Sulphates	1,000*	1,500
Phenol	1	0.3
DOC	500***	160
STD	4,000*****	-

(IB) Inert waste limit (limit values organic parameters):

Table 2: Limit value for inert waste material (organic parameters).

Other parameters	**Limit value (mg/kg) dry material**
TOC	30,000****
BTEX	6
PCB	1
Mineral oil	500
PAH	55 **

Below the following clarifications:
** Although the waste material dies not accomplish this value corresponding to sulphate, it may be considered to fulfill the criteria for admission if the leaching does not exceed any of the following values: 1,500 mg / l in Co with a ratio of 0.1 l/kg and 6,000 mg / kg with an L/S ratio of 10 l/kg.*
*** Sum of the following substances: Acenaphthene, Acenaphthylene, Anthracene, Benzo (a) anthracene, Benzo (a) pyrene, Benzo (b) fluoranthene, Benzo (g, h, i) perylene, Benzo (k) fluoranthene, Chrysene, Dibenzo A, h) Anthracene, Phenanthrene, Fluoranthene, Fluorene, Indene (1,2,3-c, d) Pyrene, Naphthalene and Pyrene.*
**** If the residue does not fulfill the dissolved organic carbon (DOC) values with its own pH, it can alternatively be tested with an L/S = 10 l/kg and pH between 7.5 and 8.0. The waste may be considered to comply with the DOC according to the criteria stablished.*

*****A limit value higher than those indicated for TOC may be accepted by the competent environmental department provided that the dissolved organic carbon (DOC) reaches its limit value at a ratio L/S = 10 l/kg either at the residue's own pH or at a pH between 7,5 and 8,0.*
****** Total Dissolved Solids (STD) values may be used as alternative to sulphate and chloride values.*

(IIA) Non-Hazardous waste limit (leaching limit values)

Table 3: Limit value for non-hazardous waste material.

Components	**Limit value for leaching L/S = 10 l/kg (mg/kg of dry material)**	**Co (percolation test) (mg/l)**
As	2	0.3
Ba	100	20
Cd	1	0.3
Cr	10	2.5
Cu	50	30
Hg	0.2	0.03
Mo	10	3.5
Ni	10	3
Pb	10	3
Sb	0.7	0.7
Se	0.5	0.2
Zn	50	15
Chlorides	15,000	8,500
Fluorides	150	40
Sulphates	20,000*	7,000
Phenol	1	0.3
DOC	800***	250
STD	60,000*****	-

(II B) Non-hazardous waste limit (limit values organic parameters):

Table 4: Limit value for non-hazardous waste material (organic parameters).

Other parameters	Limit value (mg/kg) dry material
TOC	50,000****

(IIIA) Hazardous waste limit (leaching limit values)

Table 5: Limit value for hazardous waste material.

Components	**Limit value for leaching L/S = 10 l/kg (mg/kg of dry material)**	**Co (percolation test) (mg/l)**
As	25	3
Ba	300	60
Cd	5	1.7
Cr	70	15
Cu	100	100
Hg	2	2
Mo	30	30
Ni	40	40

Pb	50	50
Sb	5	5
Se	7	7
Zn	200	200
Chlorides	25,000	25,000
Fluorides	300	500
Sulphates	50,000*	17,000
Phenol	-	-
DOC	1,000***	320
STD	100,000*****	-

(IIIB) Hazardous waste limit (limit values organic parameters):

Table 6: Limit value for hazardous waste material (organic parameters).

Other parameters	**Limit value (mg/kg) dry material**
TOC	60,000****

(IV) Limit values of the composting end-product must be fulfilled in order to use the new end-product as growing media according Royal Decree 506/2013 on fertilizers, Royal Decree 1039/2012 and Government Instruction PRA/1943/2016 on growing substrates.

These regulations set limit values and demands of heavy metals and pathogens (Salmonella, Listeria monocytogenes and E. coli) so that end compost to be recognized as a potential fertilizer.

Table 7: Limit value for final product used as fertilizer (heavy metals).

Heavy metals mg/kg	**Class A**	**Class B**	**Class C**
Cd	0.7	2	3
Cu	70	300	400
Ni	25	90	100
Pb	45	150	200
Zn	200	500	1,000
Hg	0.4	1.5	2.5
Cr	70	250	300
Chromium (VI)	No detectable	No detectable	No detectable

Table 8: Limit value for final product used as fertilizer (microorganisms).

Microorganisms	**Units**	**Limit Value for compost**
Salmonella	Neg/25 g	Not found in a sample of 25 grams
Escherichia coli	cfu/g	Less than 1,000 cfu/g in growing media
Listeria monocytogenes	Neg /1 g	Not found in a sample of 1 gram

(V) For wastewater from the heaps the values should not exceed the limits according to *Basque Country Government following instruction 98/83.*

Table 9: Limit value for wastewater.

Parameters (mg/l)	Limit Value
Total nitrogen (N)	75
$NH4^+$	50
Phosphorus total (P)	15
Conductivity at 20ºC (µS/cm)	5,000
BOD (Biological Oxygen Demand)	500
COD (Chemical Oxygen Demand)	2,000
Phenol (C_6H_6O)	5
pH (U.pH)	5.5-9.5
Solid material	600
Fluorides (F^-)	10
Aluminium (Al)	20
Cadmium (Cd)	0.10
Chromium (Cr)	1
Cupper (Cu)	1
Iron (Fe)	20
Mercury (Hg)	0.01
Nickel (Ni)	2
Lead (Pb)	0.50
Zinc (Zn)	3
Thermo resistant coliform microbes (ufc/100 ml)	-
BTEX	10
PAH compounds	10

Table 10: Equipment and procedures

Equipment for solid samples	Procedure- specification
Laboratory volumetric material	PEC/EN/A-091 UNE-EN 12457-4:2003 N-VH-PED 132
Infra red spectrometer	TEC-ME-PE-0018 UNE-EN 12457-4:2003
UV-VIS spectrometer	TEC-I-PE-0015 UNE-EN 12457-4:2003
Mass spectrormeter	TEC-ME-PE-0001 UNE-EN 12457-4:2003
Ionic cromatrografy	TEC-C-PE-008 UNE-EN 12457-4:2003
Gas cromatrografy	TEC-ME-PE-0021 ICP-OES UNE-EN 12457-4:2003
Optic emission espectrometer	TEC-ME-PE-0019
Ultrasonic equipment	A-BS-PE-0047 UNE-EN 12457-4:2003
Electrómeter	TEC-I-PE-0002 UNE-EN 12457-4:2003
Solvita equip	A-E-PE-0098 UNE-EN ISO 6579:2003/A1:2007
Balance	EC/EN/A-050 N-VH-PE0132-2 UNE EN 15934:2012

Equipment for liquid samples	Procedure-Norm
Balance	TEC-VH-PE-0061
Spectro fotometer	TEC-I-PE-0078
UV-VIS spectrometer	TEC-I-PE70015
Electrometer	TEC-I-PE-0007
Manometer	TEC-I-PE-0062
Ionic cromatografy	TEC-I-PE-0008
Optic Emission spectrometer	TEC-ME-PE-0019
Filter	TEC-M-PE-0040

4. Results of the composting tests

4.1Waste foundry sands

The following table show the results from the analysis of SFS prior to composting.

Binder system types used in composting test heap:

- washed organic waste sand (from green moulding sand process) : GREEN SAND
- unwashed inorganic waste sand (from silicate moulding process): SILICATE SAND
- ecologic inorganic waste sand (from cores formed with ecological binder, Inotec, from moulding green sand process for aluminum foundry) : ECO-SAND

Composting test heaps in Spain:

- 4 test heaps from February 2019 until June 2019. 4*20 tons = 80 tons. Two heaps with inorganic waste sand from silicate moulding process and two heaps with organic washed green moulding sand from the closed Ecofond washing company).

- 2 test heaps from August 2019 until March 2020 with ecologic waste sand from cores of an aluminum foundry

  In total of 6*20 tons = 120 tons of composting material and foundry waste sands were cleaned by composting method. Waste sand portion of 18-20%.

Figure 11: Results of the analyses of SFSs.

Sand types %w	Green sand	Silicate sand	Eco-sand
Fe_2O_3	1.40	2.50	0.05
Al_2O_3	2.70	0.46	0.23
MnO	<0.05	0.05	<0.01
MgO	1.4	17	<0.01
Cr_2O_3	0.87	0.06	<0.01
TiO_2	0.12	<0.05	0.03
NiO	<0.05	0.12	<0.01
CaO	<0.05	<0.05	<0.01
Na_2O	0.28	0.56	0.20
K_2O	0.53	0.11	0.07
P_2O_5	<0.05	<0.05	<0.01
C	0.62	0.18	0.10
S	0.02	<0.01	<0.01
N	0.03	0.02	-
Lost 950ºC	0.88	0.56	0.35

Lost 550ºC	0.84	0.44	0.30
Humidity(%)	19.5	0.19	0.23

4.2 Composting materials

The following tables show results for soluble metals in the test heaps.

Table 12: Results (soluble metals) of green sand composting test heaps.

Soluble metal (mg/kg)	Green sand	Stage 1	Stage 2	Stage 3	Limit value for inert waste
Aluminum (Al)	5.50	13.10	5.20	7.80	-
Antimony (Sb)	<0.01	<0.01	<0.01	0.011	0.06
Arsenic (As)	<0.01	0.10	0.14	0.18	0.50
Barium (Ba)	<0.20	1.10	1.00	1.60	20.00
Cadmium (Cd)	<0.01	<0.01	<0.01	<0.01	0.04
Chromium (Cr)	<0.20	<0.20	<0.20	<0.20	0.50
Copper (Cu)	<0.20	0.49	0.20	0.55	2.00
Iron (Fe)	<0.20	17.40	41.50	21.90	-
Lead (Pb)	<0.20	0.33	0.33	0.83	0.50
Mercury (Hg)	<0.01	<0.01	<0.005	<0.005	0.01
Molybdenum (Mo)	<0.20	<0.20	<0.20	<0.20	0.50
Nickel (Ni)	<0.20	<0.20	<0.20	<0.20	0.40
Selenium (Se)	<0.05	<0.05	<0.05	<0.05	0.10
Zinc (Zn)	<0.20	1.30	1.30	1.70	4.00

Table 13: Results (soluble metals) of silicate sand composting test heaps.

Soluble metals (mg/kg)	Silicate sand	Stage 1	Stage 2	Stage 3	Limit value for inert waste
Aluminium (Al)	13.70	12.10	7.00	18.50	-
Antimony (Sb)	<0.01	<0.01	0.011	0.014	0.06
Arsenic (As)	0.012	0.17	0.12	0.29	0.5
Barium (Ba)	2.50	1.90	1.20	1.60	20.00
Cadmium (Cd)	<0.01	<0.01	<0.01	0.012	0.04
Chromium (Cr)	<0.20	<0.20	<0.20	<0.20	0.50
Copper (Cu)	4.02	0.78	0.58	0.33	2.00
Iron (Fe)	45.90	15.60	17.00	102.00	-
Lead (Pb)	5.60	0.72	0.28	0.73	0.50
Mercury (Hg)	<0.01	<0.01	<0.01	<0.005	0.01
Molybdenum (Mo)	1.30	0.21	<0.20	<0.20	0.50
Nickel (Ni)	1.10	<0.20	<0.20	<0.20	0.40

Selenium (Se)	<0.05	<0.05	<0.05	<0.05	0.10
Zinc (Zn)	74.9	3.00	15.80	2.80	4.00

Table 14: Results (soluble metals) of eco sand composting test heaps.

Soluble metals (mg/kg)	**ECO sand**	**Stage 1**	**Stage 2**	**Stage 3**	**Limit value for inert waste**
Aluminium (Al)	5.50	5.00	7.60	5.25	-
Antimony (Sb)	<0.01	<0.01	<0.01	0.013	0.06
Arsenic (As)	<0.01	0.76	0.038	0.094	0.50
Barium (Ba)	<0.20	<0.01	<0.20	1.32	20.00
Cadmium (Cd)	<0.01	<0.01	<0.01	<0.01	0.04
Chromium (Cr)	<0.20	<0.20	<0.20	<0.20	0.50
Copper (Cu)	<0.20	0.28	<0.20	1.34	2.00
Iron (Fe)	<0.20	16.40	13.60	18.30	-
Lead (Pb)	<0.20	0.44	0.38	0.35	0.50
Mercury (Hg)	<0.01	<0.005	<0.005	<0.005	0.01
Molybdenum (Mo)	<0.20	<0.20	<0.20	0.23	0.50
Nickel (Ni)	<0.20	<0.20	<0.20	<0.20	0.40
Selenium (Se)	<0.05	<0.05	<0.05	<0.05	0.10
Zinc (Zn)	<0.20	1.50	2.10	3.45	4.00

The following tables show results for hazardous parameters in the test heaps

Table 15: The results for hazardous parameters

Hazardous parameters (mg/kg)	**Green sand**	**Stage 1**	**Stage 2**	**Stage 3**	**Limit value for inert waste**
Chlorides	<50.00	608.00	549.00	611.00	800.00
Fluorides	<5.00	<5.00	5.60	<5.00	10.00
Sulphates	<50.00	565.00	363.00	633.00	1,000.00
Phenol	<0.50	0.60	<0.50	<0.50	1.00
DOC	169.00	1,070.00	1,630.00	1,670.00	500.00
TOC	<1,000.00	16,500.00	18,900.00	11,800.00	30,000.00
BTEX	<0.04	<0.15	<0.04	<0.04	6.00
PCB	<0.10	<0.10	<0.10	<0.10	1.00
Mineral oil	<20.00	67.00	<20.00	<20.00	500.00
PAH	<0.16	<0.16	<0.16	<0.16	55.00
pH (U. pH)	7.50	7.90	7.40	7.50	>6.00
Conductivity (µS/cm)	<45.00	649.00	745.00	732.00	-
Humidity (%)	6.70	43.40	39.20	32.10	<65.00

Table 16: Results for hazardous parameters in silicate sand composting test heaps.

Hazardous parameters (mg/kg)	Silicate sand	Stage 1	Stage 2	Stage 3	Limit value for inert waste
Chlorides	<50.00	928.00	984.00	841.00	800.00
Fluorides	6.00	<5.00	<5.00	<5.00	10.00
Sulphates	<50.00	286.00	329.00	337.00	1,000.00
Phenol	0.80	<0.50	<0.50	<0.50	1.00
DOC	608.00	1,770.00	2,480.00	4,060.00	500.00
TOC	1,300.00	17,300.00	17,000.00	19,000.00	30,000.00
BTEX	0.24	<0.076	<0.04	<0.04	6.00
PCB	0.10	<0.10	<0.10	<0.10	1.00
Mineral oil	<20.00	<34.00	<20.00	<20.00	500.00
PAH	<0.160	<0.160	<0.169	<0.160	55.00
pH (U. pH)	10.40	7.70	8.30	7.90	>6.00
Conductivity (µS/cm)	833.00	958.00	1015.00	940.00	-
Humidity (%)	0.30	48.30	42.80	43.90	<65.00

Table 17: Results for hazardous parameters in eco sand composting test heaps

Other hazardous parameters (mg/kg)	ECO sand	Stage 1	Stage 2	Stage 3	Limit value for inert waste	Limit value for non hazardous
Chlorides	<50.00	166.00	<50.00	1,170.00	800.00	15,000.00
Fluorides	<5.00	<5.00	<5.00	<5.00	10.00	150.00
Sulphates	63.30	90.40	<50.00	180.00	1,000.00	20,000.00
Phenol	<0.50	<0.50	1.90	<0.50	1.00	-
DOC	77.50	1,000.00	640.00	2,360.00	500.00	800.00
TOC	1,000.00	213,000.00	168,000.00	204,000.00	30,000.00	50,000.00
BTEX	<0.01	<0.01	<0.01	<0.01	6.00	-
PCB	<0.01	<0.01	<0.01	<0.01	1.00	-
Mineral oil	<20.00	<39.00	25.00	78.00	500.00	-
PAH	<0.160	<0.160	<0.160	<0.160	55.00	-
pH	10.90	7.40	7.90	7.90	>6.00	>6.00
Conductivity at 20ºC (µS/cm)	496.00	684.00	280.00	1,069.00	-	-
Humidity (%)	0.20	54.40	57.70	46.40	<65.00	<65.00

The following tables show results for total metals in the heaps

Table 18: Results for total metals in green sand composting test heaps.

Total metals (mg/kg)	Green waste foundry sand	Stage 1	Stage 2	Stage 3	Limit value for fertilizer Class C
Aluminium (Al)	3,480.00	14,500.00	19,600.00	15,500.00	-
Antimony (Sb)	<1.00	<1.00	2.70	<2.00	-
Arsenic (As)	<1.00	4.76	7.00	5.41	-
Barium (Ba)	24.70	94.60	132.00	87.40	-
Cadmium (Cd)	<1.00	<1.00	<1.00	<2.00	3.00
Chromium (Cr)	14.70	199.00	73.00	147.00	300.00
Copper (Cu)	18.30	33.70	40.00	36.40	400.00
Iron (Fe)	5,750.00	20,500.00	19,400.00	17,200.00	-
Lead (Pb)	4.40	29.00	30.00	28.10	200.00
Mercury (Hg)	<0.10	<0.10	<0.50	<0.50	2.50
Molybdenum (Mo)	1.01	1.71	11.00	<2.00	-
Nickel (Ni)	51.30	86.10	30.00	72.80	100.00
Selenium (Se)	<1.00	<1.00	1.21	<2.00	-
Zinc (Zn)	56.00	122.00	205.00	112.00	1,000.00

Table 19: Results for total metals in silicate sand composting test heaps.

Total metals (mg/kg)	Silicate sand	Stage 1	Stage 2	Stage 3	Limit value for fertilizer Class C
Aluminium (Al)	288.00	10,800.00	19,000.00	10,100.00	-
Antimony (Sb)	<1.00	1.36	2.43	<2.00	-
Arsenic (As)	<1.00	5.59	5.66	2.71	-
Barium (Ba)	2.87	74.50	119.00	45.10	-
Cadmium (Cd)	<1.00	<1.00	<1.00	<2.00	3.00
Chromium (Cr)	16.80	57.40	36.40	187.00	300.00
Copper (Cu)	1.48	23.70	24.30	21.10	400.00
Iron (Fe)	13,300.00	17,700.00	17,500.00	15,700.00	-
Lead (Pb)	1.48	27.20	22.20	12.00	200.00
Mercury (Hg)	<0.10	<0.10	<0.50	<0.50	2.50
Molybdenum (Mo)	<1.00	1.71	4.04	<2.00	-
Nickel (Ni)	606.00	246.00	237.00	261.00	100.00
Selenium (Se)	<1.00	1.26	1.11	<2.00	-
Zinc (Zn)	8.50	127.00	131.00	67.20	1,000.00

Table 20: Results for total metals in eco sand composting test heaps.

Total metals (mg/kg)	ECO sand	Stage 1	Stage 2	Stage 3	Limit value for fertilizer Class C
Aluminium (Al)	727.00	9,670.00	16,700.00	11,000.00	-
Antimony (Sb)	<2.00	<2.00	<2.00	<2.00	-
Arsenic (As)	<2.00	2.82	4.01	3.97	-
Barium (Ba)	5.86	77.50	112.00	79.80	-
Cadmium (Cd)	<2.00	<2.00	<2.00	<2.00	3.00
Chromium (Cr)	<2.00	18.10	139.00	115.00	300.00
Copper (Cu)	<2.00	21.10	31.10	32.80	400.00
Iron (Fe)	230.00	8,190.00	20,100.00	16,400.00	-
Lead (Pb)	<2.00	23.10	26.00	27.10	200.00
Mercury (Hg)	<0.50	<0.50	<0.50	<0.50	2.50
Molybdenum (Mo)	<2.00	<2.00	2.00	2.04	-
Nickel (Ni)	<2.00	28.20	82.10	77.60	100.00
Selenium (Se)	<2.00	<2.00	<2.00	<2.00	-
Zinc (Zn)	2.88	99.60	157.00	128.00	1,000.00

4.3 Maturity composting process

The level of pathogen microorganisms was analysed at Stage 3 to verify the result of the final product compared to Law of fertilizers 506/2013 and of substrates 1039/2012 as the table below shows (Table 25).

Our compost took 5-6 months to become mature enough for use following stage 3.

Table 21: Microbes analysed from composting test heaps.

Microbiological parameters	Green sand	Silicate sand	Eco sand	Limit value for fertilizer Class C
Salmonella spp. (g)	0	0	Present	Not found in a sample of 25 grams
Escherichia coli (NMP/g)	5	1	5	Less than 1,000 NMP/g in growing media *NMP units

The table below shows the results for Phytoxicity parameters. Note that ecosand results are not currently available due to logistical problems associated with Covid-19 lockdown.

Table 22: Phytoxicity parameters.

Phytoxicity parameters	Green sand	Silicate sand	Eco sand	Limit value for compost product in Spain
Soil respiration CO_2 respiration (mg C-CO_2/kg hour)	12.80	9.30	-	125.00
Dry matter (%)	65.43	64.65		-

The following tables show the chemical component as nutrients;

Table 23: Chemical component as nutrients and other parameters of green sand composting heap.

Chemical component and other parameters (mg/kg)	Green waste Stage 1	Green waste Stage 2	Green waste Stage 3
N (g/kg)	5.40	4.60	4.40
Calcium (Ca)	21,500.00	22,700.00	21,000.00
Magnesium (Mg)	5,880.00	6,360.00	5,110.00
Potasium (K)	4,310.00	5,470.00	4,180.00
Nitrates (NO^{3-})	<5.00	<10.00	<10.00
Ortophosphates $(PO^4)^{3-}$	76.20	68.00	63.80
Total Phosphorous (P)	982.00	859.00	714.00
NH4+	64.30	46.87	57.62
Humidity (%)	41.50	38.40	32.10
Organic matter (%)	28.30	32.52	20.30

Table 24: Chemical component as nutrients and other parameters of silicate sand composting heap.

Macronutrients and other parameters (mg/kg)	Silicate Stage 1	Silicate Stage 2	Silicate Stage 3
N (g/kg)	5.80	6.60	5.30
Calcio (Ca)	38,700.00	18,900.00	17,600.00
Magnesio (Mg)	30,600.00	35,500.00	23,100.00
Potasio (K)	5,430.00	6,700.00	3,340.00
Nitrates (NO^{3-})	3.50	<10.00	<10.00
Ortophosphates $(PO^4)^{3-}$	140.00	195.00	242.00
Total Phosphorous (P)	1,150.00	1,400.00	822.00
NH4+	84.58	49.96	63.76
Humidity (%)	46.10	43.00	33.70
Organic matter (%)	29.70	29.20	32.70

Table 25: Chemical component as nutrients and other parameters of eco sand composting heap.

Macronutrients and other parameters (mg/kg)	Eco Stage 1	Eco Stage 2	Eco Stage 3
N (g/kg)	6.90	7.50	8.30
Calcio (Ca)	15,700.00	26,300.00	47,100.00
Magnesio (Mg)	4,480.00	6,880.00	6,830.00
Potasio (K)	3,870.00	4,750.00	4,080.00.00
Nitrates (NO^{3-})	<2.00	<1.00	<5.00
Ortophosphates $(PO^4)^{3-}$	360.00	140.00	156.00
Total Phosphorous (P)	1,300.00	1,590.00	1,500.00
NH4+	107.20	79.90	90.90
Humidity (%)	54.30	54.04	43.80
Organic matter (%)	36.60	28.90	35.00

4.4 Water seeping from the heaps

The following tables show the values of chemical components of water seepage collected from test heaps at the first stage of the composting process and at the third (only collected in eco sand heaps, in the others no enough quantity to analyzed).

Table 26: Water seepage and limit values at the first stage of the compostings.

Parameters (mg/l)	Water from Green sand	Water from Silicate sand	Water from Eco sand	Limit Value
Total Nitrogen (N)	54.00	18.80	-	75.00
$NH4^+$	6.00	6.10	41.10	50.00
Fosforo total (P)	7.00	1.98	111.00	15.00
Conductivity at 20°C (µS/cm)	431.00	723.00	4,050.00	5,000.00
BOD (Biological Oxygen Demand)	200.00	120.00	5,405.00	500.00
COD (Chemical Oxygen Demand)	2,968.00	437.00	-	2,000.00
Phenol (C_6H_6O)	<0.05	0.11	-	5.00
pH (U pH)	7.00	9.40	-	5.50-9.50
Solid material	2,880.00	153.00	-	600.00
Fluorides (F^-)	0.19	0.16	<0.25	10.00
Aluminium (Al)	2.87	<0.05	<0.05	20.00
Cadmio (Cd)	<0.02	<0.02	<0.02	0.10
Cromo (Cr)	<0.02	<0.02	<0.02	1.00
Cupper (Cu)	<0.02	<0.02	<0.02	1.00
Iron (Fe)	9.88	0.20	1.75	20.00
Mercury (Hg)	<0.01	<0.01	<0.01	0.01

Nickel (Ni)	0.02	<0.02	<0.02	2.00
Lead (Pb)	0.16	<0.02	<0.02	0.50
Zinc (Zn)	0.95	<0.02	0.038	3.00
Coliform microbes (ufc/100 ml)	110,000.00	<1.00	-	-
BTEX	<0.001	<0.002	-	10.00
PAH compounds	<0.01	<0.01	-	10.00

Table 27: Water seepage of eco sand and limit values at the third stage of the composting.

Parameters (mg/l)	**Water from Eco sand Stage 3**	**Limit Value**
$NH4^+$	41.10	27.20
Fosforo total (P)	111.00	14.60
Conductivity at 20ºC (µS/cm)	4,050.00	3,370.00
BOD (Biological Oxygen Demand)	5,405.00	5,645.00
pH (U pH)	7.90	7.80
Fluorides (F^-)	<0.25	<0.25
Alumminio (Al)	<0.05	0.32
Cadmio (Cd)	<0.02	<0.02
Cromo (Cr)	<0.02	<0.02
Cupper (Cu)	<0.02	<0.02
Iron (Fe)	1.75	2.56
Mercury (Hg)	<0.01	<0.0005
Nickel (Ni)	<0.02	<0.02
Lead (Pb)	<0.02	<0.02
Zinc (Zn)	0.038	0.093

5. Emissions to air

In addition to analyzing the composting material and water from the heaps, emissions to air were measured during the last stage. The aim was to evaluate the environmental impact of incorporating foundry waste sand in the composting process. Gases measured due to their ability to cause variation in atmospheric composition were O_2, CO_2, CO, CH_4 and NH_3.

Table 28: Gases emitted by sand composting heaps.

Type of gaseous pollutants	Value
O_2 (%)	21.07
CO (ppm)	<3.00
CO_2 (%)	0.14
CH_4 (%)	<0.001

NH_3 (mg/Nm^3)	<0.21

6. Conclusions

Three types of sand were analysed, green sand, silicate sand and ecologic sand, representing both organic and inorganic processes. The sand came from three types of foundry; green sand used for automotive iron casting (organic), silicate sand used for railway steel casting (inorganic) and eco sand used for automotive and machine tool aluminium casting (inorganic).

The different types of sand behaved similarly throughout biodegradation.

Eco sand (inorganic) and silicate sand (inorganic) are equally suitable for composting, as they give similar results. This means that regarding environmental matters foundries should choose any inorganic sand over organic sand.
Both sand types are equally suitable for producing compost for use as fertilizer (both within pathogen limits).
Washed green sand (organic) is suitable for use as a component of compost for use as fertilizer. There was no difference in the final results obtained from this washed sand compared to previous studies with equivalent unwashed green sand.

Nitrate/ammonium ratio is a confirmation of stability and maturity of the final compost. Nitrate/ammonium ratio must be > 1 in order to consider the compost as mature. If the nitrate/ammonium ratio <1 the material can be still considered fresh compost. In order to reach maturity, compost with silicate and green sand took three months. Compost from eco sand takes longer.