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:

Results of composting tests with organic binder system foundry dusts in Finland in 2019-2022

Authors: Meehanite Technology Ltd
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Contents

Abbreviations

BOD	Biochemical oxygen demand
BTEX	Benzene, toluene, ethylbenzene, and xylenes
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
Phenol index	Includes phenol compounds analysed by method SFS-EN ISO 14402:en, Water quality – Determination of phenol index by flow analysis (FIA and CFA) (ISO 14402:1999)
TOC	Total organic carbon

1 Introduction

The main objective of the Green Foundry LIFE project was to decrease the environmental impact of the European foundry industry by introducing new clean technology systems in practice. Organic binders are almost exclusively synthetic resins, which are cured by the addition of a separate hardener or catalyst. Inorganic binders are based on sodium silicates and they are water-soluble and therefore more environmentally friendly. By introducing inorganic binders in iron and steel foundries the aim was to reduce emissions and improve indoor air quality in ferrous foundries. The piloted technologies are feasible and transferable aiming to wide scale implementation in foundry industry across Europe.

In this project the inorganic binder systems will be demonstrated and tested in iron and steel pilot foundries. Also different surplus foundry sand purification and reuse methods will be demonstrated to reduce the amount of waste sand and to develop new reuse applications for surplus foundry sands.

Cleaning the surplus foundry sands by composting method is one of the reuse methods to be demonstrated. This cleaning method was piloted with organic binder system foundry waste sands in previous Foundrysand LIFE project (LIFE13 ENV/FI/285) in 2015-2017. Based on the results it was expected that the hazardous organic compounds (like phenols, BTEX, PAHs) will be cleaned with the efficiency of about 90-95% and the composted end-product will meet the limit values set for mixture soil material suitable for geo-construction, road construction and green construction applications.

In the composting tests organic and inorganic foundry waste sand and dust specimens were tested. They represented organic phenolic Alphaset and furan binder systems and the new inorganic binder system. In the composting process organic harmful substances of the waste sands and dusts are degraded and cleaned in 5-6 months. After this the post-maturing period of about 6 months is needed, so that the compost material will be mature. The aim is that the new end-product will meet the national regulations and limit values set for mixture soil material and it can be reused for green construction applications.

In Finland we had composting tests in two locations. In Tampere region and in northern Finland (anonymous foundry and location). In this report we present the composting test results which were carried out with furan sand system dusts origin from sand regeneration system.

In 2019 two smaller size test heaps of 16 and 20 tons were constructed. The test results of these tests are reported here first. Based on the successful composting tests and good results, tests were continued in 11/2020-05/2022 with industrial scale composting tests in northern Finland. Two bigger scale test heaps of 91 tons and 182 tons were constructed and results are reported from the chapter 8 ahead. In totally

309 tons of composting material were cleaned in the composting process and the foundry dust proportion varied from 30-50%. The cleaned mixture soil material will be reused in the landscaping work of a noise embankment. For this reuse purpose there is an environmental permit existing.

Between 2019-2022 in Finland 7 test heaps with the total volume of 361 tons of composting material were constructed and tested. In the grant agreement min 6 test heaps were written. In these composting tests organic binder system foundry waste sand and dust specimens and inorganic binder system waste sand specimens from test casts in Karhula Foundry were used. The aim was to make clean mixture soil material suitable for new reuse green construction work applications.

2 Composting process

The degradation of organic material is rather fast in the beginning of the composting because there are plenty of nutrients present that are used as energy resource by the microbes. Heating of the compost is the result from the thermal energy production of microbes. Easily degradable components will degrade first and poorly degradable components, like cellulose and lignin, will degrade at the latter part of the composting process. The activity of microbes in the compost decreases when the amount of nutrients decrease and this can be established by cooling of the compost. The composting process itself continues longer and the degradation of compost will become even. This stage is called the stabilization. Several chemical and physical reactions occur parallel with the degradation of organic compounds. By measuring and following these reactions relevant information of the composting progress and maturity will be gathered, see the Figure 1 (the original figure in Finnish, VTT 2006).

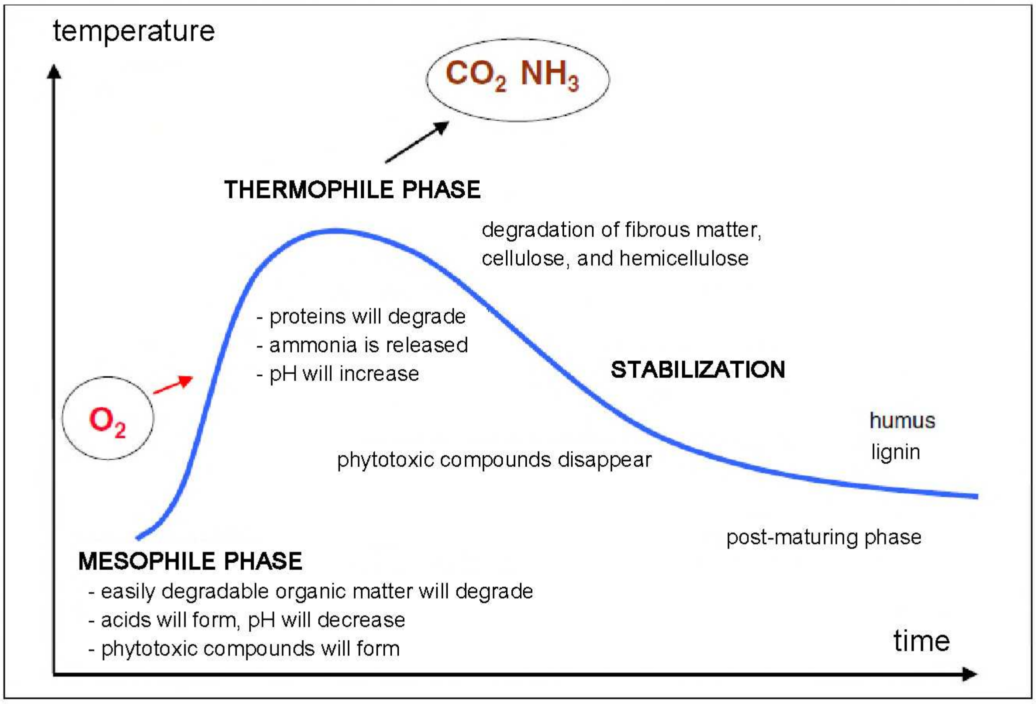

Figure 1. Different stages of the composting process (VTT 2006).

Requirements for the maturity and stabilization of the composting end-product are set in *the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011)*. Once the requirements are fulfilled the composted end-product can be used as growing media ("Mixture soil") in Finland. These requirements and limit values will be followed in this Green Foundry LIFE -project.

3 Small scale composting tests with highly contaminated organic binder system foundry dusts in 2019-2020

Dust specimens from the mechanical sand reclamation were tested and cleaned by composting method. Dusts were delivered from an iron foundry in Finland using furan resin sand system for mold and core making.

Two test heaps were constructed on 19th of June 2019 on a pilot site of 120 m^2 located on a waste treatment center in northern Finland (Fig. 2). Heaps were constructed according to Meehanite instructions and under the supervision of Meehanite. Meehanite and AX-LVI Consulting Ltd were responsible for the sampling procedure from dust specimens and composting materials. Samples were delivered for analyses to Eurofins Viljavuuspalvelu Ltd.

The sizes of the test heaps were approximately 20 tons and the portion of organic foundry dusts varied. In these composting test heaps foundry dust and other additive organic materials were used (Fig. 3, 4, 5, 6).

Figure 2. Pilot site at the waste treatment center. Waste waters are conducted to the settling tank and from there to municipal waste water treatment plant.

Waste waters from the waste water treatment center and pilot site are conducted to the settling tank and after this to the municipal waste water treatment plant.

Figures 3-4. Constructing the composting test heaps in June 2019.

Composting materials were weighed by a bucket loader, mixed several times, watered and then heaps were constructed. Different recipes were used for test heaps.

Figures 5-6. Full size test heaps of approximately 20 tons.

4 Monitoring the progress of composting tests and sampling procedures

The progress of the composting process was controlled by measuring temperature regularly and mixing the heaps during the composting period. Composting material analyses were collected from test heaps right after mixing the composting materials and in the end of the test period, in November. Waste waters from the pilot site were conducted to settling tank and led to municipal waste water treatment center.

Figure 7. Measuring the temperatures of composting heaps.

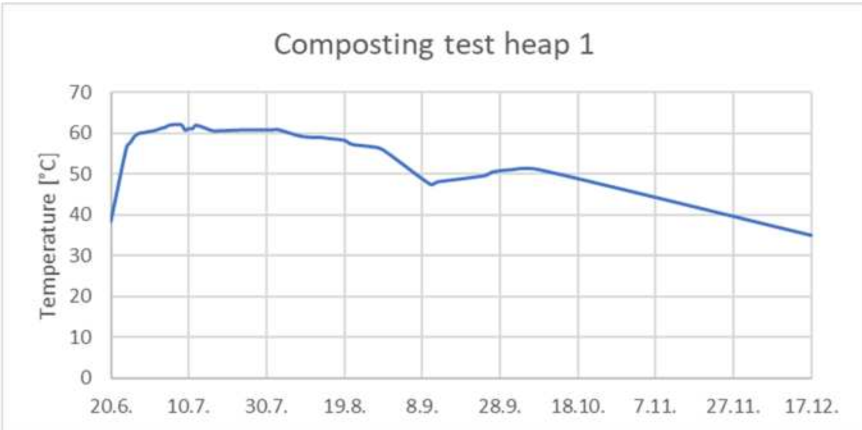

Figure 8. Temperature in the test heap 1 during the composting period from June-December 2019.

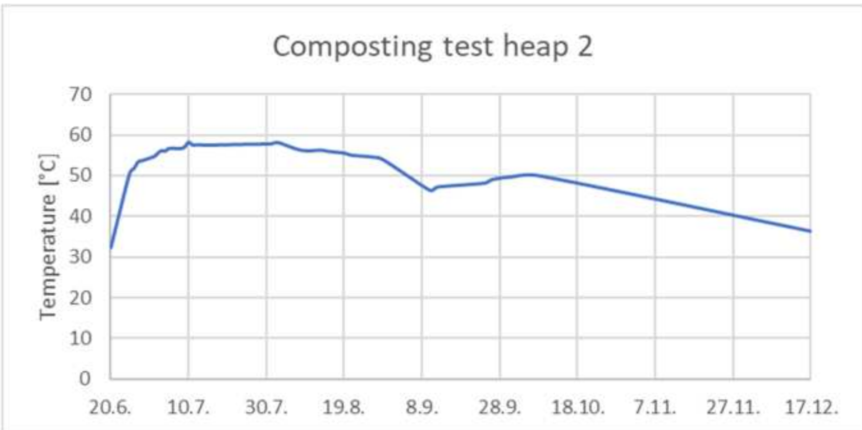

Figure 9. Temperature in the test heap 2 during the composting period from June-December 2019.

Temperatures raised rapidly above 50-60 degrees after starting the composting tests (Fig. 8, 9). The temperatures were well above 50 degrees in the beginning and stayed for over 2 months from June – August. According to the decree of 24/11 the temperatures should stay over 55 degrees for 14 days. The results demonstrate efficient composting method.

Figure 10. Sampling procedure.

Sampling procedure was carried out from foundry dusts and mixed composting materials in the beginning of the composting tests (Fig. 10, 11). Same procedure is followed in the end of the composting tests. The standard for the soil improvers and growing media and sampling procedure is according to the SFS-EN 12579.

Figure 11. Composting material samples for analyses.

Final measurements and sampling procedure of the composting tests was performed in the end of November 2019. In total the test heaps were composted for 5 months. After composting tests the harmful organic substances were degraded and the composted end-product as a mixture soil material fulfilled the limit values set in decree 24/11. Post maturing of about 6 months is needed so that the end-product will be mature. This will be determined e.g. by CO_2 measurements, phytotoxicity analyses and NO_3-N / NH_4-N ratio.

5 National regulations and limit values for composting material

In Finland following *regulations and limit values of the composted end-product* must be fulfilled in order to use the new end-product as the growing media ("Mixture soil").

1) Regulations and limit values set for the composted end-product are set in *the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2).* This regulation sets limit values and demands for heavy metals of the end-product, pathogens (*Salmonella* and *E. coli*) and impurities (weeds, garbage).

Table 1. Heavy metal limit values for the end-product to be fulfilled (24/11).

LIITE IV

LANNOITEVALMISTEIDEN HAITALLISET AINEET, ELIÖT JA EPÄPUHTAUDET

Tässä liitteessä esitettävät vaatimukset haitallisista aineista, eliöistä ja epäpuhtauksista sekä kasviperäisten raaka-aineiden käsittelystä koskevat kaikkia lannoitevalmisteita, ellei muuta ole mainittu. Nämä raja-arvot eivät koske kaatopaikkojen tai muiden suljettujen alueiden, kuten suljettujen teollisuusalueiden ja lentokenttien, maisemoinnissa käytettäviä maanparannusaineita, kasvualustoja tai muita lannoitevalmisteita eikä sellaisina käytettäviä sivutuotteita.

A. HAITALLISET AINEET

Haitalliset metallit ja niiden enimmäispitoisuudet on ilmoitettu taulukossa 1. Tuoteselosteessa tulee pitoisuudet ilmoittaa Eviran kansallisten lannoitevalmisteiden tyyppinimiluettelossa mainittujen tuotteiden osalta taulukon järjestyksessä, todettuna enimmäispitoisuutena esim. "Arseeni (As) enintään xx mg/kg".

Taulukko 1. Haitallisten metallien enimmäispitoisuudet epäorgaanisissa lannoitteissa ja kalkitusaineissa typpihapolla uutettuna sekä muissa lannoitevalmisteissa kuningasvesimärkäpolttomenetelmällä uutettuna.

Alkuaine	Enimmäispitoisuus mg/kg kuiva-ainetta	Metsätaloudessa käytettävissä tuhkalannoitteissa tai niiden raaka-aineena käytettävässä tuhkassa enimmäispitoisuus mg/kg ka.
Arseeni (As)	25	40
Elohopea (Hg)[1)]	1,0	1,0
Kadmium (Cd)	1,5 [2)]	25
Kromi (Cr)	300 [3)]	300
Kupari (Cu)	600[4)]	700
Lyijy (Pb)	100	150
Nikkeli (Ni)	100	150
Sinkki (Zn)	1500[4)]	4500[4)]

[1)] Elohopean määritys EPA 743-menetelmällä
[2)] 2,5 mg Cd/kg ka maa- ja puutarhataloudessa sekä viherrakentamisessa ja maisemoinnissa käytettävässä tuhkalannoitteissa tai niiden raaka-aineena käytettävässä tuhkassa
[3)] Sellaisenaan kalkitusaineena käytettävälle sivutuotteelle teräskuona (tyyppinimi 2A2/3) määritetään kromi liukoisena kuuden arvoisena kromina (Cr 6+). Raja-arvo liukoiselle kuuden arvoiselle kromille on 2,0 mg/kg kuiva-ainetta.
[4)] Enimmäispitoisuuden ylitys lannoitevalmisteissa voidaan sallia, kun maaperäanalyysin perusteella on todettu puutetta kuparista tai sinkistä. Metsätaloudessa enimmäispitoisuuden ylitys lannoitevalmisteena käytettävässä sivutuotteessa on sallittu ainoastaan sinkkiä suometsissä käytettäessä, silloin kun sinkin puute on kasvustosta todettu joko maaperä-, lehti- tai neulasanalyysillä Tällöin maksimimäärä sinkkiä lannoitevalmisteena käytettävässä sivutuotteessa saa olla enintään 6000 mg Zn/kg ka.

Additionally, in the decree of 24/11 there is a following demand for composted end-product:

"In case mineral soil from metallurgical industry is used as raw material for mixture soil, such as **waste foundry sand**, it must meet the criteria of **harmful metals and organic harmful substances for positioning to the inert solid landfills"**.

Therefore, soluble harmful metals and organic substances are analysed from the surplus foundry sands and dusts before the composting process starts. Same analyses are carried out also from the cleaned composted end-product.

Following regulations and limit values of foundry waste sand must be fulfilled in order to re-use foundry sand in ground construction or gardening purposes in Finland:

2) The Finnish regulations of waste foundry sand as according to the *Government Decree of landfills (331/2013)*: Foundry sand must fulfill the limit values set for the non-hazardous inert waste. "Waste material may not endanger surface or ground water quality and may not re-act or no harmful substances can dissolve from it."

Tables 2 and 3. The Finnish regulations of non-hazardous inert waste as according to the Government Decree of landfills (331/2013).

Taulukko 2

Aine/muuttuja	Raja-arvo, mg/kg kuiva-ainetta (L/S = 10 l/kg)
Arseeni (As)	0,5
Barium (Ba)	20
Kadmium (Cd)	0,04
Kromi yhteensä (Cr_{kok})	0,5
Kupari (Cu)	2
Elohopea (Hg)	0,01
Molybdeeni (Mo)	0,5
Nikkeli (Ni)	0,4
Lyijy (Pb)	0,5
Antimoni (Sb)	0,06
Seleeni (Se)	0,1
Sinkki (Zn)	4
Kloridi (Cl^-)	800
Fluoridi (F^-)	10
Sulfaatti (SO_4^{2-})	1 000 [1)]
Fenoli-indeksi	1
Liuennut orgaaninen hiili (DOC) [2)]	500
Liuenneiden aineiden kokonaismäärä (TDS) [3)]	4 000

[1)] Jätteen katsotaan täyttävän kelpoisuusvaatimuksen myös, jos sulfaattipitoisuus ei ylitä seuraavia arvoja: 1 500 mg/l (läpivirtaustestin ensimmäinen uutos uuttosuhteessa L/S = 0,1 l/kg) ja 6 000 mg/kg (uuttosuhteessa L/S = 10 l/kg): pitoisuuden määrittämiseksi uuttosuhteessa L/S = 0,1 l/kg on käytettävä läpivirtaustestiä: pitoisuus uuttosuhteessa L/S = 10 l/kg voidaan määrittää joko ravistelu- tai läpivirtaustestillä.

[2)] Jos liuenneen orgaanisen hiilen raja-arvo ylittyy jätteen omassa pH:ssa, voidaan jäte vaihtoehtoisesti testata uuttosuhteessa L/S = 10 l/kg pH:ssa 7,5–8,0: jätteen katsotaan täyttävän liuenneen orgaanisen hiilen kelpoisuusvaatimuksen, jos pitoisuus on enintään 500 mg/kg.

[3)] Liuenneiden aineiden kokonaismäärän raja-arvoa voidaan soveltaa sulfaatin ja kloridin raja-arvojen sijasta.

Taulukko 3

Aine/muuttuja	Raja-arvo, mg/kg kuiva-ainetta
Orgaanisen hiilen kokonaismäärä (TOC)	30 000 (3 %)
Bentseeni, tolueeni, etyylibentseeni ja ksyleenit (BTEX)	6
Polyklooratut bifenyylit (PCB) [1)]	1
Mineraaliöljy (C10–C40)	500
Polyaromaattiset hiilivedyt (PAH) [2)]	40

[1)] Kongeneerien 28, 52, 101, 118, 138, 153 ja 180 kokonaismäärä.

[2)] Yhdisteiden (antraseeni, asenafteeni, asenaftyleeni, bentso(a)antraseeni, bentso(a)pyreeni, kryseeni, bentso(b)fluoranteeni, bentso(g,h,i)peryleeni, bentso(k)fluoranteeni, dibentso(a,h)antraseeni, fenantreeni, fluoranteeni, fluoreeni, indeno(1,2,3-cd)pyreeni, naftaleeni, pyreeni) kokonaismäärä.

After composting process the composted end-product must meet the regulations and limit values of 1) "mixture soil" (24/2011) and 2) soluble harmful metals and organic harmful substances to inert solid landfills (331/2013). Mature and pure composted end-products can be reused in green construction, geo-engineering and road construction purpose.

During the project composting tests the analysis results are delivered to local authorities and potential environmental impacts are assessed.

The Fertiliser Product decree was renewed on 5th July 2019: "*The EU Degree on Fertiliser Product (2019/1009)*" including now new limit values and regulations e.g. for compost products and digestate-based organic fertilisers. The national law of Finland is planned to enter into force after the year of 2022. Until then, the existing limit values of Decree of 24/11 are followed. However, the new limit values and regulations (2019/1009) are taken into account for the future products which are demonstrated in this project.

6 Results of the composting tests

Analyses were made from different composting fractions:

1) foundry dust specimen,
2) animal manure,
3) mixed composting materials

Following parameters were analysed:

- pH, conductivity, humidity, nutrients, fluoride, sulphate, chloride, heavy metals, hazardous organic compounds, organic matters.
- in the end also pathogens and compost maturity tests.

Figures are presented of the results that exceeded the limit values, or in some cases were below the limit values / thresholds, if the limit value presented the minimum value. Limit values / thresholds are marked to the figures with red line. All the other results, that are not presented in graphs have fulfilled the requirements of non-hazardous inert solid waste and fertilizer product.

6.1 pH

Composting progress can be followed by measuring nitrogen compounds and pH changes. In the beginning of the composting pH can reduce but it will rise again during the maturation of compost (VTT 2006).

There is no limit value for pH for non-hazardous inert waste. Neutral value for pH is 7. pH values in compost heaps were common and suitable for the re-use of the composting material (Fig. 12).

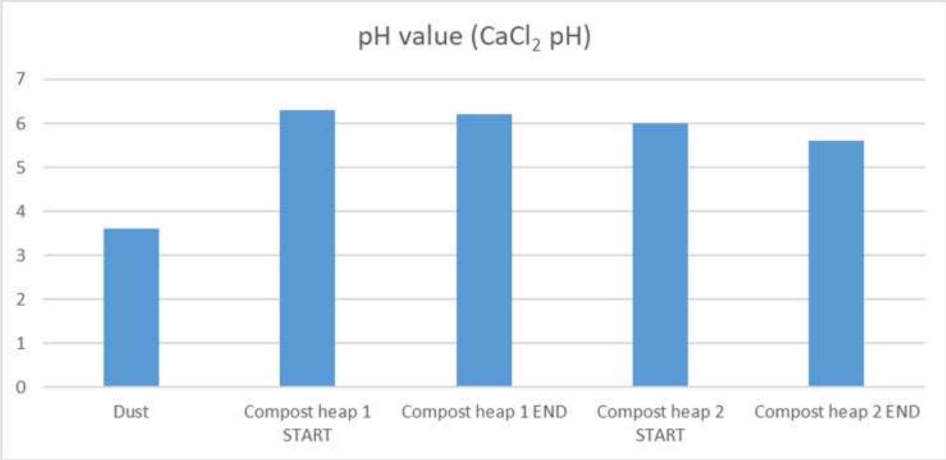

Figure 12. pH in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.2 Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC)

Dust specimens exceeded the limit values of TOC (3 % dm) (Fig. 13) and DOC (500 mg/kg dm) (Fig. 14)) for non-hazardous inert waste. During the composting tests the TOC concentrations were slightly reduced and DOC concentrations were reduced remarkably in both test heaps. In the end of the composting tests the TOC and DOC compounds were still above the limit values set for non-hazardous inert waste. But there are no limit values for organic compounds such as TOC, DOC and sulphate in the decree of 24/11 for mixture soil materials, therefore the end-product can be used for geo-construction purposes.

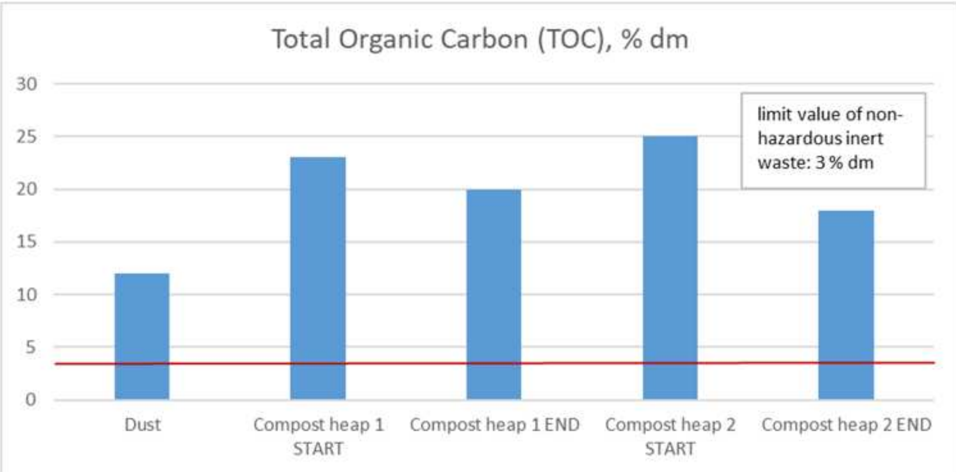

Figure 13. TOC concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

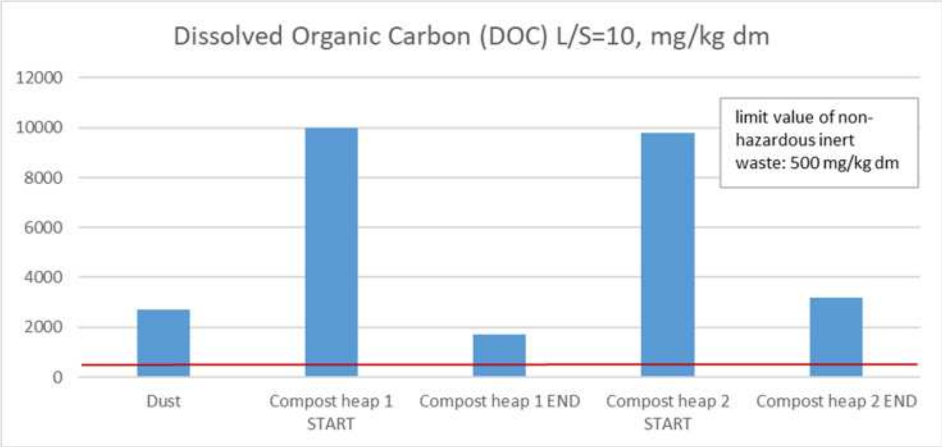

Figure 14. DOC concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.3 Fluoride

Fluoride concentration exceeded the limit value (10 mg/kg dm) in dust specimen before starting the composting tests (Fig. 15). In the end of the composting tests the concentration reached the limit value (with respect to uncertainty of measurement).

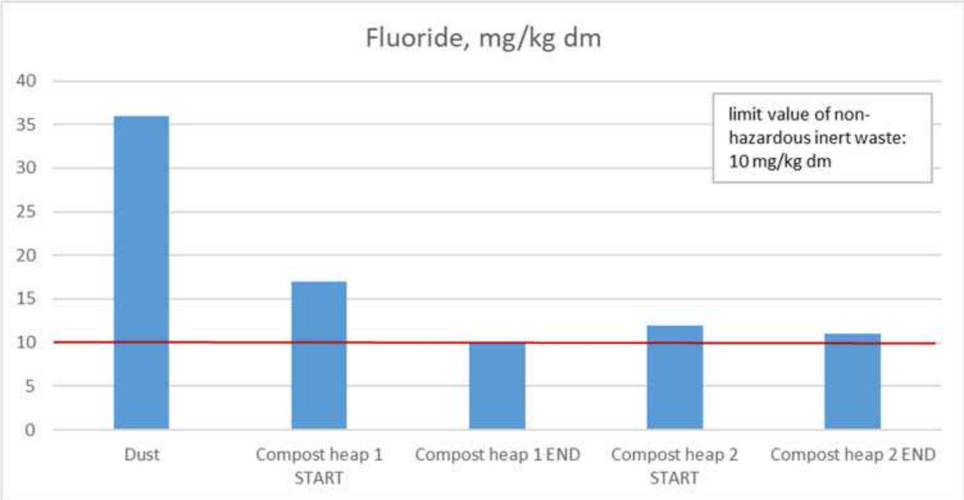

Figure 15. Fluoride concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.4 Sulphate

Sulphate concentration exceeded the limit value (1000 mg/kg dm) in dust and in all the compost samples (Fig. 16). The sulphate concentrations did not decrease remarkably during the compost test.

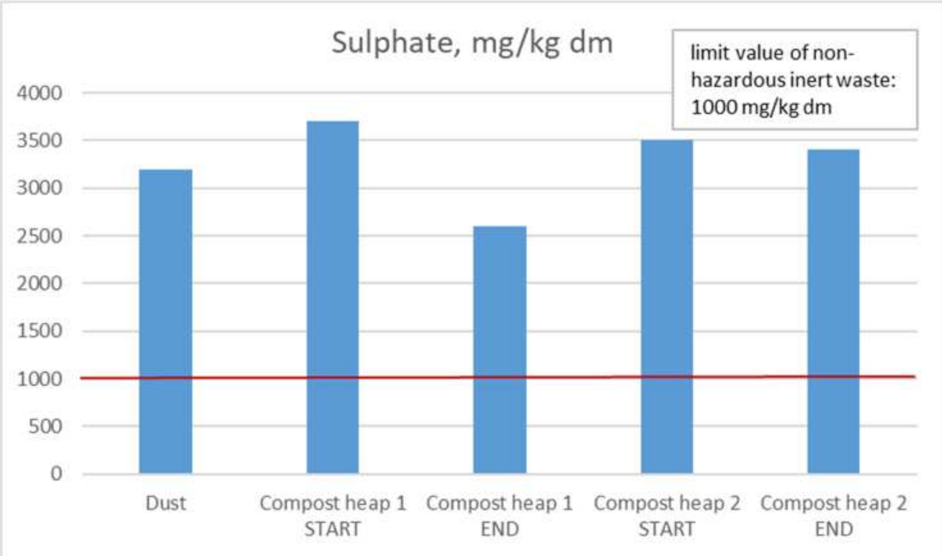

Figure 16. Sulphate concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.5 BTEX compounds

BTEX concentration in dust exceeded the limit value of non-hazardous inert waste (6 mg/kg dm) (Fig. 17). During the composting tests BTEX concentrations decreased. In the end of the composting test BTEX concentrations were very low and well below the limit value.

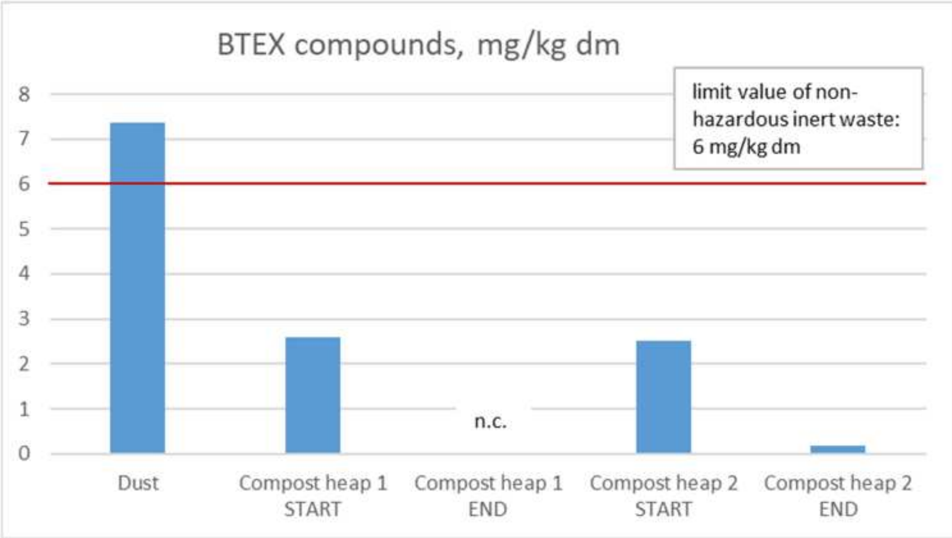

Figure 17. BTEX concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.6 Concentrations of dissolved metals and total concentrations of metals

The concentrations of dissolved metals and total concentrations of metals in dust and in compost samples were under limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/11 and Government Decree of landfills 331/2013 (limit values for non-hazardous inert solid waste), except nickel and zinc concentrations in foundry dust.

The dissolved concentrations of nickel and zinc in dust specimens exceeded the limit values set for non-hazardous inert solid waste (Fig. 18, 19). However, the concentrations of these metals in compost heaps in the end of the tests were below the limit values.

The total concentrations of nickel and zinc in compost materials were below the limit values set for fertilizer products in decree 24/11.

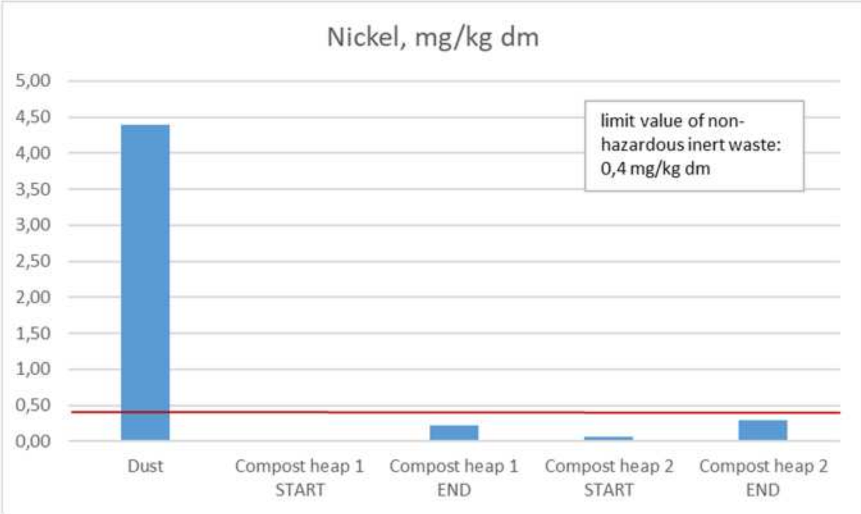

Figure 18. Nickel concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

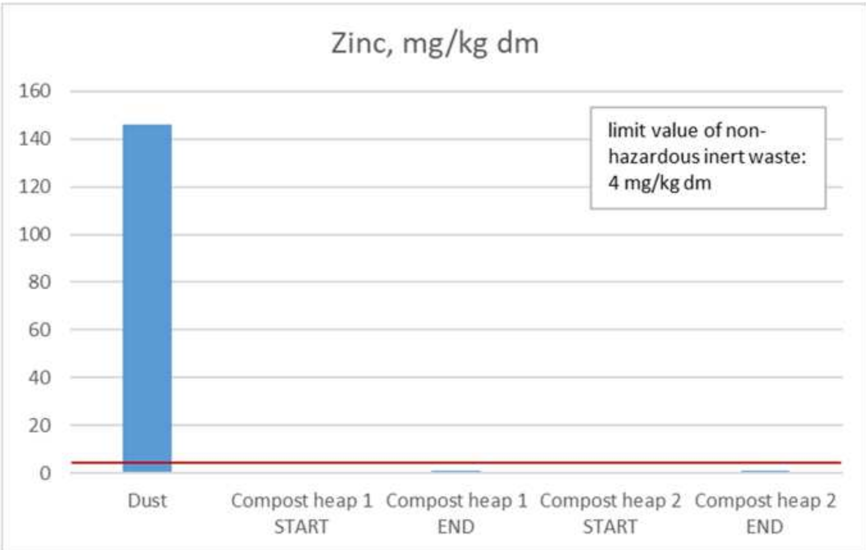

Figure 19. Zinc concentrations in dust and compost heaps 1 and 2 (in the beginning and in the end).

6.7 Compost maturity

The compost maturity can be tested with different kind of tests. Very common tests to study the compost material are germination test and root length index, that tell how plants can grow in the compost material and if it is too toxic for plant growth. Carbon dioxide productivity tell about the microbial activity of the compost materia – if there is lots of compounds that can be degraded, microbial activity is high and so is the carbon dioxide production.

NO_3-N / NH_4-N ratio describes the maturity of the compost because the state of nitrogen changes in the composting process. In raw compost material nitrogen is mainly in state of ammonium or ammonia. During maturing the portion of nitrate and nitrite grows. In mature compost material the NO_3-N / NH_4-N ratio should be over 1.

Pathogen tests tell how well the materia is composted and hygienized.

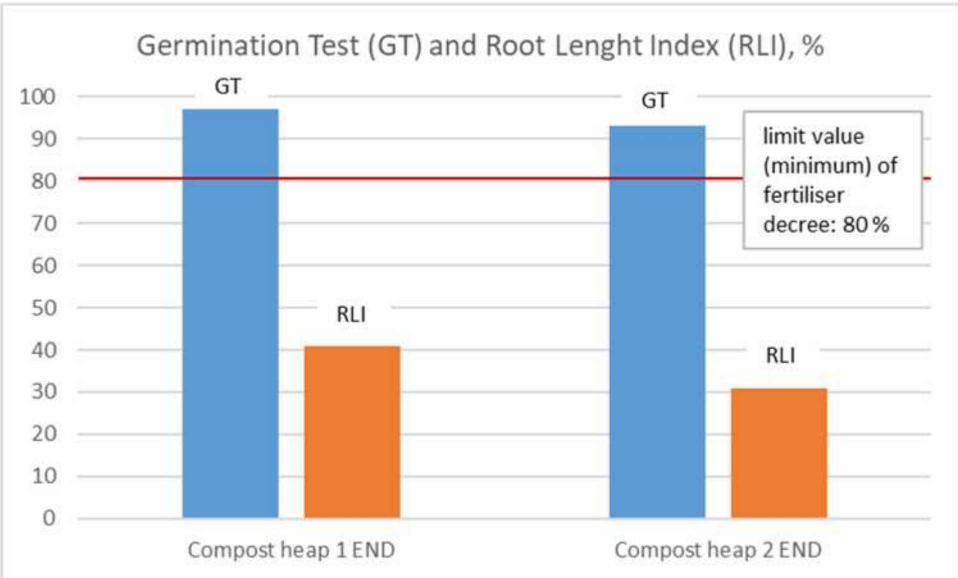

Figure 20. Germination test and root length index results of compost heaps' end situations. Value should be above 80% to fill the criteria of fertiliser decree 24/11.

The germination test gave good results for the end situation samples of compost heap 1 and 2 (Fig. 20). Anyhow, the root length index showed that the limit value of 80 % was not fulfilled. This tells that the plant seeds germinated very well, but the plants could not grow well in the compost samples so the root length index was under the limit value of 80 %.

Table 4. Maturity test results of the end situation samples of compost heaps 1 and 2 and limit values set by the legislation for the composting end product.

Analysis	Unit	Compost heap 1 END	Compost heap 2 END	Limit value of Fertiliser Product Decree 24/11
Germination test	%	97	93	>80
Root lenght index	%	**41**	**31**	>80
Carbon dioxide production	mg C/g volatile solids	<0,2	0,21	<3
NO_3-N / NH_4-N -ratio		**0,423**	**0,007**	>1
E. coli	cfu/g	<10	**3000**	<1000
Salmonella	/ 25 g	Not detected	Not detected	Must not be detected.

The carbon dioxide production results for the end situation samples of compost heap 1 and 2 indicate, that the carbon dioxide production was not detected (compost heap 1) or it was very low (compost heap 2).

The NO_3-N / NH_4-N ratio describes immature compost material in both compost heaps.

Salmonella was not detected in compost heaps 1 and 2.

E. coli colony forming unit value of compost heap 1 was below the detection limit (10 cfu/g). In compost heap 2 the colony forming unit value was very high. The result tells that the compost heap 2 was not sterilised during the composting or the test samples were not taken widely enough. After post maturing of 6 months new samples are taken and results evaluated.

7 Conclusions of small scale composting tests

Composting tests with foundry dust specimens were carried out in Northern Finland. Two test heaps were constructed size of about 20 tons each. Dust portions varied in test heaps. Composting tests were carried out from June-December 2019 and post-maturing period continued until spring 2020. Degradation of harmful compounds was monitored by regular temperature measurements on site and by analysing samples in the beginning and in the end of composting tests. Post-maturing tests will be repeated in spring 2020.

Based on the results the harmful organic compounds were degraded and metal concentrations decreased during the composting tests. The end-product materials fulfill the limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011 set for mixture soil material. The post-maturing of about 6 months is always needed to ensure that the end-product will be mature. The mature mixture soil material can be used as substrate and for gardening purposes.

In the beginning of the composting tests the dust samples were analysed. Limit values exceeding concentrations of BTEX, fluoride, nickel and zink were detected. pH of foundry dust was about 4. During the composting tests all these compounds and concentrations were reduced and in the end of the composting tests all concentrations were under the limit values set for non-hazardous inert solid waste. Also pH was increased to about 6 in test heaps.

DOC and TOC concentrations of dust specimens exceeded the limit values for non-hazardous solid inert waste. After mixing the dust with other organic materials, the concentrations of organic compounds were naturally higher in the beginning of the composting tests. During the composting tests TOC and DOC concentrations were decreased. In the end the concentrations were not under the limit values set for the inert waste because the composting end-product is organic soil material. Therefore, there are no limit values for organic substances in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011 to be used for geo-construction purposes.

High sulphate concentration was detected in dust specimens. Sulphate is originated from a foundry process where it is used as a hardener (p-Toluenesulfonic acid). Hardener is used in hardening sand molds and cores in foundries. Sulphate is a salt of sulphuric acid and it will degrade during the composting if the conditions are aerobic. Therefore, the aeration is needed during the composting process. Sulphate is not harmful substance and there are no limit values for it in Fertiliser Product Decree 24/11. However, sulphate concentration affects to maturation of the compost material because plants can not grow in high salt concentration.

Based on the results of the composting tests in summer-winter 2019, we can assume that the harmful substances were degraded during the composting tests and the composting end-product will fulfill the limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011 and can be used as substrate and for gardening purposes. Post-maturing period is needed and maturity test samples will be taken in spring 2020.

8 Industrial scale composting tests in 2020-2022

8.1. Test arrangements

In 2019 two smaller size test heaps of 16 and 20 tons were composted. Based on the successful tests and good results, composting tests were continued in 11/2020-05/2022 with industrial scale composting heaps. Two test heaps of 91 tons and 182 tons were constructed where the foundry dust proportion was average 25%. Results are reported herein.

A waterproof film was installed in the test field which was covered with the virgin sand layer to avoid breaking the film. All wastewaters from the test field were collected into a container and transported to the local waste treatment center. A test permit for these tests was applied from local environmental authority by Meehanite and AX. Authorities also approved the construction work before the tests were started.

The composting tests started in the beginning of November 2020 and ended in November 2021. Post-maturing will continue until May 2022. Figures 21-27 will visualize the test arrangements.

Figure 21. Wastewater collection system

Aeration and heating system was installed in order to ensure the sufficient oxygen level in the composting test heaps and need for heating during the wintertime (Fig 22-23).


Figure 22-23. Left: Aerating and heating system pipelines in the base of the composting test heaps. Right: Fan for heating and aerating and a dam for collecting wastewater samples.


Figure 24-25. Wood ships, foundry dust, animal manure before weighting and mixing into composting heaps.

Figure 26. Two industrial scale test heaps in summer and wintertime.

Figure 27. Test heaps under construction.

Temperatures were measured regularly (manually) in order to follow the composting progress. When the temperatures were decreased the test heaps were mixed or aeration or heating in wintertime was increased.

8.2 Temperatures

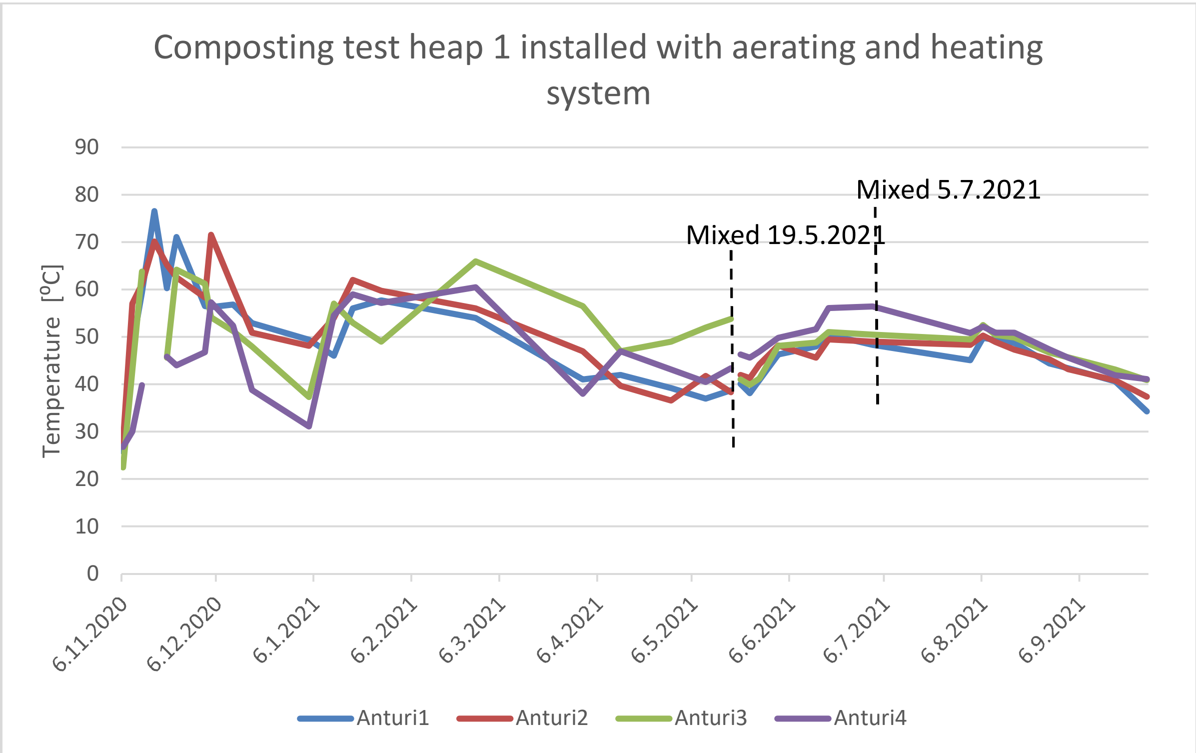

Figure 28. Temperatures in the Composting test heap 1.

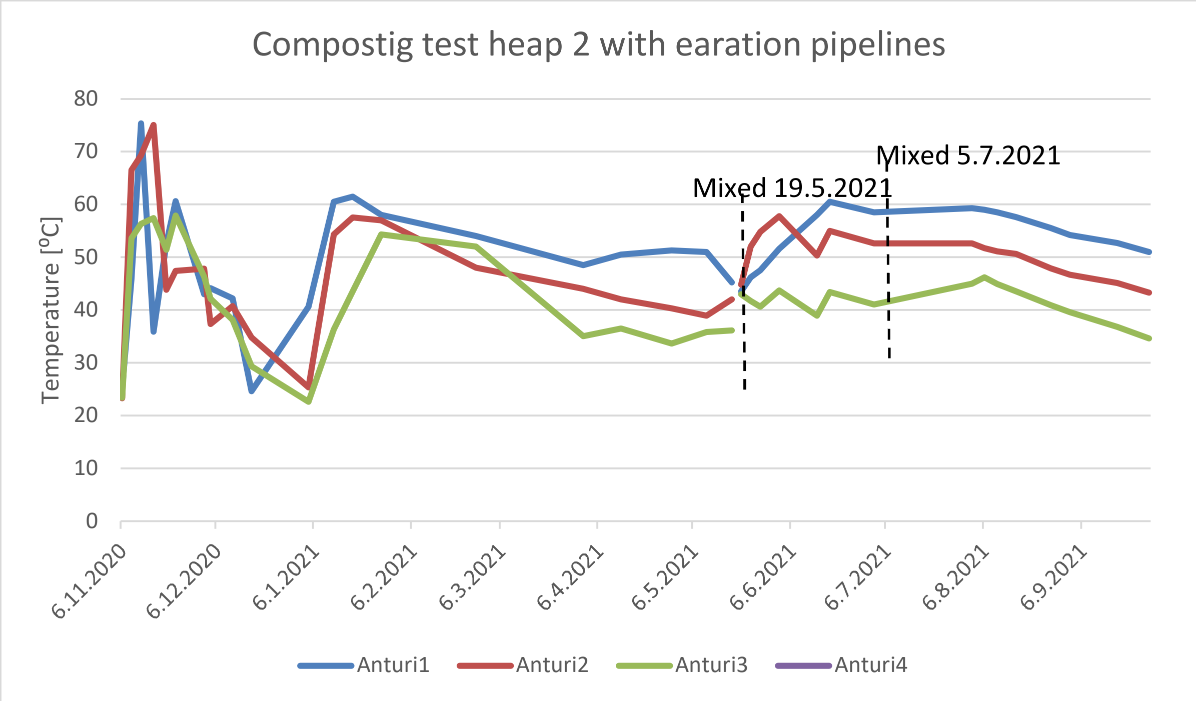

Figure 29. Temperatures in the composting test heap 2.

Based on the temperature measurements the composting processes were successfully and the materials were well hygienized. The requirements for the treatment of composting material in accordance with MMM Decree 24/11 require that the waste material must be treated by composting so that it reaches a temperature of at least 55 ° C for two weeks.

9 Test results

9.1 pH

At the beginning of composting, the pH may drop, but rise again during the maturation of the compost. The pH of the neutral is 7. The pH of the foundry dust was 3,6 before mixing in the compost heaps. The pH values of the compost materials were close to neutral throughout the whole experiment (about pH 6). The pH of the mechanically aerated compost heap 1 was slightly higher than the pH of the non-mechanically aerated heap 2.

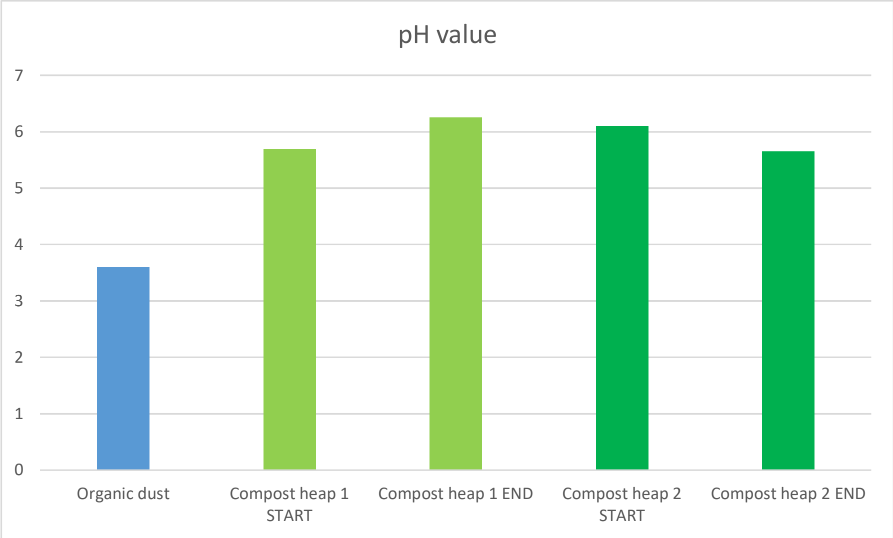

Figure 30. pH values during the composting tests.

9.2 Dissolved organic carbon

The dissolved organic carbon (DOC) content of the foundry dust did not exceed the limit value set for inert waste (500 mg / kg dm). When foundry dust and other organic materials (animal manure and wood material) were mixed with the compost, DOC concentrations naturally increased (Fig. 30). During composting process, DOC concentrations decreased in both heaps and were below the limit value for inert waste at the end of the experiment.

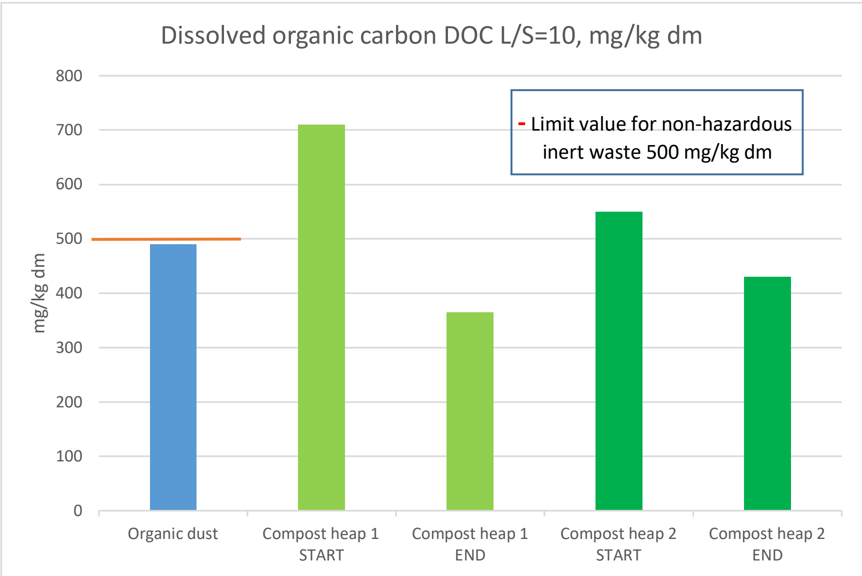

Figure 31. DOC concentrations during the composting tests.

But, there are no limit values for DOC or TOC in the Fertilizer Regulation (24/11), so any exceedances of the limit values for inert waste do not block the reuse of the cleaned mixed soil material in green construction purposes.

9.3 Fluoride

The fluoride content of the foundry dust exceeded the limit value set for inert waste (10 mg / kg dm), but at the end of the compost tests the concentrations were close to the limit value in both heaps taking. uncertainty. The fluoride in the foundry dust origins from the feeders used in the casting. There is no limit value for fluoride in the Fertilizer Regulation set for mixture soil material.

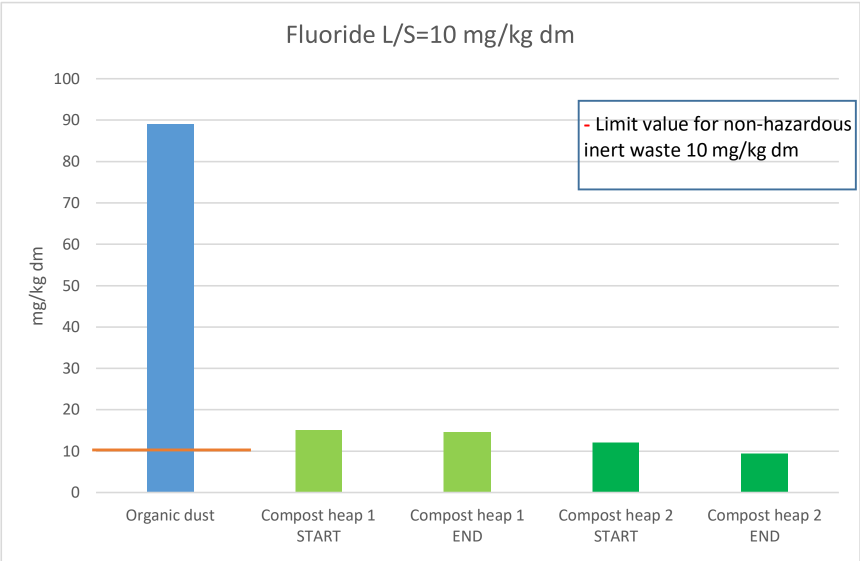

Figure 32. Fluoride concentrations during the composting tests.

9.4 Sulphate

The sulphate concentration in the foundry dust exceeded the limit value set for inert waste (1000 mg / kg dm). After mixing in the compost heaps the concentration decreased but increased slightly during the experiment in both heaps. There is no limit value for sulphate in the Fertilizer Regulation set for mixed soil.

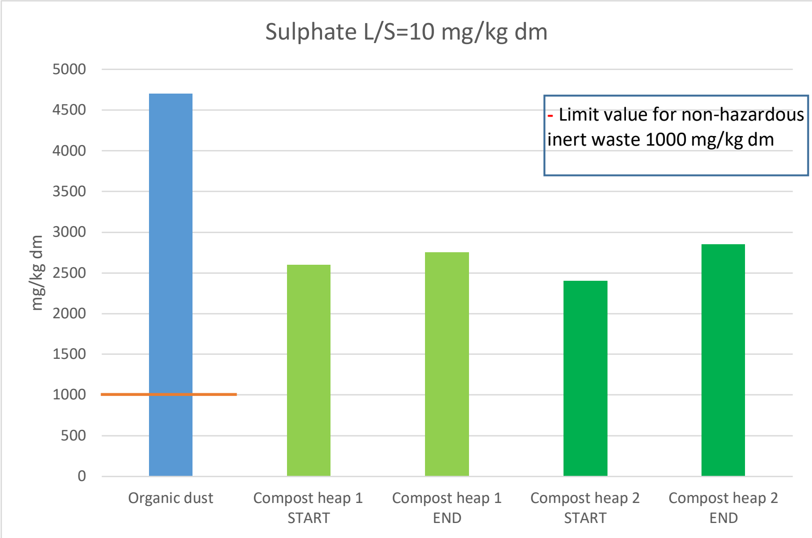

Figure 33. Suphate concentrations during the composting tests.

9.5 Chloride

The chloride does not come from foundry dust but from the horse manure. Chloride compounds are salts which are added in the horse food. Horse manure is organic fertilizer material that is used in the composting process. There is no limit value for chloride in the Fertilizer Regulation set for mixture soil material.

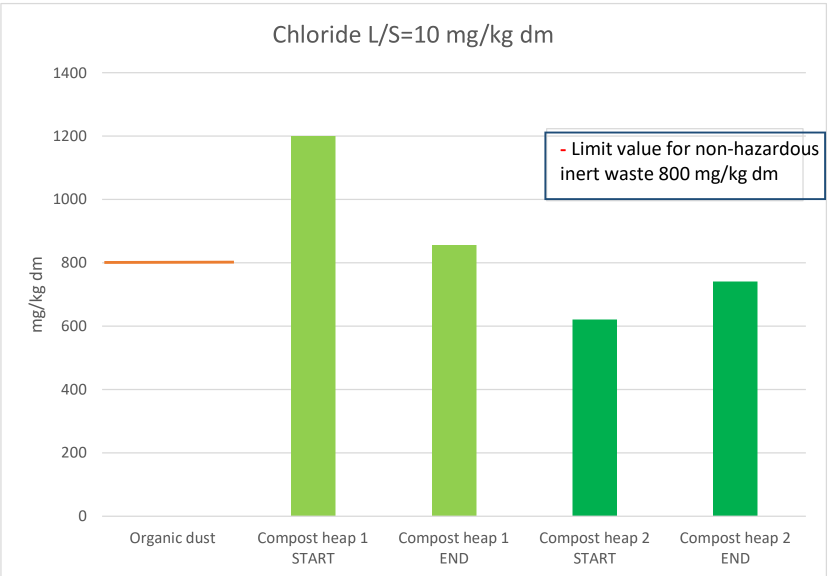

Figure 34. Chloride concentrations during the composting tests.

9.6 Dissolved and total metals

The concentrations of soluble nickel and zinc in the foundry dust exceeded the limit values for inert waste from landfills 331/2013 of the Decree regulation. At the end of the composting experiments, the concentrations of these metals were below the limit values of both the inert waste and the Fertilizer Regulation.

Table 5**.** Foundry dust and compost test material results in the beginning and end of the compost tests related to dissolved metal and total metal concentrations and limit values set for compost end-product (inert waste limit values are marked with yellow).

Analysis		Organic binder system dust	Compost heap 1, START	Compost heap 1x, END	Compost heap 1y, END	Compost heap 2, START	Compost heap 2x, END	Compost heap 2y, END	Limit value for non-hazardous inert waste	Limit value for compost product (current)	Limit value for compost product (future)
Soluble in water											
Antimony (Sb), L/S=10	mg/kg dm	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,06	-	-
Arsenic (As), L/S=10	mg/kg dm	<0,01	<0,01	<0,01	<0,01	<0,01	0,01	0,01	0,5	-	-
Barium (Ba), L/S=10	mg/kg dm	0,64	0,04	0,06	0,07	0,05	0,09	0,08	20	-	-
Cadmium (Cd), L/S=10	mg/kg dm	0,04	<0,003	<0,003	<0,003	<0,003	<0,003	<0,003	0,04	-	-
Chromium (Cr), L/S=10	mg/kg dm	0,06	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,5	-	-
Copper (Cu), L/S=10	mg/kg dm	2,09	0,08	0,28	0,28	0,09	0,32	0,31	2	-	-
Lead (Pb), L/S=10	mg/kg dm	0,01	<0,01	<0,01	0,01	<0,01	<0,01	<0,01	0,5	-	-
Molybdenum (Mo), L/S=10	mg/kg dm	<0,01	<0,01	0,12	0,17	0,01	0,10	0,08	0,5	-	-
Nickel (Ni), L/S=10	mg/kg dm	10,4	0,07	0,19	0,17	0,09	0,18	0,20	0,4	-	-
Selenium (Se), L/S=10	mg/kg dm	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,1	-	-
Zink (Zn), L/S=10	mg/kg dm	171	0,2	0,9	0,8	0,2	1,4	1,5	4	-	-
Mercury (Hg), L/S=10	mg/kg dm	<0,002	<0,002	<0,002	<0,002	<0,002	<0,002	<0,002	0,01	-	-
Total amount (aqua regia digestion)											
Antimony (Sb)	mg/kg dm	<1	<1	-	-	<1	-	-	-	-	-
Arsenic (As)	mg/kg dm	2,9	1,3	<5,1	<5,1	1,7	<5,1	<5,1	-	25	40
Barium (Ba)	mg/kg dm	78	65	-	-	63	-	-	-	-	-
Cadmium (Cd)	mg/kg dm	<0,2	<0,2	0,22	<0,2	<0,2	<0,2	0,79	-	1,5	1,5
Chromium (Cr)	mg/kg dm	37	25	39	40	24	36	29	-	300	-
Copper (Cu)	mg/kg dm	151	79	77	94	76	79	76	-	600	200
Lead (Pb)	mg/kg dm	9	5	4	4	14	5	5	-	100	120
Molybdenum (Mo)	mg/kg dm	13	7	-	-	6	-	-	-	-	-
Nickel (Ni)	mg/kg dm	59	34	35	46	35	36	38	-	100	50
Zink (Zn)	mg/kg dm	442	227	200	270	217	240	210	-	1500	500
Mercury (Hg)	mg/kg dm	<0,07	<0,07	<0,07	<0,07	<0,07	<0,07	0,08	-	1	1
Chromium (Cr) VI	mg/kg dm	-	-	-	-	-	-	-	-	-	2

Based on the results in the table above, the compost end-product was clean and free from contaminants and met the requirements and limit values set for mixture soil material.

9.7 Maturity test results

In addition to the chemical analyses and compounds limit values the clean compost material must be mature. The maturity of the compost means that the material is suitable as soil improver, in which case the harmful compounds to the plants have been decomposed during composting process. This is more clearly described in the section 6.7 Maturity tests.

Table 6. Compost maturity test results.

Compost maturity results		Compost heap 1 END	Compost heap 2 END	**Limit value of Fertiliser Product Decree 24/11**
Germination test	%	90,5	91,5	>80
Root lenght index	%	74,5	81,5	>80
Carbon dioxide production	mg C/g volatile solids	0,32	<0,2	<2
NO3-N	g/kg tp	0,015	0,0455	
NH4-N	g/kg tp	0,0035	0,0095	
NO3-N/NH4-N-ratio		4,3	4,8	>1
E. coli (Includes meth. ISO 9308-2:2014)	MPN/g (represents result of pmy/g)	57,5	<10	<1000 pmy/g
Salmonella (NMKL 71)	/ 25 g	Not detected.	Not detected.	Not detected.

Figure 35. Compost material maturity test results.

Based on these maturity test results, the compost material in both compost heaps is mature and suitable as a raw material for the growing media used as a soil improver and for green construction purposes.

Post maturing continued until 05/2022 and progress was monitored regularly. The clean and hyginised material was used in the landscaping purposes at the noice embankment.

9.8 Wastewater

Analysis	Unit	Compost heap 5/2021	Compost heap 8/2021	Compost heap 10/2021	Limit value[1]	Limit value[2]
Solid Matter	mg/l	39	9,6	140	**	300*
Electrical Conductivity (25 °C)	mS/m	400	610	290	-	-
pH	mg/l	6,5	7,2	6,9	6,0-11,0	6,0-11,0
CODCr	mg O_2/l	420	540	590	-	-
BOD7-ATU, liukoinen	mg/l	8,5	-	5,3	**	-
DOC	mg/l	110	190	130	-	-
Total Nitrogen , TNb	mg/l	19	26	27	-	-
AmmoniumNitrogen	mg/l	3,1	7,1	2,5	-	-
Total Phosphorus	mg/l	1,3	2,2	5,2	-	-
Chloride (Cl^-)	mg/l	450	650	270	**	-
Sulphate (SO_4)	mg/l	1200	1800	720	400	400
Fluoride (F^-)	mg/l	0,21	0,33	0,61	-	-
Total Metal concentrations						
Antimony (Sb)	mg/l	<0,001	<0,001	<0,001	-	-
Arsenic (As)	mg/l	0,0044	0,005	0,0067	0,1	0,1
Mercury (Hg)	mg/l	<0,0001	<0,0001	<0,000	0,01	0,01
Cadmium (Cd)	mg/l	0,0016	0,0014	0,0011	0,01	0,01
Cobalt (Co)	mg/l	0,15	0,13	0,069	-	-
Chromium (Cr)	mg/l	0,0055	0,0035	0,015	1	1
Copper (Cu)	mg/l	0,27	0,29	0,35	2	2
Lead (Pb)	mg/l	0,0034	0,0021	0,010	0,5	0,5
Nickel (Ni)	mg/l	0,25	0,23	0,19	0,5	0,5
Zink (Zn)	mg/l	0,11	0,13	0,29	3	3
Vanadium (V)	mg/l	0,0062	0,0054	0,0240	-	-
Organic compounds						
Phenol Index	mg/l	<0,05	-	-	-	-
PAH compounds, sum	mg/l	n.c.	-	-	-	0,05
BTEX compounds total	mg/l	n.c.	-	-	3	3
Total Hydrocarbons (C10-C40)	mg/l	<0,02	-	-	100	100
Petrol fractions C5-C10	mg/l	<0,05	-	-	-	-

n.c. = incalculable, because all the concentrations were below detection limits.

[1]The limit values for waste water received by Tampere Vesi on 1.1.2016.

[2]Limit values for effluents discharged to HSY's wastewater treatment plants on 20.12.2021.

* Construction site solids

** A limit value can be set on a case-by-case basis

Wastewater samples demonstrated high sulphate concentrations at the beginning and middle of the test, due to the high sulphate concentrations in the foundry dust. However, the sulphate content of the effluent decreased significantly towards the end of the test (1800 →720 mg / l). No other limit values were exceeded in the compost test effluents. The pH of the effluent was neutral throughout the compost test.

9.9. Conclusions of the industrial scale composting tests

The purpose of these tests was to degrade the organic harmful substances of foundry dusts or foundry sands by composting method and produce clean compost material (mixed soil material) suitable for green construction applications. The end-product met the limit values set for mixture soil material in the MMM Fertilizers Regulation (24/11) and concerning the harmful metals and organic pollutants in the decree of inert waste landfills (331/2013). Based on the results the soil material can be reused as surface and landscaping material e.g. in the noise embankments.

10 References

Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2)

Government Decree of landfills (331/2013)

SFS-EN 12579 Soil improvers and growing media. sampling.

VTT 2006: Kompostin kypsyystestit – Menetelmäohjeet. VTT Tiedotteita 2351. (in English: Compost Maturity Tests – Method Instructions.)