LIFE17 ENV/FI/000173

Green Foundry

1/7/2018-30/6/2022

Action B.4 Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts

DeB4.4 Conclusions of the results of waste sand cleaning methods

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Date: 30.4.2021

1. Introduction

In this report the results of the three waste sand cleaning methods which have been tested in the Action B4 Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts are summarized. The cleaning methods in question are

- B4. 1 Cleaning by composting method,
- B4.2 Cleaning by thermal reclamation method and
- B4.3 Cleaning by washing method.

The results and experiences are presented by following categories:

- *cleaning efficiency*
- *construction,*
- *operation,*
- *costs and*
- *capacity*

Each test run has been monitored, analysed and documented. Analyses have been taken in the beginning and in the end of each test and results are reported in individual project deliverables. In this report the main results are summarized and compared on environmental, cleaning efficiency, investment and running costs perspectives.

Current use of foundry waste sand

The summary of the actual and potential reuse applications of different types of spent foundry sand in Europe is shown below.

Summary of the possibilities of reusing foundry waste	Spent Foundry Sands (SFS)					
	Green sand	Alkaline phenolic	Phenolic urethane	Furan resin	Shell resin	Sodium silicate
Asphalt	X	X	+	O	+	O
sand and gravel ballast						
Manufacture of blocks	+	X	+	+	X	+
Brick production	X	X	+	+	+	
Cement	X	X	+		X	X
Coarse aggregate substitute						
Concrete		X	+	+	+	
A substitute for fine aggregate	X	X	+	+	+	+
Foam concrete	X	X	+			
Insulation / glass / mineral wool	+	+	+	+	+	+
Production of lightweight aggregate						
Mortar production						+
Substrate for road structures		X	+		+	X

X - confirmed use of reuse
+ - a re-use application that has been theoretically proven, but there is no ongoing research project,
O - not suitable for re-use unprocessed

Finland: Currently over one third of annual foundry waste sands (aprox 94.000 tons*) is landfilled, 64.896 tons is used for geo-construction purposes and 10.000 tons is treated by the Figure 1. thermal reclamation and recycled back to foundry processes.

*Arenas y Finos, Total (t) 119.683 35.004 209 154.896. FEAF Boletin nº4 2021

Spain: Currently over half of annual foundry waste sands (approx. 150.000 tons) the major applications are the following: landfill (58%), in cement production as silica carrier in mortar (38%), kiln (2%), in the brick industry low-quality ceramics (1%) and in asphalt as a filler (1%), see figure 1.

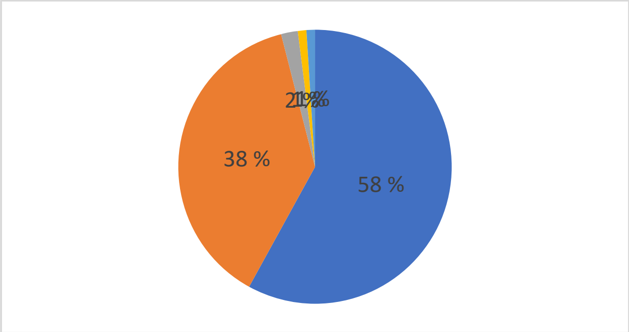

Figure 1. The applications of foundry waste sand in Spain (Source: FEAF, Spanish Federation of Foundry Associations)

2. Composting method

2.1 Regulations in Finland and Spain for compost end-material

Finland:
The mature and clean compost end-product to be used in geo-construction and green construction purposes as *mixture soil material* must fulfil the national regulations and limit 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). There is also a following demand in this regulation:

"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". This demand applies when the foundry sand is mixed with the composting material *in the end of the composting process*.

Foundry sands or dusts rarely fulfil all the limit values set in the *Government Decree of landfills (331/2013)* and therefore waste sands must be treated by a cleaning process in order to be re-used in other applications. One reuse application is that foundry waste sand is *mixed with composting material in the beginning of the composting process* and harmful substances will be degraded by the microbiological activity during the composting process. The cleaning process will take approximately 5-6 months.

For mixture soil material there are no limit values for organic substances (Decree 24/11) because the compost end-product is used as organic material. Organic substances (DOC, TOC, sulphate) in the compost end-product do not cause any problems in utilizing the mixture soil material in growing media purposes. Concerning *harmful metals the compost end-product must also fulfil limit values set for the non-hazardous inert waste in the Government Decree of landfills (331/2013)*.

Spain
As the pertinent laws and guidelines on compost, fertilizer and organic substances are Europe wide, the Spanish legislation and limit values are in line with the Finnish legislation (http://www.euskadi.eus/web01-a2inghon/es/contenidos/informacion/leg_residuos/es_def/index.shtml).

2.2 Results of composting tests in Finland and Spain

In Finland we have carried out composting tests with
1. Phenolic Alphaset binder system waste sand and dust (organic),
2. Furan binder system dust and (organic)
3. Inorganic binder system waste sand (inorganic)

In total 337 tons of composting materials have been treated and cleaned by composting method. The proportions of foundry waste sand and dust in the composting test heaps have been between 20-30%. Other organic materials like animal manure and wood chips were added into the composting heaps.

In Spain we carried out composting tests with:
1. Silicate binder system (inorganic) - combined waste foundry sand and dust (75% and 25% respectively)
2. Bentonite binder system (organic) - washed green waste foundry sand (partially cleaned prior to composting)
3. Inotec ecological binder system (inorganic) - waste sand from cores

In Spain the total weight of material composted was 120 tons of which WFS compromised approx. 20%.

Fig 2. Composting test heaps 20 tons each in Finland.

Analyses were gathered from waste sands and dusts before mixing into the composting heaps. Analyses are also gathered from the composting materials in the beginning of the composting tests (after mixing all materials together) and then after the end of the composting test period (about 5-6 months).

Fig 3. Sample procedure.

Spain

Analysis of WFS was carried out prior to use. Subsequent analysis was carried out at the start, in the middle, and at the end of composting (timing based on temperature readings). Overall time 5-6 months. Prior to use as fertilizer, the 5-6 month old compost needs to be matured (minimum 6 months) and further analysed.

Results of composting tests with *organic binder* system waste sands and dusts (Tarastenjärvi, Finland)

Degradation of harmful substances of the foundry waste sands or dusts are followed by analysing the composting materials during the test. Duration of composting test was on average 5-6 months in different test heaps. Additionally, the post-maturing will continue about 6 months. Total composting process will take at least 12 months after which the compost end-product is clean and mature and ready to be re-used for green construction purposes.

In Table 1, composting test results of the *organic binder system (Phenolic sand) waste sands and dusts* are presented. The composting test heaps were started in July 2019 and completed in June 2020.

The degradation of harmful substances of organic binder system dust (compost heap number 1) and waste sand (compost heap number 2) during the composting tests are illustrated below.

Table 1. Degradation of the harmful substances of organic binder system waste sands and dusts during the composting test (L/S=10).

	Dust	Silo sand	Limit value for non-hazardous inert waste	Compost heap 1 (dust) START	Compost heap 2 (sand) START	Compost heap 1 (dust) END	Compost heap 2 (sand) END	**Compost heap 1 (dust) Degradation efficiency**	**Compost heap 2 (silo sand) Degradation efficiency**
DOC, mg/kg dm	4500	1600	500	7800	4700	2100	1700	**73 %**	**64 %**
Phenol index, mg/kg dm	1,20	2,10	1	5,5	1,4	<0,10	<0,10	**98 %**	**93 %**
Fluoride, mg/kg dm	180	23	10	39	6	21	<5,0	**46 %**	**17 %**

DOC, phenol and fluoride concentrations exceeded the non-hazardous inert waste limit values before the composting tests. Also some small molybdene concentrations were detected in waste sand and dust samples. All these compounds were reduced during the composting process.
In the end of the composting tests *all concentrations were under the limit values set for mixture soil material (Decree of Fertilisers 24/11).* After post-maturing period of 6 months the mixture soil materials were mature and ready to be re-used in green construction purposes.

In Table 2, composting test results of the *organic binder system (Furan sand) foundry dusts* are presented. The composting test heaps started in June 2019 and completed after 12 months.

TOC, DOC, BTEX, fluoride and sulphite concentrations exceeded the non-hazardous inert waste limit values before composting tests. After composting process BTEX, fluoride concentrations were below inert waste limit values. Nickel and zinc concentrations exceeded the non-hazardous limit values in dust samples but after composting process these were below the limit values.

As a conclusion the compost end-product fulfilled the Fertiliser Decree 24/11 limit values and the harmful metals were under limit values set for inert waste (Decree 331/2013). After post-maturing the mixture soil material can be used for green construction applications.

Table 2. Degradation of the harmful substances of *organic binder system* foundry dusts during the composting process (L/S=10).

	Dust	Limit value for non-hazardous inert waste	Compost heap 1 (25%) START	Compost heap 2 (30%) START	Compost heap 1 (25%) END	Compost heap 2 (30%) END	**Compost heap 1 (25%) Degradation efficiency**	**Compost heap 2 (30%) Degradation efficiency**
TOC, % dm	12	3	23	25	20	20	**13 %**	**20 %**
DOC, mg/kg dm	2700	500	10000	9800	970	930	**90 %**	**91 %**
BTEX, mg/kg dm	7,38	6	2,60	2,50	0,30	0,29	**88 %**	**88 %**
Fluoride, mg/kg dm	36	10	17	12	8,9	8,9	**48 %**	**26 %**
Sulphate, mg/kg dm	3200	1000	3700	3500	2000	2000	**46 %**	**43 %**

Results of *inorganic binder system* waste sands in Finland

Tested inorganic binders are all 100 % inorganic material but some manufacturers use small amount of organic compounds in the hardener to enable that the sand moulds are hardened in the room temperatures.

At Karhula Foundry *three different inorganic binder systems were tested* in sand moulds and samples analysed. Only one inorganic binder system was used in composting tests because there were no major differences between these inorganic binder system waste sands.

Based on the analyse results ***only one inorganic binder system type sand samples (A1-A3) fulfilled*** *all the limit values set for* ***the non-hazardous inert waste values*** *(Decree of 331/2013) and for* ***wastes suitable for earth constructions*** *(Decree of 873/2017)* (Table 3). But also with inorganic binder system organic compounds were detected varying from 37-230 mg/kg dm (limit value for DOC 500 mg/kg dm).

In some inorganic binder system samples *DOC and fluoride concentrations were slightly above the limit values for non-hazardous inert waste (Decree of 331/2013) and wastes suitable for earth constructions (Decree of 873/2017)* for certain reuse applications. DOC concentrations origin from the hardener where small amount of organic substances can be present (1,5-3%). Fluoride concentrations might origin from the sand used for test purposes which was 70% recycled and 30% virgin sand as commonly used in foundries for the moulds.

As a comparison in Table 3 both the inorganic and organic binder system sand samples results are presented for main compounds.

Table 3. Results of different inorganic and organic binder system waste sands samples

		INORGANIC SANDS						ORGANIC SANDS		
		Sample A1	**Sample A2**	**Sample A3**	**Sample B1**	**Sample B2**	**Sample C**	**Sample D**	**Sample E**	**Limit value for non-hazardous inert waste**
Dissolved organic carbon (DOC)	mg/kg dm	90	37	230	**640**	**680**	**610**	**1600**	**4500**	**500**
Phenol index	mg/kg dm	<0,1	<0,1	0,11	<0,10	<0,10	<0,10	**2,10**	**1,20**	**1**
Fluoride	mg/kg dm	<5	5,5	<5,0	<5,0	**41**	**32**	**23**	**180**	**10**
Molybdenum (Mo) (mg/kg LS = 10 l/kg)	mg/kg dm	0,04	0,02	0,03	0,03	<0,01	<0,01	0,02	**1,08**	**0,5**

In spite of the higher DOC concentrations (above the limit value of 500 mg/kg dm) the inorganic binder system waste sands could be mixed in the compost material also in the end of the composting process since there is no need for actual cleaning process. But during the composting process potential harmful organic substances can be degraded and therefore it is recommended that foundry waste sands are added in the composting process in the beginning of the process. But there are no limit values for DOC concentration for fertilizer product as compost material.

Since the concentrations of harmful substances in the inorganic waste sand samples were not high in the beginning of the composting tests, the degradation of the harmful substances during composting process were minor. These results should be regarded as trend-setting and changes also between same type of inorganic binder system sand samples occur.

As a conclusion the result demonstrate that there are far less organic compounds present in the inorganic binder system waste sands compared with the organic binder system waste sands. Also by using inorganic binders the emissions in the casting process are reduced by 70-80% as demonstrated in the measurements and this was one of the objectives set for the Green Foundry project.

Spain

Table 4. Degradation of the harmful substances contained in inorganic binder system WFS during the composting process (L/S=10)

	Sand	Limit value for non-hazardous inert waste	Compost heap 1 (sand) START	Compost heap 1 (sand) END	**Compost heap 1 Degradation efficiency**
Chlorides, mg/kg dm	<50,00	800	928	841	9%
Mineral oil, mg/kg dm	<20,00	500	<34	<20	41%

Degradation occurred in all harmful substances, the minimum level of efficiency being 9% in chlorides and the maximum being 41% in Mineral oil.

Table 5. Degradation of the harmful substances contained in organic binder system WFS during the composting process.

	Sand	Limit value for non-hazardous inert waste	Compost heap 1 (sand) START	Compost heap 1 (sand) END	**Compost heap 1 Degradation efficiency**
TOC, % dm	<0,10	3	1,65	1,18	28%
BTEX, mg/kg dm	<0,04	6	<0,15	<0,04	73%
Mineral oil, mg/kg dm	<20,00	500	67	<20	70%

Degradation occurred in all harmful substances. Note that there was a wider range between minimum and maximum efficiency compared to inorganic binder. Its higher carbon content lends itself better to biodegradation. The minimum level of efficiency being 28% in TOCs, and the maximum being 73% in BTEX. Mineral oil degradation efficiency was 70%.

Table 6. Degradation of the harmful substances of eco-inorganic binder system waste foundry sand during the composting process (L/S=10)

	Sand	Limit value for non-hazardous inert waste	Compost heap 1 (sand) START	Compost heap 1 (sand) END	**Compost heap 1 Degradation efficiency**
DOC, mg/kg dm	77,5	500	1000	640	36%
TOC, % dm	<0,10	3	21,3	16,8	21%

Degradation occurred in all harmful substances. Note that there was a smaller range between minimum and maximum efficiency compared to both organic and inorganic binders. The minimum level of efficiency being 21% in TOCs, and the maximum being 36% in DOC.

Based on the composting tests with inorganic binder system waste sands we demonstrated that tests were successful and the compost end-products (mixture soil material) fulfilled the limit values set of Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011. The mixture soil can be used for green construction and gardening purposes.

2.3 Constructing the composting field site

The composting tests always need *an environmental permit* from authorities in Finland and also in Spain. There must be a water-tight surface layer to avoid any contamination of the surroundings or ground water. Ground water areas should be avoided. A water-tight double-layer concrete asphalt is used for permanent applications for composting process surface, but a waterproof film structure could be used for small scale composting test purposes. Virgin sand is used on top of the film layer. It is not allowed to enter drive with any vehicle on the film area. Waste waters from the composting field are gathered to a separate container, where only waste waters from the composting field are conducted. Proper lines for waste waters to the container/sink must be constructed. Other effluents from the surroundings must be prevented.

Fig. 4-5. Constructing the composting test field.

Waste waters are analysed approximately three times during each composting test period and treated according to the environmental legislations and authority instructions. The container will be drained e.g. to a local wastewater treatment company.

Fig. 6 Waste water collection pipelines and a container.

Composting materials are analysed according to the regulations set by the authorities and according to the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011) for Substrate – Mixture soil (5A2). For harmful metals the compost material must fulfil the limit values set for the non-hazardous inert waste in the Government Decree of landfills (331/2013).

All results are reported to the responsible authority and conditions and regulations related to end-user process are clarified. Composting materials are analysed in the beginning and in the end of the composting test to be able to demonstrate the efficient degradation process during the composting process. After the composting process the post-maturing period of about 6 months is needed in order that the mixture soil material is mature and there are no growth preventive materials existing in the mixture soil.

For successful composting process an *aeration system is recommended* to improve the oxygen content of the composting material. Therefore, an aeration pipeline is constructed inside the composting heap and equipped with a fan. Electric power is needed for the fan of the aeration system. Aeration is recommended in the beginning of the composting process to start the microbe activity effectively.

A *storage site for raw materials* (manure, waste sands, wood chips) is also needed. The raw materials can be stored next to the site only couple of weeks before constructing the composting heaps.

Odors and emissions. In case the composting site locates near the settlement there can occur smell expressions while constructing the composting heaps or after mixing the heaps during the composting process. Mixing is made approximately 2 times during the 6 months composting period. Constructing the heaps is not recommended on a windy weather also to avoid any potential dust problems.

Total emissions from composting heaps were measured during in the Foundrysand LIFE project in 2015-2016. Based on these results there were higher concentrations of ammonia, CO, formaldehyde, benzene and odours in the beginning of the composting process. After 5 months most of the emissions were under the detection limits.

2.4 Costs of the composting process

Finland:

The cost calculation is based on a constructed, actual composting site in Finland. The cost calculation is based on the assumption, that the composting site is constructed specially for the treatment of waste foundry sand. The used land area is 30x150 m = 4500 m^2 and the planned annual composting capacity is 1000 tons.

The construction costs involved:

- Cutting of the trees and cleaning the area by bulldozer: 3000 €
- Adding filler sand: 5000 €
- Covering foil: 4000 €
- Wastewater pipes: 1000 €
- Wastewater tank: 2000 €
- Pump for circulating wastewater: 1000 €
- Aeration equipment ie. fan and tubes: 15000 €
- Electric power line: 2000 €
- A cabin for aeration equipment: 5000 €
- Total construction cost: 35000 €.

The cost of the land area is not calculated. For the operating time of 10 years, annual fixed cost without interest is 3500 €.

The annual running and maintenance costs:

- Animal manure or similar organic material (only transportation cost): 1000 €
- Wood chips and sticks: 500 € (90 % of the sticks are circulating in the process)
- Electric power: 1000 €
- Turnover of the composting heaps (4 times a year, 4x2 days by excavator): 4000 €
- Emptying of the wastewater tank: 500 €
- Total annual running costs: 7000 €

Total annual costs are: fixed costs 3500 € + running costs 7000 € = 10500 €. On average about 30% waste foundry sand can be added to the compost. The annual capacity of 1000 tons of compost means that 300 tons of waste sand can be treated in this site. The ton wise cost of composting treatment for waste foundry sand is accordingly 10500 €/300 tons = 35 €/ton.

Waste foundry sand, on the other hand, substitutes screened natural sand which is added to compost which is used as soil improvement material. The cost of screened natural sand in Finland is ca. 5 €/ton. Thus **the actual cost of composting treatment for waste foundry sand is ca. 30 €/ton.**

The transportation cost of waste foundry sand is not included in the cost calculation. Normally it is not reasonable to transport sand over 100 km distance.

In the existing composting sites the cost of waste foundry sand treatment could be much lower. Typically composting companies utilize local cheap, of free of charge, organic materials such as animal or chicken manure, garden waste, collected biowaste, etc. To the vendible compost end products natural sand is normally added. Instead of natural sand, they can add waste foundry sand, which is transported to the site at the cost of foundries. It would also be possible to collect a gate fee from the foundries.

Spain:
Costs are essentially the same in Spain as in Finland, with the exception of the transportation cost which is slightly lower in Spain (approx. 5-10% lower). In Spain, compost producers traditionally source ballast sand from train manufacturers, chicken farmers and pig farmers. Today, WFS is also being used following the success of this project in the area of the Basque Country.

2.5 Capacity

The capacity of composting method depends on the area of the composting site. On average, it is possible to annually compost 2200 tons and accordingly treat ca. 660 tons of waste foundry sand in the area of 10000 m^2 = 1 ha.

If there is a need to treat annually 10000 tons of waste foundry sand, the size of the composting site must be about 10000/660 ha = 15 ha.

Spain:
Spanish capacity of composting method is the same

3 Washing method

In this document we analyze waste sand prior to and after washing in three scenarios:

- Inorganic binder system waste foundry sand (lab scale washing trials by Tecnalia)
- Organic binder system waste foundry sand (industrial scale washing by Ecofond)
- Inorganic binder system foundry sand (industrial scale wet attrition by AKW Apparate + Verfahren GmbH Technical Laboratory & Trials)

3.1 Washing method and regulations

Note: Original sup-supplier Ecofond unexpectedly closed down shortly after the project started. Tecnalia therefor stepped in to perform washing at laboratory scale using its own method.
Ecofond supplied sand which had been through their washing method and was later analysed by Tecnalia for comparison purposes, however, their exact washing method is under Ecofond intellectual property. Consequently, in this report we describe the Tecnalia washing method.

Washing Method (Leaching)
The principle behind the method was that by using basic chemical products (5M hydrochloric acid and distilled water) contaminated moulding sand could be cost-effectively washed and made reusable.

The quantities of unwashed sand started at 30 grams, and as the experiments progressed, were scaled up to 450g. In all, approx. 100 kilos of sand were washed.

Washing method: Step one was to wash the sand with distilled water in an Erlenmeyer flask. This was then analyzed for pH and rewashed using fresh water until the level obtained by washing in water stabilized, i.e. no further reduction. Once pH showed no further change, step two was to add the damp sand to another Erlenmeyer flask containing HCl (hydrochloric acid). This was then mixed with a magnetic agitator for eight hours. The solution was then filtered to separate the sand from the acid, and the pH level of the sand was checked. The sand was then returned to an Erlenmeyer flask containing fresh HCl to repeat the washing, agitation and analyzing process until the desired pH range was obtained twice, i.e. no further change.

The final stage was to dry the sand using a Mufla furnace. The dry sand was then ground for full chemical analysis.

The method explained in detail below shows the experiment conducted with a 450g sample of contaminated sand and material quantities.

Equipment and materials were:

- 5M HCl*
- Distilled water (50litres)
- Mufla furnace Tª max 230ºC
- pH flask
- Filter paper of 0.45 µm
- Precipitate glass of 2 litres
- Magnetic mixer (300rpm)
- Büchner funnels of 2 litres
- Erlenmeyer flasks of 2 litres

- Vacuum filtren system

*Data: Molecular mass=36.46 g/mol and mass density 1.18g/ml→ 633.19 ml HCl

Process for 450g sand (chemical quantities can be scaled up proportionately):

- Wash the sand with distilled water in a ratio of one-part sand to two parts water
- Check pH and repeat washing until ≤ 9.35 pH is achieved
- Filter the sand from the water and allow to air-dry
- Mix the air-dried sand with HCl 5M** for 8 hours using a magnetic agitator at 300 rpm
- ** (7.5 mol → 276.45 (37%)→ 747.16 grams HCl)
- The sand is further washed with the same ratio of distilled water to sand until the pH becomes neutral (≥7)
- The sand is filtered using filter paper of 0.45 µm
- Dry the sand in a mufla furnace at 105ºC for a further 3 hours
- Grind the wash sand and analyze it

The following figures show the different equipment used for washing sand.

Figure 7: Washing sand with distilled water

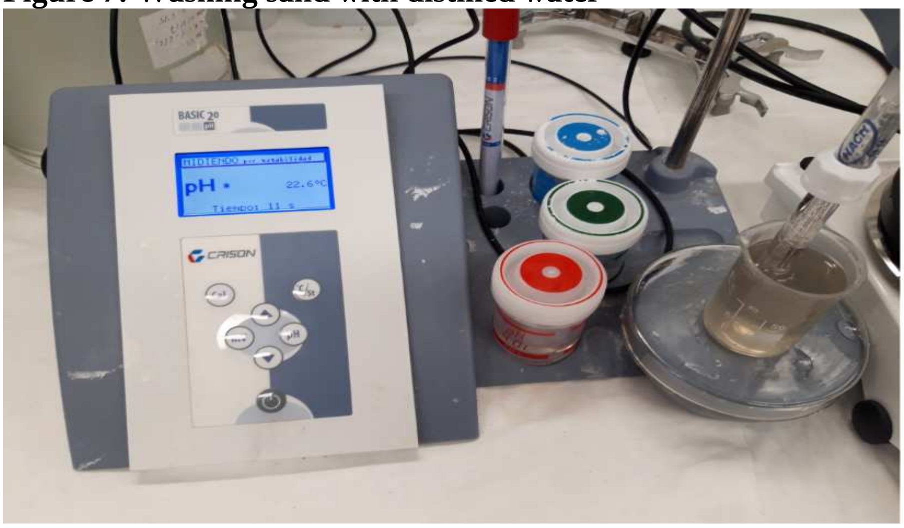

Figure 8: pH test during first washing

Figure 9: Büchner funnels equipment

Figure 10: Filtering the sand

Figure 11: Sands after washing

3.2 Washing method results

The tables below (1a and 1b) show the results of washing both organic and inorganic WFS. Note that inorganic WFS was washed at laboratory scale, while organic WFS was washed at industrial scale by Ecofond. The results from inorganic WFS trials were extrapolated for comparison purposes. These costs are based on the laboratory scale tests carried out in the Green Foundry LIFE project, not actual production size plant costs.

Table 7: Inorganic binder waste sand process before and after washing

Table 7a: The following table shows the results of scaling up to 30g sand before and after washing.

Total metal (mg/kg)	Before washing	After washing	Washing efficiency
Barium (Ba)	2.87	<2.00	30
Chromium (Cr)	16.80	<2.00	>100
Iron (Fe)	13,300.00	10,400.00	22
Molybdenum (Mo)	<1.00	<2.00	50
Nickel (Ni)	606.00	575.00	5
Zinc (Zn)	8.50	6.81	20

After washing 30g, the metal content of the WFS was reduced in all cases, most notably in Cr and Mo.

Table 7b: The following table shows the results of scaling up to 450g sand before and after washing.

Total metal (mg/kg)	Before washing	After washing	Washing efficiency
Barium (Ba)	7.85	4.55	42
Chromium (Cr)	15,800.00	163.00	99
Iron (Fe)	15,800.00	13,400.00	15
Molybdenum (Mo)	3.24	<2.00	38
Nickel (Ni)	718.00	640.00	11
Zinc (Zn)	13.20	10.50	20

After washing 450g, the metal content the WFS was reduced in similar proportion to the 30g sample, demonstrating that the process is suitable for scaling up. Note that in the case of Ba, higher starting levels lead to a greater reduction after washing.

Table 8: Organic binder waste sand process before and after washing

The following table shows the values for Total Heavy Metals in WFS before and after washing by Ecofond and analysis by Tecnalia. Approx. weight 3 tons.

Heavy metals (mg/kg)	Before washing	After washing	Washing efficiency
Aluminium (Al)	15,580.00	3,480.00	82
Barium (Ba)	70.60	24.70	65
Chromium (Cr)	31.20	14.70	53
Copper (Cu)	22.10	18.30	17
Iron (Fe)	11,500.20	5,750.00	50
Zinc (Zn)	106.00	55.90	53

The washing process reduced heavy metal values for Al, Sb, As, Fe, Ba, Cu, Cr, Se y Zn.
In the case of organic WFS there was sufficient quantity to analyse for other hazardous parameters. Although it was not possible to analyse inorganic samples for the same, the premise is that the process would be similarly effective. Further trials should be carried out to demonstrate this.

Other hazardous parameters (mg/kg)	**Before washing**	**After washing**	**Limit value for inert waste**	**Washing efficiency**
Fluorides	7.80	<5.00	10.00	36
Phenol	0.80	<0.50	1.00	38
DOC	480.00	169.00	500.00	65
TOC	8,900.00	<1,000.00	30,000.00	89
BTEX	0.22	<0.04	6.00	100

Fluorides, Phenol, DOC and TOC values were found to be lower than in unwashed sand .

3.3 Industrial scale process and set-up costs in Spain

Industrial scale process and set-up costs

For the purposes of this report, we have based costs on a covered plant of approx. 1,000m2 divided into goods- in (200m2), process area (500 m2), laboratory (80 m2), office (80 m2), and storage (140 m2). This would be staffed by four full-time employees. And the production would be 1000 ton per year.

Equipment:

Three tons pneumatically linked stainless steel vessels for the three-stage process. The first for mixing the WFS with distilled water, the second for adding the acid, and the third for rinsing with distilled water.

Equipment	Cost € /u
Stainless steel vessel distilled water	6,300
Stainless steel vessel mixer	6,300
Stainless steel vessel acid mixer	6,300
Water pipes	1,000
Pump for circulation	1,500
Aeration tubes and magnetics	15,000
Electric power line	4,000
Store silo 1 capacity 6 ton	3,500
Store silo 2 capacity 6 ton	3,500
TOTAL	47,400

Washing process costs:

There are two main consumable costs to take into account: chloric acid and distilled water.
The total HCl used would be aprox.1,400 l and distilled water 3,000 liters. (30,000€+20,000€) plus labarotory tests, such as, filters, 24,000€. If we recycled at least, 40% of the raw materials.

Total annual costs are fixed costs 3,500 € + running costs 17,000 € +raw materials 50,000+ 24.000= 94,500 €. If we recycled at least, 40% of the raw materials. The annual capacity of 1,000 tons of washing sand means that 1,000 tons of waste sand can be treated in this site. The ton wise cost of washing treatment for waste foundry sand is accordingly 94,500 €/1,000 tons = 9,45 €/ton. **The total cost will be 10 €/tn.** In this cost there are no waste water treatment method and annual treatment costs included.

Advantages and disadvantages of leaching methods (the above costs are calculated for the single acid and washing method):

Method	Advantages	Disadvantages
Single acid and washing	Acid solubilises most minerals such as phosphates, carbonates, sulphates depending upon the acid used	Not all the minerals are washed with just one acid
Stepwise acid Washings	Two acids could be used with the ability of one acid to remove those minerals which could not be removed in the earlier washings	The use HF, HCl and HNO3 would require special and rugged materials of construction of reactors.

3.4 Wet attrition method, results and cost estimations

These additional tests were made to get industrial scale results also for inorganic binder waste sands. The used treatment method is specific, combing wet treatment and mechanical attrition.
The interaction effects of this method and thermal reclamation treatment (chapter 4.) on the quality of reclaimed waste sand and treatment cost of is also discussed here.

Test procedure:

The tests were performed with so called AKA-DRUM, which is used for dissolving raw materials. The goal of these tests was to clarify the autogenous cleaning of inorganic foundry waste sands by removal of fines of the surface of grains by means of intensive wet stirring, see figure 12.

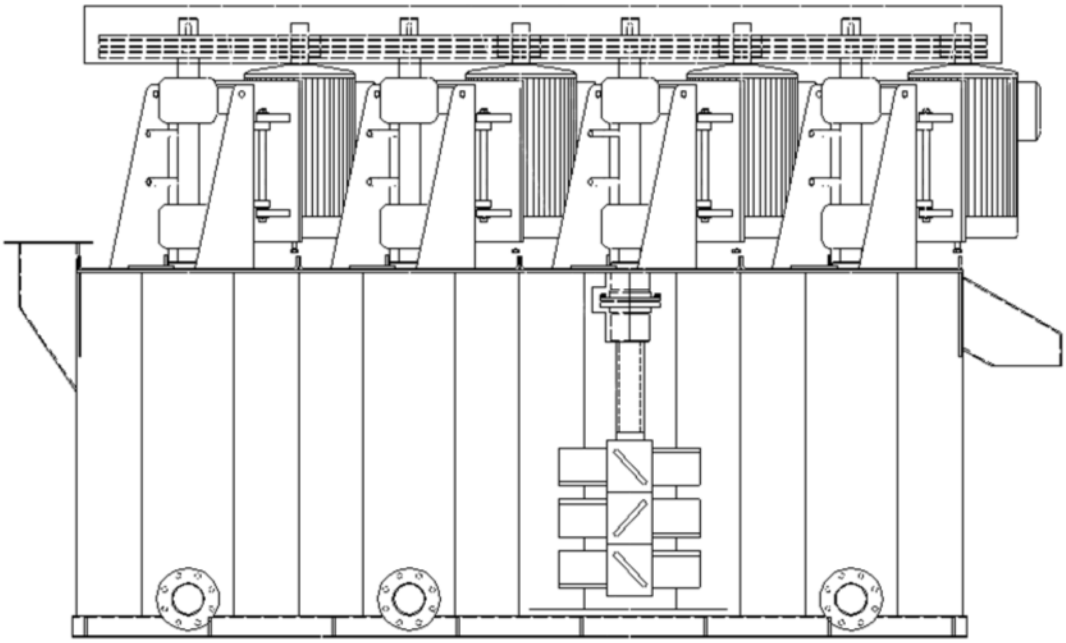

Figure 12. Principle image of the test apparatus.

The process of the wet attrition test consisted of four steps:

1. First the sample was classified with a 4 mm sieve
2. After sieving it was put through attrition. Solid content in these test was 1,3 kg sand/1 liters water. Attrition time was 5 minutes with 400 rpm
3. The sample was then deslimed
4. Sieved again with a 0,063 mm sieve

The grain size distribution and loss on ignition were then analysed in the lab. Microscopic pictures from the sand before and after the tests were also taken. The tests were conducted by AKW Apparate + Verfahren GmbH Technical Laboratory & Trials. Tests were done in June 2020.

Results:

Screening

Results of the initial screening, 4 mm sieve:

Screening at [mm]	[mm]	4
Residue	[Ma.-%]	4,4
Undersize	[Ma.-%]	95,6

Attrition

The parameters for the attrition test were as follows:

Solid content	[g/l]	1300
Rpm	[min^{-1}]	400
Attritioning time	[min]	5
Deslimed fraction < 0,063 mm	[Ma.-%]	0,9

The microscopic pictures taken from the samples show no visible change in the sample.

Figure 13. Sample before attrition

Figure 14. Sample after attrition

Loss of Ignition, LOI

The results of the LOI stay within the measurement accuracy unchanged. The LOI test was conducted in a temperature of 550° C.

Sample	Raw material	63-4000μm attritioned + deslimed
Loss on ignition in %	0,17	0,19

Final grain size distribution

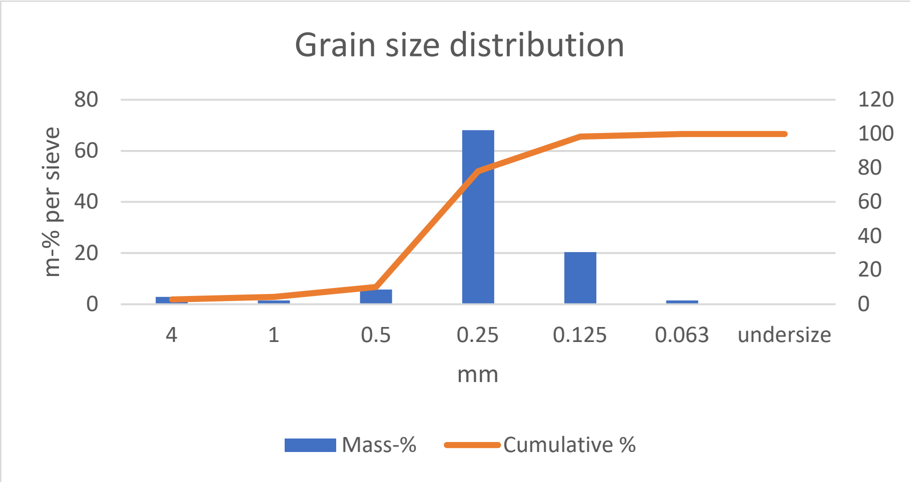

Figure 15. Grain size distribution after wet attrition.

Cost estimation:

In the case of ester cured phenolic resin sand wet scrubbing add costs approximately 20 % (electricity + water), but it saves at the same time in thermal process chemical additive amount significantly and also minimizes some gas consumption. Altogether the sum is about +- 0. The investment for water scrubbing unit is between 500.000 – 1.000.000 euros (scrubber, water treatment plant etc.).
In the case of inorganic waste sand the scrubbing unit investment is about the same, but there are no savings concerning chemical additives needed in ester cured phenolic resin sand types which means wet scrubbing of inorganic sands add costs approximately 10 % in thermal reclamation process.

Conclusions:

Wet scrubbing of used foundry sands before thermal reclamation is a technology used with organic foundry sands, especially with ester cured phenolic resin sands. Wet scrubbing of organic sands removes effectively harmful inorganic compounds of phenolic sands before thermal reclamation and also adjusts the pH level more suitable for thermal reclamation.
Wet attrition tests performed with the AKA-DRUM and with Inotec inorganic sand showed that there is no visible change in sand grain microscopy with untreated and treated samples. Also the loss of ignition of untreated and treated samples were the same within the measurement accuracy.
The separate results of thermal reclamation of inorganic used foundry sands in this Green Foundry project showed slight improvement of mould strength properties compared to purely mechanically reclaimed sands. Compared to those results these wet attrition tests of inorganic sands show that there is no advantage technically or economically to wet scrub these sand types before thermal reclamation.

4 Thermal reclamation method

Thermal reclamation tests were done on ester cured phenolic resin and, furan bonded sand, two different inorganic binder systems and for green sand.

4.1 Thermal reclamation process

The thermal reclamation tests were done at Finn Recycling’s existing thermal reclamation process plant in Urjala, Finland. The reclamation plant is used commercially for ester cured phenolic resin no-bake sands (APNB). The reclamation temperature i.e. the temperature of the sand leaving the thermal process was set to 650° C, which is the set temperature used with APNB sands. The process line consists of the feeder, thermal reclamation oven and a cooling screw. An additional automated sieve follows the process line so that the commercially deliveries conform to the requirements of the reclaimed sand. The following requirements have been set by Finn Recycling to the reclaimed sand together with its foundry customers.

Dust content	Loss on Ignition
<1%	<0,3%

4.2 Results

The quality tests conducted on the sands were the Loss on Ignition (LOI) test and the 3-point bending strength test. The Loss on Ignition test is a standardized test which shows the level of organic matter or water of crystallization in the tested sand. The bending strength test is used the analyse the bending strength of a ready foundry sand mix to ensure that cores made of different sands can withstand the pressure the molten metal impacts to the cores during casting. Before the test were conducted, the samples were sieved with a 1mm sieve to remove the remaining coarse particles from the sand.

The tests were done by applying the standards AFS 5100-12-S and VDG Merkblatt P 33. The ignition temperature was 900° C and the time in the ignition temperature was 3 hours. The samples, seen in figure 6, of 25±5g were dried in 100° C before setting them in the hot laboratory oven.

Fig. 16 Loss on Ignition samples

Test bars made according to the standard VDG Merkblatt M 11 with a cross section of 22,7 x 22,7 mm^2 were made following the instructions of the binder manufacturer. The bending strengths were the tested with a Morek Multiserw LRu-2e strength test machine for test bars made of new sand, reclaimed sand and used sand. Test bars and the bending machine are featured in figure 17.

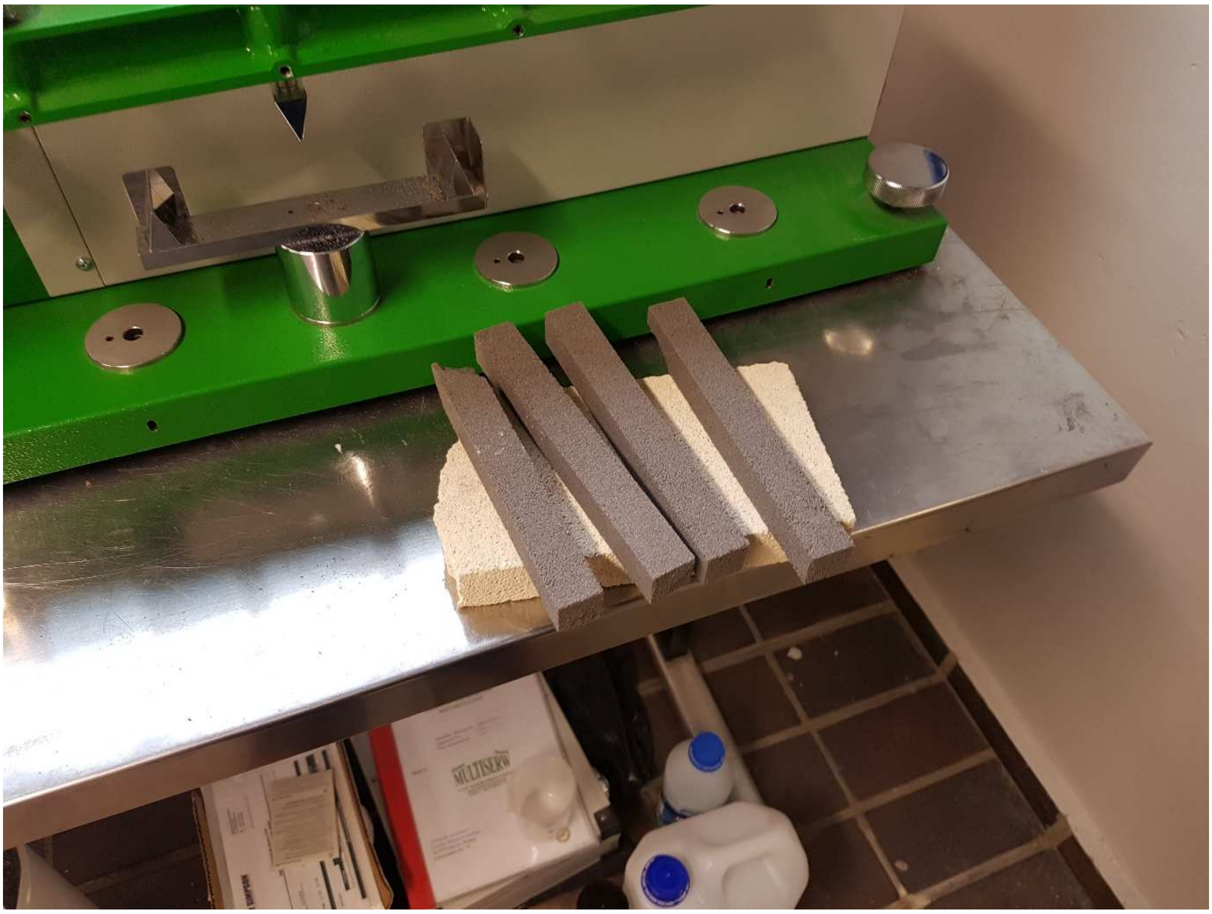

Fig. 17 Test bars and the bending strength test machine

4.2.1 Peak Inorganic

The results of the LOI tests are featured in table 1. The results show that the un-reclaimed sand had much more matter in it which was removed during the test compared to the reclaimed sand. This could be caused by water of crystallization, which did not evaporate during drying from the un-reclaimed sand but evaporated from the reclaimed sand during the thermal reclamation.

Table 9 Loss on Ignition results for Peak

LOI	Reclaimed	Used sand	New sand
Sample 1 before	23.162	22.510	24.11
Sample 1 after	23.152	22.397	24.07
Result 1	0.04%	0.50%	0.17%
Sample 2 before	20.663	20.597	22.87
Sample 2 after	20.66	20.538	22.84
Result 2	0.02%	0.29%	0.13%
Result average	**0.03%**	**0.39%**	**0.15%**

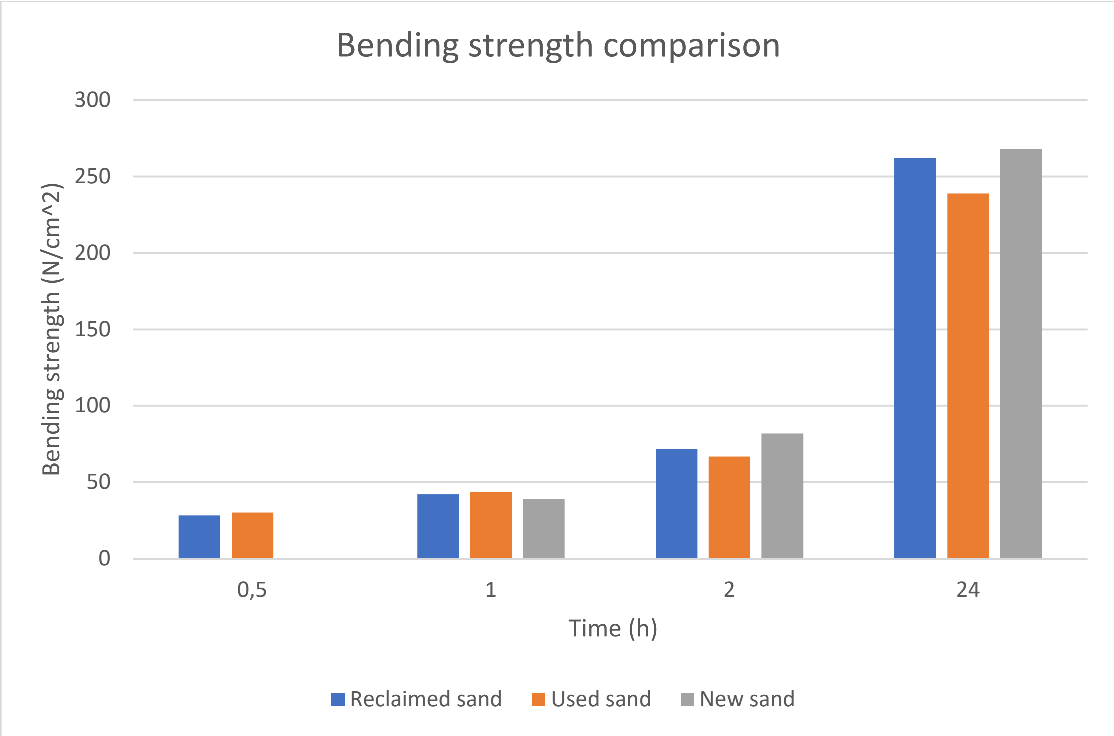

Fig. 18 Peak bending strength results

The bending strength test results (figure 11) show that the reclaimed sand has initially lower strength results compared to the used sand, but after two hours the reclaimed sand performs better. Same kind of trend is seen with new sand, which is the strongest of the three sands after two hours but is the weakest before that. The new sand was so fragile after 0.5 hours of hardening that the test equipment could not get a low enough reading. The amount of binder used was 2.5% of the sample mass and hardener was 12 % of binder mass.

The results show that thermal reclamation has some effect on the Peak Clean Cast Inorganic sand. The range of 2-24 hours is the realistic hardening time at least in Finnish foundries, so the bit lower strength in the start of the hardening time in not a huge problem. Mainly problems can rise especially with the new sand if a core must be removed from a core box too early when the sand has not hardened enough to endure it. Also, the bending strengths were comparably low when compared to APNB or other organic resins at least In the early stages of hardening. After 24 hours the bending strengths were in the same area as APNB sands.

4.2.2 Inotec Inorganic

The results of the LOI tests are featured in table 3. The results show that the un-reclaimed sand had much more matter in it which was removed during the test compared to the reclaimed sand. This could be caused by water of crystallization, which did not evaporate during drying from the un-reclaimed sand but evaporated from the reclaimed sand during the thermal reclamation. This is supported by the fact that the crushed un-reclaimed sand started to form blobs when stored but the reclaimed sand did not.

Table 10 Loss on Ignition results for Inotec

LOI	Reclaimed	Used sand	New sand
Sample 1 before	23.26	21.38	24.11
Sample 1 after	23.19	21.11	24.07
Result 1	0.30%	1.26%	0.17%
Sample 2 before	20.27	20.58	22.87
Sample 2 after	20.23	20.34	22.84
Result 2	0.20%	1.17%	0.13%
Result average	**0.25%**	**1.21%**	**0.15%**

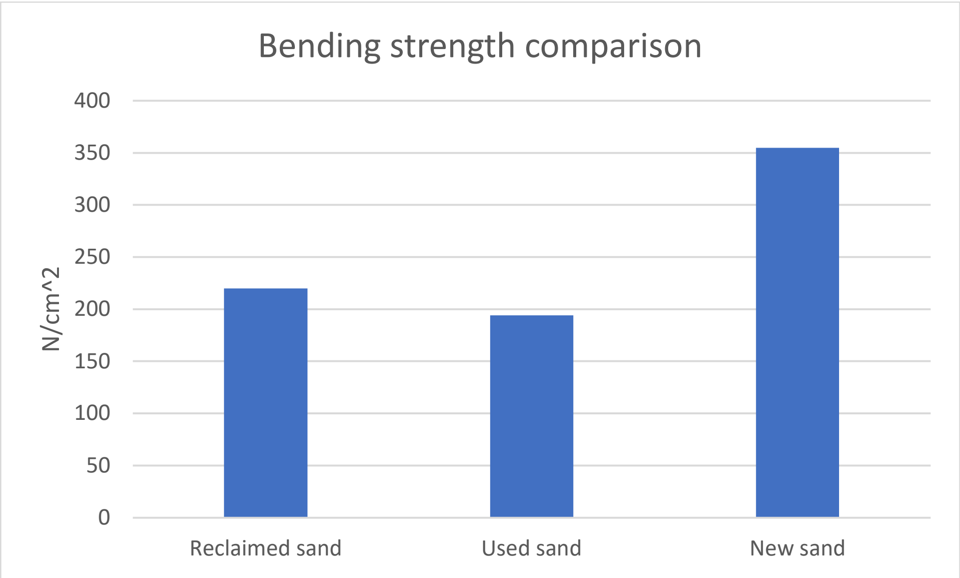

Fig. 19 Bending strength results of Inotec

The used amount of binder was 2 % and the amount of promoter was 0.6 %. The results show that with only thermal reclamation no significant regeneration of the sand with Inotec takes place while the process consists only of thermal reclamation. On the other hand, the thermal reclamation of APNB sands works properly and is currently in use at Finnish foundries.

Table 11 Bending strength results for Inotec

Sample	Reclaimed sand	Used sand	New sand
N/cm^2	175.4	215.2	328.2
	221.4	189.4	373.3
	216.4	151.5	352.0
	253.8	228	349.6
	231.8	185.6	370.9
Average:	219.76	193.94	354.8

4.2.3 APNB

When the thermal reclamation project was started, for APNB sands the acceptable level of loss on ignition was set at 0.3%. As seen in table 5, the results of the quality assurance tests show, that the thermally reclaimed sand passes the requirements clearly.

Table 12 Loss on ignition for APNB sands

Loss on ignition	Reclaimed APNB
Goal	<0.3%
Sample 1 before	22.41
Sample 1 after	22.39
Result 1	0.09%
Sample 2 before	23.54
Sample 2 after	23.52
Result 2	0.08%
Average	**0.09%**

As comparison, the bending strength test conducted on reclaimed APNB sand show that reclamation by thermal reclamation only yields good results, as seen in figure 13. The reclaimed sand is mixed with new sand with a ratio of 70:30 as per request of the foundries. Further testing shows that the addition of new sand is not required. The amount of binder used was 1.5 % of sand mass and hardener was 25 % of binder.

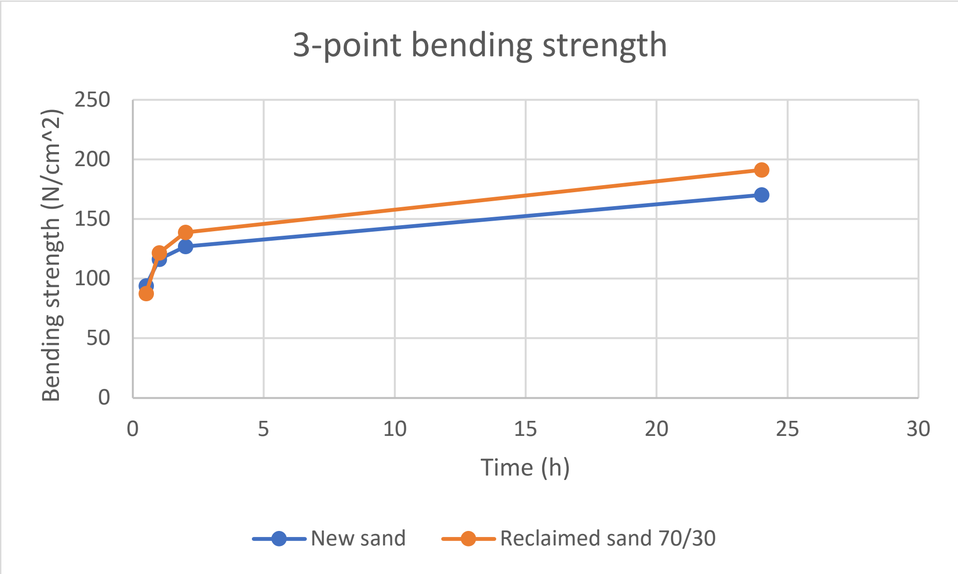

Fig. 20 Bending strength results for APNB sands

4.2.4 Furan bonded sands

Thermal reclamation of furan bonded sands has been tested at Finn Recycling in a small-scale production run of 5 tons which was then tested in a Finnish foundry. The tests are to be continued after a new production line in the Finn Recycling plant is installed during Q2/2021 The initial results were good as expected, but the process needs a little more adjusting so that the bench and hardening times of the resulting reclaimed sands are equal to those of new sands. Overall, when comparing bending strengths, the reclaimed sand was a little bit weaker than new sand. Additional problems for the thermal reclamation of furan bonded sands are the sulfuric oxides which are formed during the thermal process. Compared to the reclamation process of APNB sands, reclamation of furan bonded sands needs additional filtration systems for the flue gases. The amount of binder used was 1.1 % and the amount of hardener 45 % of the amount of binder.

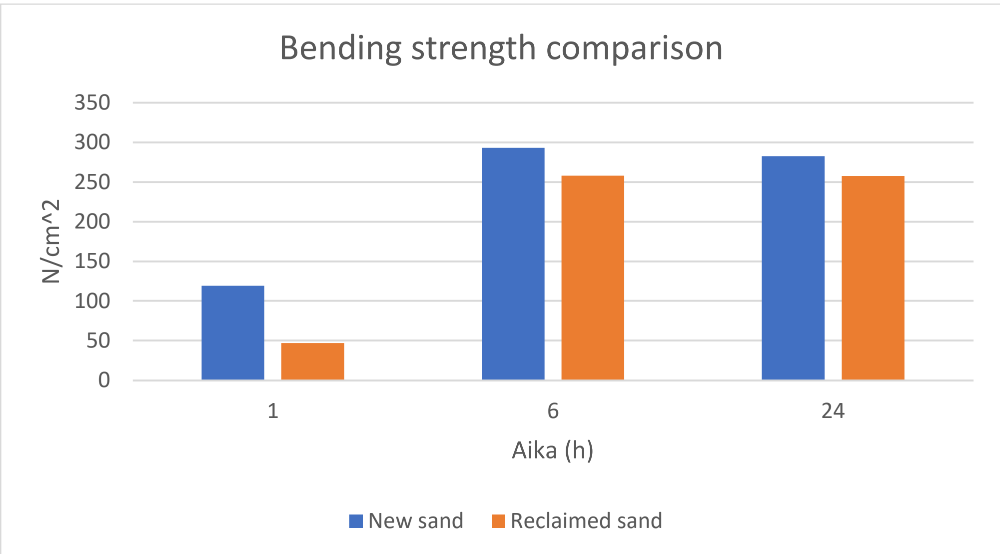

Fig. 21 Bending strength results for Furan bonded sands

The longer hardening time of reclaimed sand is probably due to the higher pH of the reclaimed sand, as the furan system uses an acid as hardener, so the higher pH acts like a buffer against hardening. This can be mitigated by foundries with the tuning of their mixer parameters.

Sample	**mass (g)**	**pH**
Reclaimes sand	25.023	7.15
New sand	25.014	6.83

Loss on ignition	**Reclaimed furan**
Target	<0.3%
Sample 1 start	20.636
Sample 1 end	20.62
Result 1	0.09%
Sample 2 start	22.366
Sample 2 end	22.348
Result 2	0.08%
Average	**0.09%**

4.2.5 Green sand

Green sand by its nature is problematic for thermal reclamation as its bonding system is based on clay. For the product to be pure, the water of crystallization must be first removed thermally and then the remaining clay shell must be removed buy mechanical treatment. The process is under development at the moment at Finn Recycling. The aim is to develop a single machine capable of the mentioned combined thermo-mechanical treatment.

The purely thermal treatment tests were done for green sand. As a result, the loss on ignition of the sand got to bit over 0.3% which is not perfect but was still considered as a success. However, in further testing with a cold-box core shooter, the test bars hardened just nominally so overall the purely thermal reclamation process is not enough to successfully reclaim green sand, as was expected. The sand with the binder and hardener mixed in felt dry compared to normal cold box sand made from new sand. It seemed as if the remaining bentonite in the sand had sucked in all the binder. The amount of both cold-box binder agents were 0.6 % of sand mass

Loss on ignition	**Greensand**
Sample 1 start	20.551
Sample 1 end	20.478
Result 1	0.36%
Sample 2 start	23.346
Sample 2 end	23.270
Result 2	0.33%
Average	**0.34%**

4.2.6 Summary

The results of thermal reclamation on the different sand systems are summarized in the table below.

Binder system	Results of Thermal reclamation
Peak	Small improvement
Inotec	Small improvement
APNB	Good results, in commercial use
Furan	Promising results as expected
Green sand	Thermal alone is not enough

4.3 Costs of a concentrated reclaiming facility

The costs of a concentrated thermal reclamation plant can be divided into fixed and running costs. A single thermal reclamation oven's annual output is 8000t so the amount of ovens depends of the amount and size of the customers.

Fixed costs:

- Thermal reclamation oven + cooler unit 950 000 €
- Gas tank 100 000 €
- Silos 50 000 €/unit
- Facility 1000 000 €
- Sieve unit 60 000 €
- Conveyors 100 000 €

Running costs:

- Operator
- Gas
- Electricity
- Maintenance
- All together around 15 €/t depending on location

The price of new sand depends for a big part of the logistical costs, as well as of the costs of landfilling the waste sand. Logistical costs of the sand also apply to a concentrated reclamation plant so the most important aspect which determines the profitability of a reclamation plant is the location in relation to its customers and on how much the customers have had to pay of their new sand, which determines how much they are willing to pay for the reclamation of their waste sand.

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Expired patents:

Purification of sand (US2952516A) Current Assignee: International Minerals and Chemical Corp

Process for purifying silica sand (US4401638A) Current Assignee: Materias Primas Monterrey SA

Process for leaching sand or other particulate material (US4042671A)