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Green Foundry

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

Subaction B4.2 Cleaning by thermal reclamation method

DeB4.2 Thermal reclamation test results with inorganic and organic surplus foundry sand specimens in Finland

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Contents

Thermal reclamation

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 commonly known as alkaline phenolic or phenolic Alphaset (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%

2. Results

The quality tests conducted on the sands were the Loss on Ignition (LOI) test and the 3-point bending strength test. Before the test were conducted, the samples were sieved with a 1mm sieve to remove the remaining coarse particles from the sand.

The sands arrived at the Finn Recycling reclamation plant in flexible intermediate bulk containers. The core and mould pieces had not been ground into uniform granulate at the foundry, as they didn't want the sand to contaminate their processes. Also, the loose sand in the bags had also started to form lumps. Before the reclamation process, the sand had to be crushed into granulate shape so that it could be inserted into the production stream.

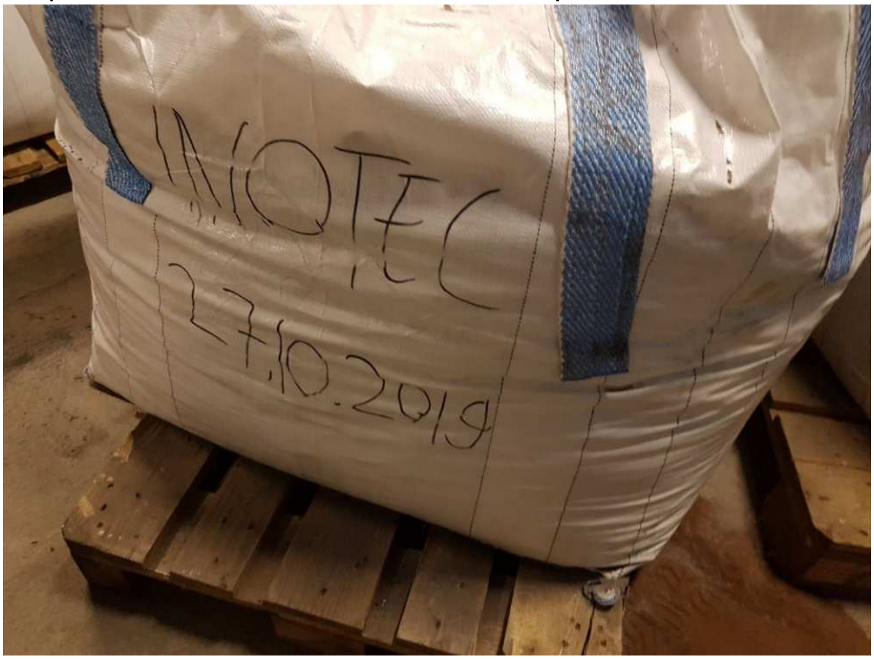

Fig. 1 Inotec arriving in a FIBC container

The sand lumps had to be crushed by a bucket crusher seen in figure 2.

Fig. 2 Crushing Inotec sand with a bucket crusher

After the sand had been crushed, the most course material was sieved from the sand, as the crushing with the bucket crusher was not as good as with a proper crushing machine used by the foundries. The bigger sand blobs were deemed a risk for the reclamation machinery, especially the cooling system. The blobs were sieved by using a 15mm sieve net seen in picture 3.


Fig. 3 Sieving of the excess blobs

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. Samples, like the ones seen in figure 4, of 25±5g were dried in 100° C before setting them in the hot laboratory oven.

Fig. 4 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 5.


Fig. 5 Test bars and the bending strength test machine

2.1 Peak Inorganic

The results of the LOI tests (Loss on Ignition) are featured in table 1. 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 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 1 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%**

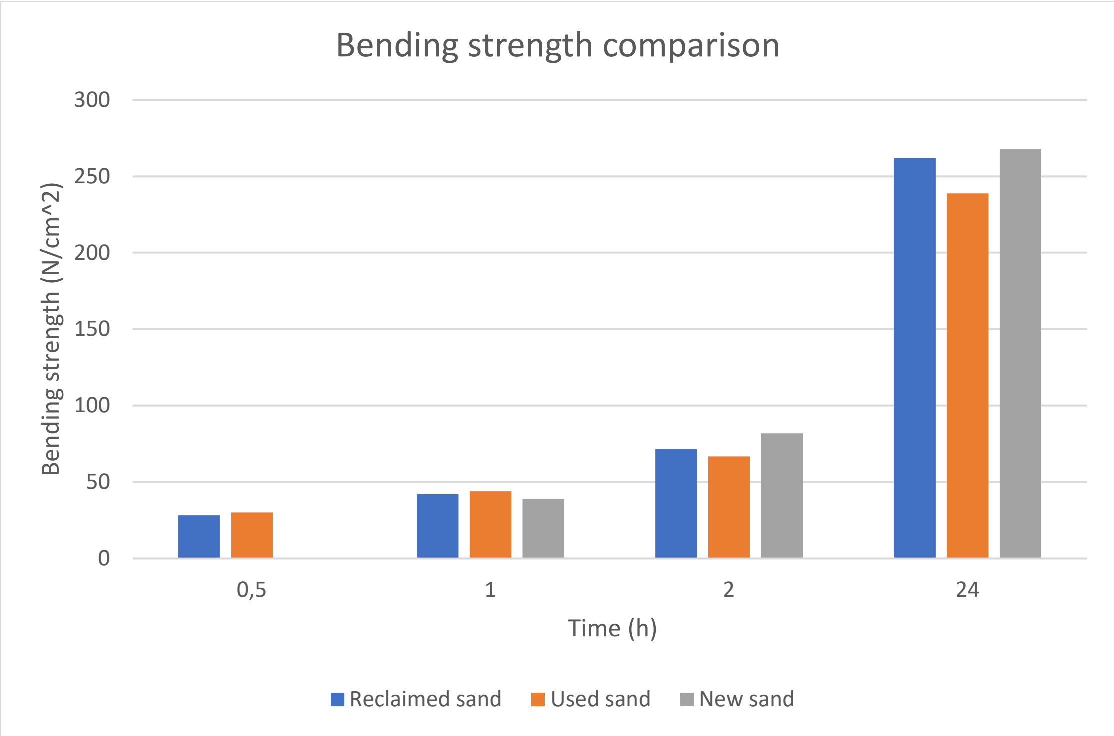

Fig. 6 Peak bending strength results

The 3-point 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. The bending strength test results (figure 6) 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.

2.2 Inotec Inorganic

The results of the LOI tests are featured in table 2. 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 2 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%**

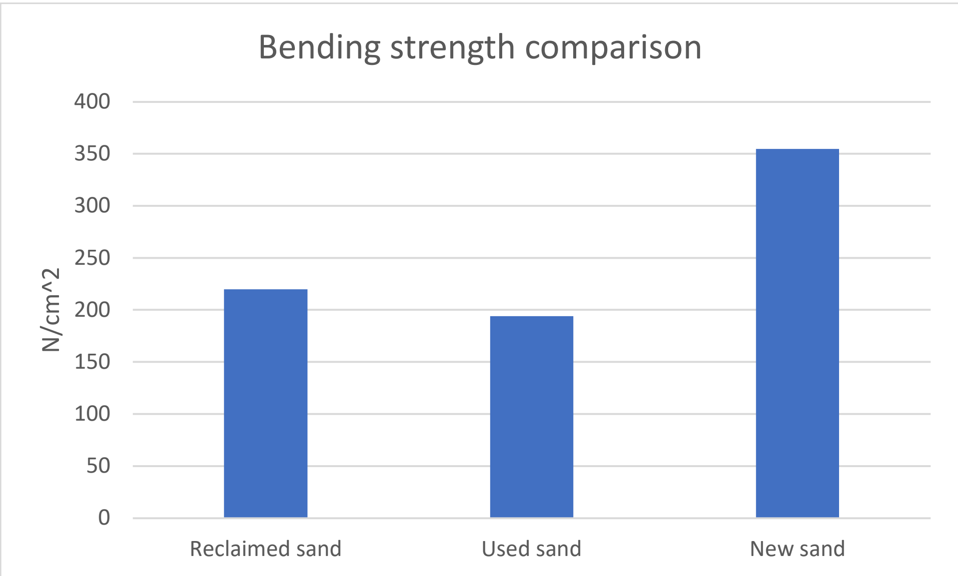

Fig. 7 Bending strength results of Inotec

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 3 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

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 4, the results of the quality assurance tests show, that the thermally reclaimed sand passes the requirements clearly.

Table 4 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 8. 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.

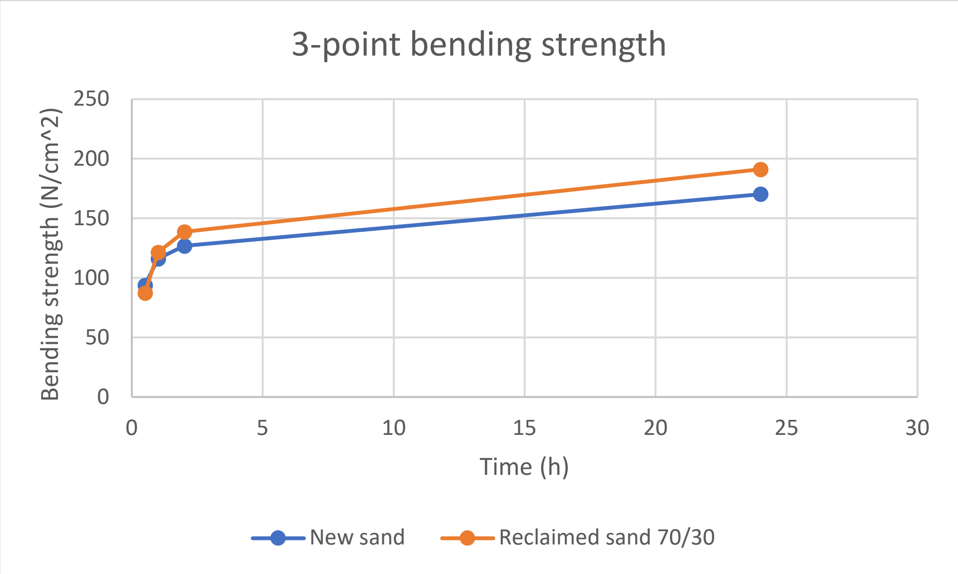

Fig. 8 Bending strength results for APNB sands

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 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.

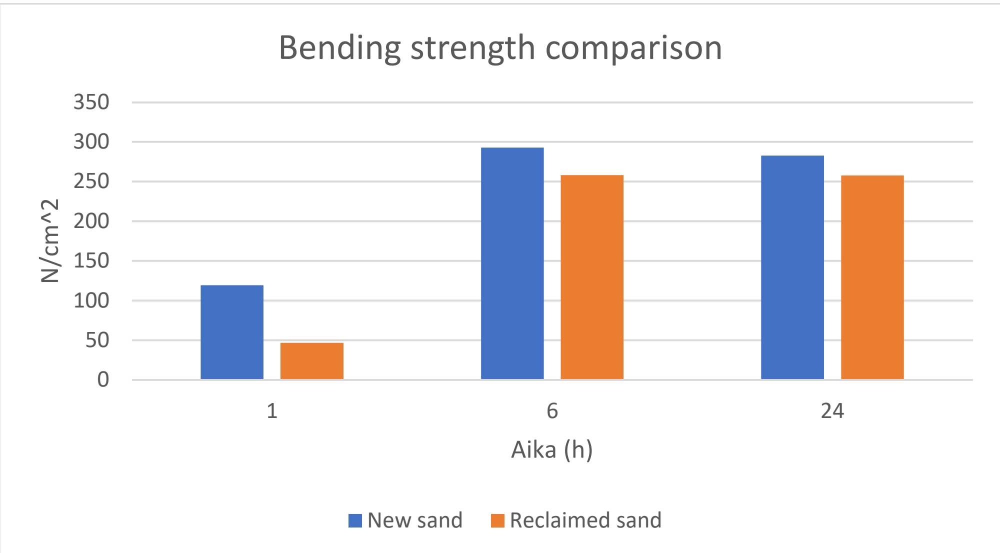

Fig. 14 Bending strength results for Furan bonded sands

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%**

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. 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%**

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

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.

4 Wet attrition method, results and cost estimations

The used treatment method is specific, combing wet treatment and mechanical attrition.

These tests were made find possible interaction effects of this method and thermal reclamation treatment on the quality of reclaimed inorganic waste sand. 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.

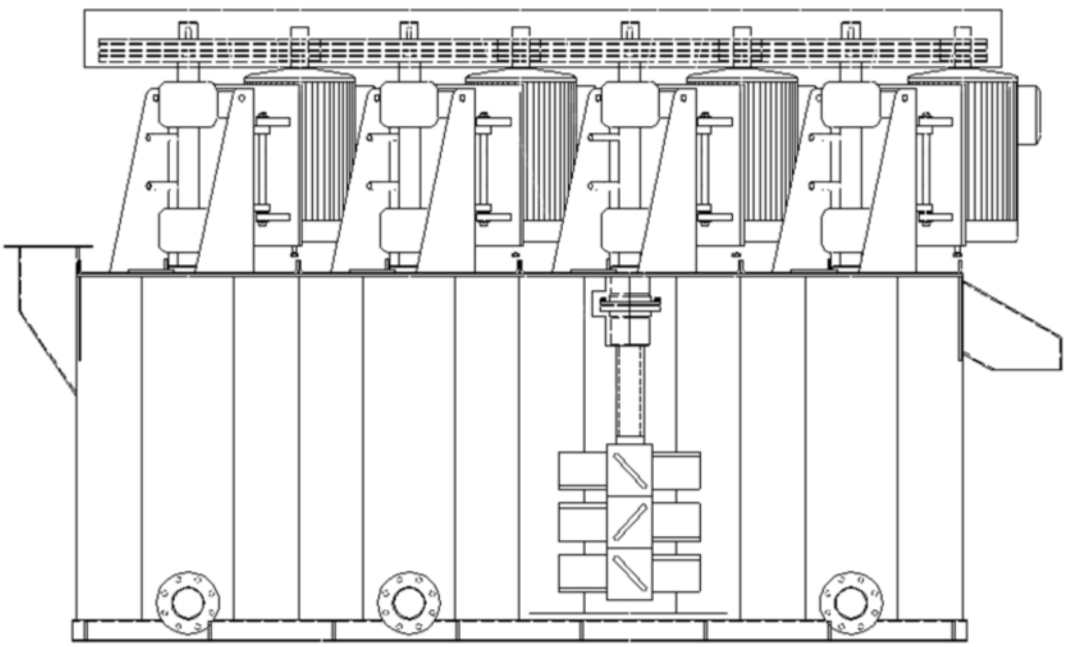

Figure 15. Principle image of the test apparatus.

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 16. Sample before attrition

Figure 17. 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

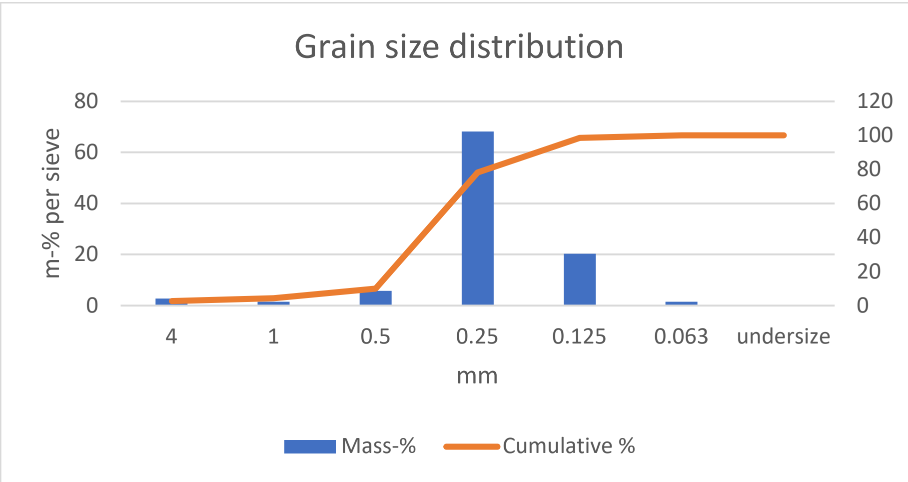

Figure 18. Grain size distribution after wet attrition.

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.