Subaction B4.6 Options for reuse of inorganic waste

DeB4.6 Reuse options of inorganic waste sand in geo-construction

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Content

1. Introduction

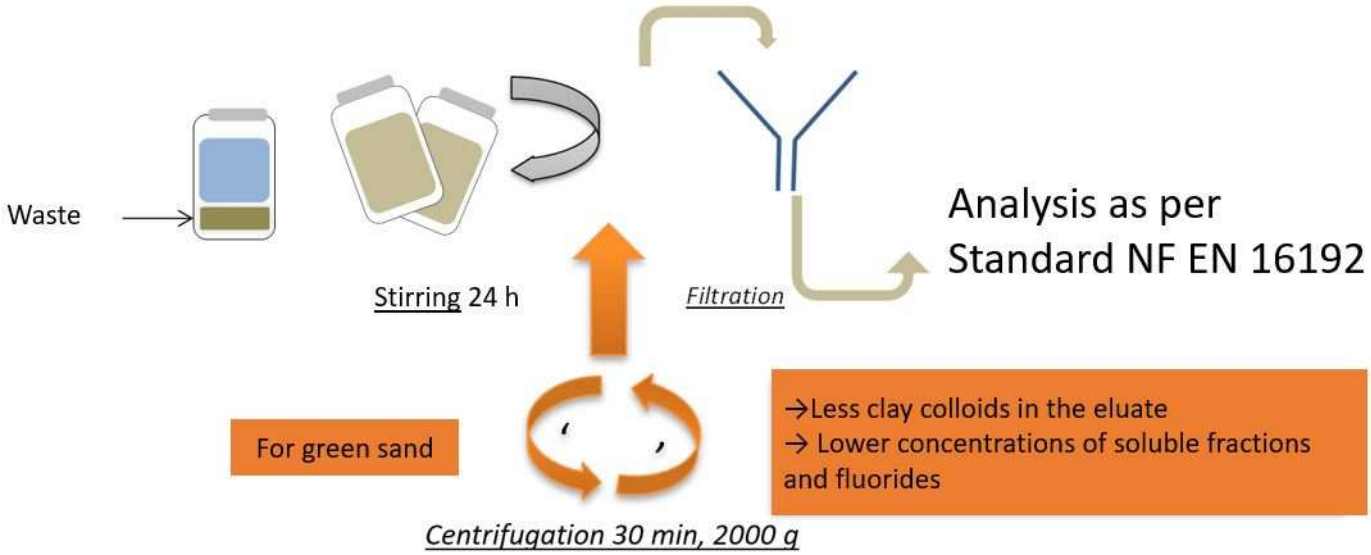
Once the steel parts have been cast by the different partners of the Green Foundry Life project in order to compare the emissions generated in the foundry between organic and inorganic sand, CTIF carried out several works for phase B4.6 of the project, regarding options for reusing inorganic sand waste in geo-construction:

- Leaching tests on inorganic sand waste,
- Leaching tests on treated sands,
- A synthesis of the results obtained in relation to the reference documents of the different countries taking part into this project (Germany, Spain, Finland, France, Italy, Poland).

2. Options for reuse of inorganic sand waste

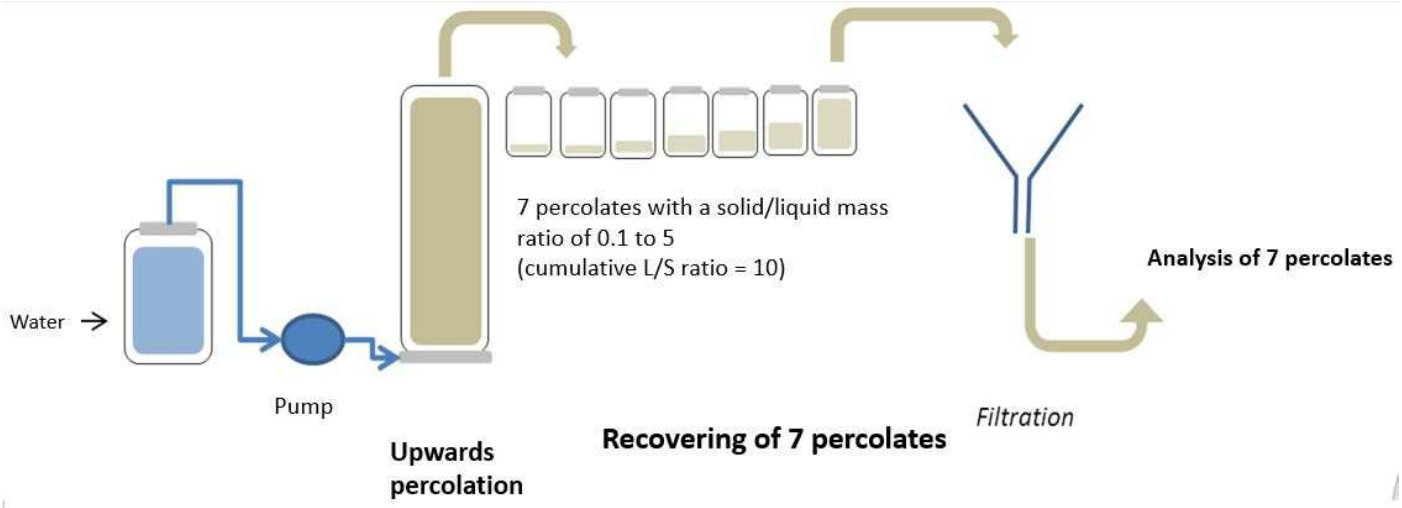
2.1. Leaching tests performed on sand samples

Principle of the leaching test (level 1): reference to standard NF EN 12457-2



Note: Paragraph 5.2.2 provides that there may be filtration difficulties and refers to Appendix E for "fine-textured, humus-rich soil waste".

Principle of the percolation test (level 2): reference to standard NF EN 14405



Note: For green sand, use a specific procedure with calcium chloride ($CaCl_2$) to deactivate the clay and flocculate it.

Limitations related to the leaching test (see the documents submitted by the partners in the appendice)

The table below was produced using the reference documents submitted by the project partners (see documents in the appendice).

Table 8 : Assessment of limit values related to the leaching test (for acceptance of inert waste centres).

Country	Germany	Spain	Filand	France	Italy	Poland
Reference document		Decree of 01.12.2015	Decree 843/2017	Decree of 12.12.2014	Decree of 02.05.1998	WAS Pollut 2016 TCLP*
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/litre	Limit values mg/kgMS
As		0,5	0,5	0,5	0,05	0,5
Ba			20	20	1	20
Cd		0,04	0,04	0,04	0,005	0,04
Cr		0,5	0,5	0,5	0,05	0,5
Cu		2	2	2	0,05	2
Hg		0,01	0,01	0,01	0,001	0,01
Mo		0,5	0,5	0,5		0,5
Ni		0,4	0,4	0,4	0,01	0,4
Pb			0,5	0,5	0,05	0,5
Sb		0,06	0,3	0,06		0,06
Se		0,1	0,4	0,1	0,01	0,1
Zn		4	4	4	3	4
Chloride		800	800	800	100	800
Fluoride		10	10	10	1,5	10
Sulphate		6000	1200	1000	250	1000
Phenolic compounds		1	5	1		1
DOC / eluate		500	500	500	30	500
Soluble fraction				4000		4000
DOC / raw				30000		30000
BTEX (sum)		< 6		6		6
TEX (sum)			25			
Benzene (LOQ 0,01 et 0,05 mg/kg dm)			0,02			
PCB-7 (sum)			1	1		1
Petroleum hydrocarbons C10-C40			300	500		500
Sum 16 EPA-PAH, excl. LOQ			30	50		1
Nitrates					50	
Cyanides					0,05	
Be					0,01	
Co					0,25	
V			2		0,25	
Asbestos					30	
Naphthalene			5			
* Water Air Soil Pollut (2016 : 227) - Toxicity Characteristics Leaching Procedure						
MAJ du 14.01.2022						

mg/l x (Volume of solution tested / mass of sand in solution) = mg/kgMS

mg/l x K = mg/kgMS (with K being a function of the leaching ratio L/S which in this case is = 10/2.65).

2.2. Results of leaching tests on sand samples

As announced in the introduction to this report, leaching tests were carried out on 12 sand samples:

- Four samples of inorganic sand to be treated (CTIF IE, GEOPOL W37-20, INOTEC and PEAK W37),

- Four samples of treated inorganic sand, with the lowest results obtained after characterisation (batches from the mechanical treatment process: see paragraphs 2.2, 2.3 and 2.4 of the report DeB4.5 Feasibility studies of the reuse of inorganic surplus foundry sand in core making and geo-construction),

- Four treated inorganic sand samples with the highest results after characterisation (batches from the hydromechanical treatment process: see paragraphs 2.2, 2.3 and 2.4 of the report DeB4.5 Feasibility studies of the reuse of inorganic surplus foundry sand in core making and geo-construction).

Table 9: results of leaching tests carried out on the sands to be treated

Waste sand samples	Waste sand CTIF IE	Waste sand INOTEC	Waste sand GEOPOL W37-20	Waste sand PEAK W37
Treatment	No	No	No	No
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS
As	0,01	0,11	0,03	0,02
Ba	< 0,05	0,07	< 0,05	< 0,05
Cd	< 0,002	< 0,002	< 0,002	< 0,002
Cr	< 0,01	0,07	0,03	0,01
Cu	< 0,02	0,05	0,04	0,02
Hg	< 0,0005	< 0,0005	< 0,0005	< 0,0005
Mo	< 0,02	0,03	< 0,02	< 0,02
Ni	< 0,03	< 0,03	< 0,03	< 0,03
Pb	< 0,02	< 0,02	0,02	< 0,02
Sb	< 0,02	0,067	< 0,02	< 0,02
Se	< 0,02	< 0,02	< 0,02	< 0,02
Zn	< 0,10	0,30	< 0,10	< 0,10
Chloride	< 10	< 10	< 10	23
Fluoride	< 2	8,9	76	110
Sulphate	< 10	76	13	20
Phenolic compounds	0,23	< 0,10	< 0,10	< 0,10
DOC (on eluate)	770	40	810	300
Soluble fraction	7000	4930	4160	3080
DOT (on raw)	< 2000	< 2000	< 2000	< 2000
BTEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
TEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
Benzene (LOQ 0,01 et 0,05 mg/kg dm)	< 0,02	< 0,02	< 0,02	< 0,02
PCB-7 (sum)	< 0,007	< 0,007	< 0,007	< 0,007
Petroleum hydrocarbons C10-C40	< 20	< 20	< 20	< 20
Sum 16 EPA-PAH, excl. LOQ	< 0,16	< 0,16	< 0,16	0,20
Nitrates				
Cyanides				
Be				
Co				
V				
asbestos				
Naphthalene	< 0,01	< 0,01	< 0,01	< 0,01
MAJ du 14.01.2022	Limit values exceeded for all countries			
PRJ1700885 Green Foundry Life	Exceeding the limit values for Italy			

Observation: The above results show that all inorganic sand samples are not acceptable for landfill for all countries.

Results of leaching tests on sand samples: cont'd

Table 10: results of leaching tests carried out on mechanically treated sands

Waste sand samples	Waste sand CTIF IE	Waste sand INOTEC	Waste sand GEOPOL W37-20	Waste sand PEAK W37
Treatment	Mechanical	Mechanical	Mechanical	Mechanical
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS
As	0,02	0,09	0,03	0,03
Ba	< 0,05	< 0,05	< 0,05	< 0,05
Cd	< 0,002	< 0,002	< 0,002	0,002
Cr	0,20	0,28	0,09	0,10
Cu	0,02	0,02	< 0,02	< 0,02
Hg	< 0,0005	< 0,0005	< 0,0005	< 0,0005
Mo	< 0,02	0,04	< 0,02	0,02
Ni	< 0,03	< 0,03	< 0,03	0,05
Pb	< 0,02	< 0,02	< 0,02	< 0,02
Sb	< 0,02	< 0,02	< 0,02	< 0,02
Se	< 0,02	< 0,02	< 0,02	< 0,02
Zn	< 0,10	< 0,10	< 0,10	< 0,10
Chloride	< 10	< 10	11	14
Fluoride	< 2	14	85	99
Sulphate	< 10	68	14	20
Phenolic compounds	0,20	0,56	0,32	0,19
DOC (on eluate)	590	45	700	240
Soluble fraction	6830	2940	3830	2710
DOT (on raw)	< 2000	< 2000	< 2000	< 2000
BTEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
TEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
Benzene (LOQ 0,01 et 0,05 mg/kg dm)	< 0,02	< 0,02	< 0,02	< 0,02
PCB-7 (sum)	< 0,007	< 0,007	< 0,007	< 0,007
Petroleum hydrocarbons C10-C40	< 20	< 20	< 20	< 20
Sum 16 EPA-PAH, excl. LOQ	< 0,16	< 0,16	< 0,16	< 0,16
Nitrates				
Cyanides				
Be				
Co				
V				
asbestos				
Naphthalene	< 0,01	< 0,01	< 0,01	< 0,01
MAJ du 11.01.2022	Limit values exceeded for all countries			
PRJ1700885 Green Foundry Life	Exceeding the limit values for Italy			

Observation: The above results show that not all inorganic sand samples are acceptable for landfill.

Mechanical treatment of inorganic sands is therefore not effective in this case.

Results of leaching tests on sand samples: cont'd

Table 11: results of leaching tests carried out on hydromechanically treated sands

Waste sand samples	Waste sand CTIF IE	Waste sand INOTEC	Waste sand GEOPOL W37-20	Waste sand PEAK W37
Treatment	Hydromechanical	Hydromechanical	Hydromechanical	Hydromechanical
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS
As	< 0,01	0,02	< 0,01	< 0,01
Ba	< 0,05	< 0,05	< 0,05	< 0,05
Cd	< 0,002	< 0,002	0,003	< 0,002
Cr	0,03	0,04	0,10	0,08
Cu	0,02	< 0,02	0,02	< 0,02
Hg	< 0,0005	< 0,0005	< 0,0005	< 0,0005
Mo	< 0,02	< 0,02	< 0,02	< 0,02
Ni	< 0,03	< 0,03	< 0,03	< 0,03
Pb	< 0,02	< 0,02	< 0,02	< 0,02
Sb	< 0,02	< 0,02	< 0,02	< 0,02
Se	< 0,02	< 0,02	< 0,02	< 0,02
Zn	< 0,10	< 0,10	< 0,10	< 0,10
Chloride	< 10	< 10	< 10	< 10
Fluoride	< 2	2,3	4,1	7,1
Sulphate	< 10	< 10	< 10	< 10
Phenolic compounds	0,19	0,46	1,10	0,10
DOC (on eluate)	28	34	36	29
Soluble fraction	561	1100	< 500	< 500
DOT (on raw)	< 2000	< 2000	< 2000	< 2000
BTEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
TEX (sum)	< 0,10	< 0,10	< 0,10	< 0,10
Benzene (LOQ 0,01 et 0,05 mg/kg dm)	< 0,02	< 0,02	< 0,02	< 0,02
PCB-7 (sum)	< 0,007	< 0,007	< 0,007	< 0,007
Petroleum hydrocarbons C10-C40	< 20	< 20	< 20	< 20
Sum 16 EPA-PAH, excl. LOQ	< 0,16	< 0,16	< 0,16	< 0,16
Nitrates				
Cyanides				
Be				
Co				
V				
asbestos				
Naphthalene	< 0,01	< 0,01	< 0,01	< 0,01
MAJ du 11.01.2022	Limit values exceeded for all countries			
PRJ1700885 Green Foundry Life	Exceeding the limit values for Italy			

Observation: the above results show that three of the inorganic sand samples would be acceptable in an inert waste landfill for all countries, except for Italy, where the limit values applied are lower (two sands would be accepted instead of three).

- A measured value for fluoride is exceeded for Italy (limit value = 5.7 mg/kgMS),

- A measured value for phenol index is exceeded for all countries (limit value = 1 mg/kgMS).

The hydromechanical treatment of inorganic sands is particularly effective in this case.

The two exceeded values are relatively low, which suggests that all sands could be accepted by optimising this treatment process.

2.3. Synthesis of results and identification of reuse options for inorganic sands

Summary of leaching results

The results obtained during the leaching tests show that the hydromechanically treated inorganic sands INOTEC and CTIF IE are acceptable in landfills in all the partner countries of the project.

Concerning the hydromechanically treated inorganic sand GEOPOL W37-20, the acceptable limit value of the phenol index is slightly exceeded (1.10 mg/kgMS for 1 mg/kgMS max), therefore this sand is not acceptable in landfill in all project partner countries.

The hydromechanically treated inorganic sand PEAK W37 is not acceptable in landfills, only in Italy, because of a slightly exceeded fluoride content (7.1 mg/kgMS for 5.7 mg/kgMS maximum).

If the optimisation of the treatment of inorganic sands GEOPOL W37-20 and PEAK W37 in hydromechanics was not feasible to improve these results, reuse options are however possible.

For all other inorganic sands (to be treated and mechanically treated), these are not acceptable for landfill in all project partner countries, with several limit values largely exceeded (fluoride, TOC/Eluate and soluble fraction).

However, there are options for reuse of these sands.

Identification of reuse options for inorganic sands

According to the documents provided by the project partners, there are several options for the reuse of foundry sands.

For Finland, the seven pathways presented in the "Governmental Decree 843/2017" for a reuse of sands in geo-construction are the following (see the extract from the reference document in the appendice):

- Roadway, covered
- Roadway, paved
- Field covered
- Field paved
- Embankment
- Floor structure of industrial or storage building
- Road constructed of crushed stone and ash

Identifying options for reusing inorganic sands: cont'd

Table 12 : Limit values to be respected for the reuse of sand in geoconstruction

Finland	Reuse options in geo-contruction						
Channels	Roadway covered[1]	Roadway paved[1]	Field covered[1]	Field paved[1]	Embankment	Floor structure of industrial or storage buildin	Crushed stones and ash[2]
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS
As	1	2	0,5	1,5	0,5	2	2
Ba	40 à 80*	100	20	60	20	100	80
Cd	0,04	0,06	0,04	0,06	0,04	0,06	0,06
Cr	2,00	10	0,5	5	1	10	5
Cu	10	10	2	10	10	10	10
Hg	0,03	0,03	0,01	0,03	0,03	0,03	0,03
Mo	1,5	6	0,5	6	1	6	2
Ni	2	2	0,4	1,2	1,2	2	2
Pb	0,5	2	0,5	2	0,5	2	1
Sb	0,7	0,7	0,3 à 0,4*	0,7	0,7	0,7	0,7
Se	1	1	0,4	1	1	1	1
Zn	15	15	4	12	15	15	15
Chloride (Cl^-)[3]	3200 à 3600*	11000 à 14000*	800	2400	1800	11000	4700
Fluoride (F^-)[3]	50	150	10	50	30	150	100
Sulphate (SO_4^{2-})[3]	5900 à 6000*	18000 à 20000*	1200	10000	3400	18000	6500
Phenolic compounds[6]	10	10	5	10	10	10	10
Soluble fraction							
DOC / Eluate	500	500	500	500	500	500	500
DOC / raw							
Σ BTEX							
Σ TEX[4]	25	25	25	25	25	10	25
Benzene (LOQ 0,01 et 0,05 mg/kg dm)	0,2	0,2	0,02	0,2	0,06	0,02	0,2
PCB-7 compounds[7]	1	1	1	1	1	1	1
Petroleum hydrocarbons C10-C40	500	500	500	500	500	500	500
PAH compounds[5]	30	30	30	30	30	30	30
Nitrates							
Cyanides							
Be							
Co							
V	2 à 3*	3	2	3	2	3	3
Asbestos							
Naphthalene	5	5	5	5	5	5	5
MAJ du 11.01.2022							
PRJ1700885 Green Foundry Life							

*Exceptions to the limit values, if the maximum thickness of the executed structure is 0,5 m (mg/kg L/S 10 l/kg)

Roadway covered : Ba=80, V=3, Cloride (Cl^-)=3600, sulphate(SO_4^{2-})=6000

Roadway paved : Cloride (Cl^-)=14000, sulphate(SO_4^{2-})=20000

Field covered : Sb=0,4

1) The maximum amount of recovered asphalt chippings and crushed asphalt at an earth construction site is 1,000 tonnes

2) The layer thickness of a road constructed of crushed stone and ash is set at the calculated thickness of the filler layer

3) The limit values set for chloride, sulphate and fluoride in Table 1 do not apply to a structure that meets all the following requirements: situated at a distance no greater than 500 m from the sea; the direction of discharge of water draining through the structure is into the sea; and there are no wells used for domestic water intake between the structure and the sea

4) Toluene, ethylbenzene and xylene (cumulative content)

5) Polyaromatic hydrocarbons: anthracene, acenaphthene, asenaphthylene, bentz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, phenanthrene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, chrysene, naphthalene and pyrene (cumulative content)

6) Phenol, o-cresol, m-cresol, p-cresol and bisphenol-A (cumulative content)

7) Polychlorinated biphenyl congeners 28, 52, 101, 118, 138, 153 and 180 (cumulative content)

Identifying options for reusing inorganic sands: cont'd

For France, the three channels presented in the CEREMA guide "Environmental acceptability of alternative materials in road techniques - Foundry sands", in the case of reuse of sands as alternative materials in road techniques are the following:

- Usage of type 1 : see guide CEREMA on web site www.cerema.fr ,
- Usage of type 2 : see guide CEREMA,
- Usage of type 3 : see guide CEREMA,

Table 13: Limit values to be respected for the reuse of sand in road technology

France	Reuse options in road ingeneering		
Channels	Alternative material for type 1 use	Alternative material for type 2 use	Alternative material for type 3 use
Setting	Limit values mg/kgMS	Limit values mg/kgMS	Limit values mg/kgMS
As	0,6	0,6	0,6
Ba	25	25	25
Cd	0,05	0,05	0,05
Cr	0,8	0,6	0,6
Cu	3	3	3
Hg	0,01	0,01	0,01
Mo	0,6	0,6	0,6
Ni	4	2	0,5
Pb	0,6	0,6	0,6
Sb	0,7	0,4	0,08
Se	0,1	0,1	0,1
Zn	20	20	5
Chloride (Cl-)	1000	1000	1000**
Fluoride (F-)	60	30	13
Sulphate (SO_4^{2})	10000	5000	1300**
Phenolic compounds	2	2	1
Soluble fraction			5000**
DOC / Eluate	500	500	500
DOC / raw	30000 / 60000*	30000 / 60000*	30000 / 60000*
Σ BTEX	6	6	6
Σ TEX			
Benzene (LOQ 0,01 et 0,05 mg/kg dm)			
PCB-7 compounds	1	1	1
Petroleum hydrocarbons C10-C40	500	500	500
PAH compounds	50	50	50
Nitrates			
Cyanides			
Be			
Co			
V			
Asbestos			
Naphthalene			
MAJ du 11.01.2022	*A limit value of 60000 mg/kgDM can be accepted, if the TOC/eluate value does not exceed 500 mg/kgDM		
PRJ1700885 Green Foundry Life	**To be compliant, either the chlorides and sulphates VL or the soluble fraction VL must be respected		

Identifying options for reusing inorganic sands: cont'd

Based on the values measured during the leaching tests carried out on the inorganic sands, CTIF IE, INOTEC, GEOPOL W37-20 and PEAK W37, and taking into account the limit values provided by the project partners, the table below summarises all the possible reuse options for all the samples tested.

Table 14: Possible reuse options for inorganic sands tested during the project

Process	Options	Accepted in center	Use of the material in geo-contruction (document from Finlande)						
	Samples tested	waste inert	Roadway covered[1)]	Roadway paved[1)]	Field covered[1)]	Field paved[1)]	Embankment	Floor structure of industrial or storage building	Crushed stones and ash[2]
Untreated sands	INOTEC	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CTIF IE	No	No	No	No	No	No	No	No
	GEOPOL W37-20	No	No	No	No	No	No	No	No
	PEAK W37	No	No	Yes	No	No	No	Yes	No
Mechanical processing	INOTEC	No	Yes	Yes	No	Yes	Yes	Yes	Yes
	CTIF IE	No	No	No	No	No	No	No	No
	GEOPOL W37-20	No	No	No	No	No	No	No	No
	PEAK W37	No	No	Yes	No	No	No	Yes	No
Hydro mechanical processing	INOTEC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CTIF IE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	GEOPOL W37-20	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	PEAK W37	Yes except in Italie	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MAJ du 12.01.2022									

Process	Options	Accepted in center	Use of the material in road ingeneering (2019 Cerema guide France)		
	Samples tested	waste inert	Alternative material for type 1 use	Alternative material for type 2 use	Alternative material for type 3 use
Untreated sands	INOTEC	No	Yes	Yes	Yes
	CTIF IE	No	Yes	Yes	Yes
	GEOPOL W37-20	No	No	No	No
	PEAK W37	No	No	No	No
Mechanical processing	INOTEC	No	Yes	Yes	No
	CTIF IE	No	Yes	Yes	Yes
	GEOPOL W37-20	No	No	No	No
	PEAK W37	No	No	No	No
Hydro mechanical processing	INOTEC	Yes	Yes	Yes	Yes
	CTIF IE	Yes	Yes	Yes	Yes
	GEOPOL W37-20	No	Yes	Yes	No
	PEAK W37	Yes except in Italie	Yes	Yes	Yes
MAJ du 12.01.2022					

3. Conclusions

The laboratory work carried out during this project made it possible to verify the impact of an inorganic sand on the quality of small steel castings.

It was found that the condition of the casting and finishing surfaces of the parts complied with the NF1370 standard according to BNIF technical recommendation no. 359 (Bureau de Normalisation des Industries de la Fonderie).

The contents of carbon, sulphur, nitrogen, hydrogen and oxygen measured on the part samples did not reveal any major problem.

The structural investigations carried out on the samples taken from the parts also confirmed that inorganic sand would apparently not have a major impact on the occurrence of defects (for the small steel parts tested in this project).

Treatment trials carried out on inorganic sand waste have shown that hydromechanical and ultrasonic technologies are particularly effective in obtaining an inert sand waste after treatment, or in allowing the treated sand to be reused in foundry, geo-construction or road engineering.

Nevertheless, these hydromechanical and ultrasonic treatment processes need to be tested on an industrial scale to verify whether these emerging technologies would be viable, compared to solutions using conventional technologies (mechanical, thermal, thermomechanical).

In this context, it would be interesting to develop a pilot capable of treating 250 kg of sand per cycle to check the feasibility and determine the consumption ratios, the production/maintenance ratios and the sand treatment costs in €/t, and to compare the results obtained with those of conventional installations.

The study of this (these) industrial pilot(s) would also enable a representative life cycle analysis and carbon impact calculation to be carried out, to find out whether the hydromechanical and ultrasonic technologies can be transferred to industry for the treatment of used foundry sand.