Action B4.5 Treatment tests of inorganic sand waste

DeB4.5 Feasibility studies of the reuse of inorganic surplus foundry sand in core making and geo-construction

The report has been prepared by:

Jean-Bernard Virolle, Project Manager

Patrick Hairy, Proofreader

Christine Colliard, Dissemination Manager

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 B4.5 concerning inorganic sand waste:

- Mechanical treatment tests,
- Hydromechanical treatment tests,
- Ultrasonic treatment tests,
- Characterisations of sand samples carried out before and after treatment, to observe the impact of the different technologies on inorganic sands, and to select sand batches to be tested in leaching (sand batches before treatment, least treated sand batches and best treated sand batches).

2. Treatment tests of inorganic sand waste

Contrary to what was initially planned at the beginning of the Green Foundry Life project, the process of treating inorganic sand waste with microwaves was not retained, as CTIF found during another project in 2019 that the microwave technology is not efficient to treat inorganic sand.

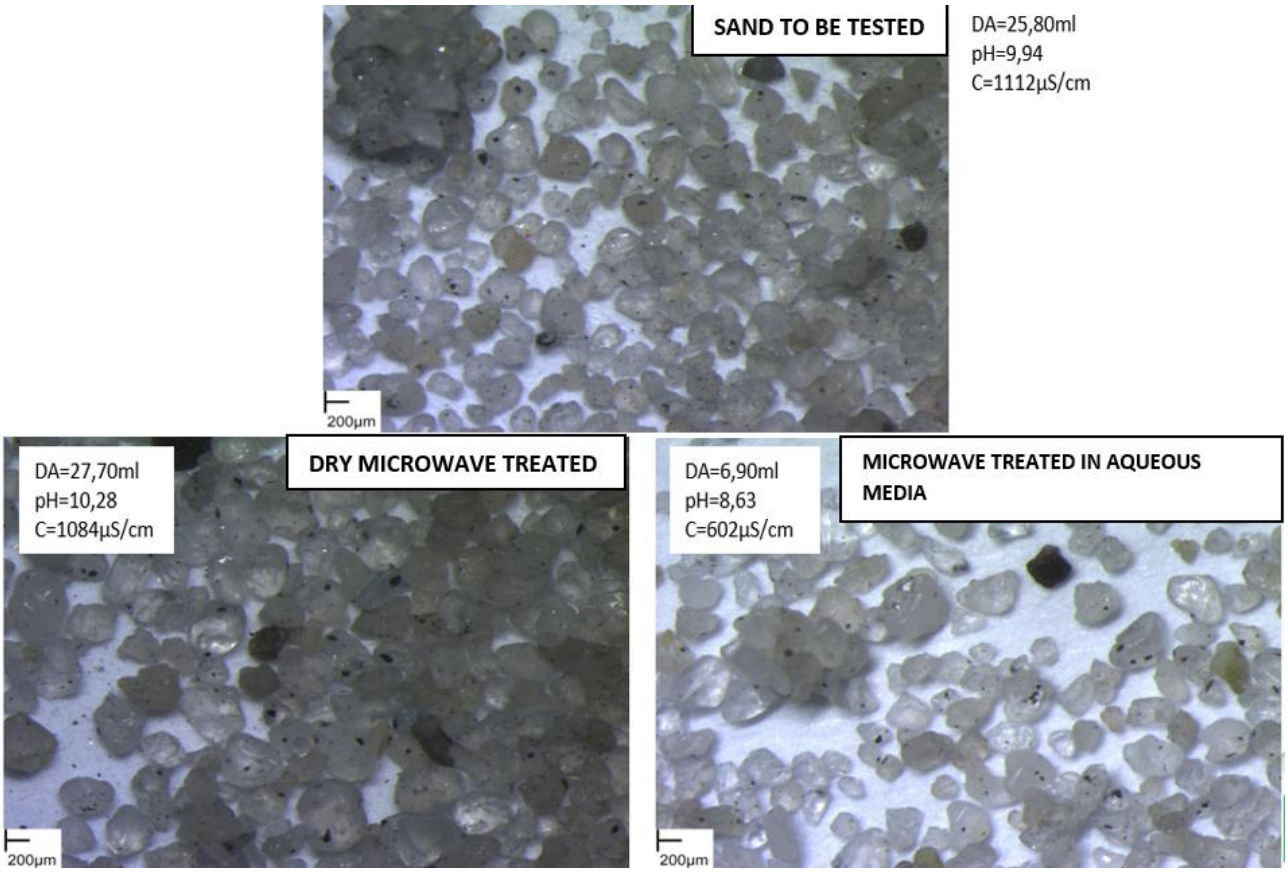
In the case of microwave treatment of inorganic sand, there is an improvement in acidic demands, but this is only due to rinsing operations.

The electrical conductivity values of the treated sand and the optical microscopy images show that:

- The large aggregates are not removed,
- The sand grains are not cleaned,
- The residual gangue remains intact.

Extract from the results of the microwave treatment of an inorganic sand carried out in 2019 in another CTIF's project:

Treatment by microwave of inorganic sand: not effective



The treatment processes selected by CTIF for the Green Foundry Life project are those capable of cleaning inorganic sand waste to obtain a quality of treated sand sufficient for reuse in foundries (moulding, core making), or for external reuse.

The processes using the emerging hydromechanical and ultrasonic technologies being the most efficient were selected for comparison with a conventional mechanical technology currently used in industry (attrition mechanical process).

Four batches of inorganic sand waste produced by the partners were tested:

- A batch of inorganic sand waste marked "GEOPOL W37-20",
- A batch of inorganic sand waste marked "PEAK W37",
- A batch of inorganic sand waste marked "INOTEC",
- A batch of inorganic sand waste marked "CTIF IE".

After the pre-treatment of the sand waste transmitted by the project partners, the sands to be treated were characterized and compared with the new reference sand (silica sand BE01).

Illustration of the pre-treatment of sand waste to be treated

Table 4: summary of the characterization of the sands to be treated

Laboratory Inspections on the sand samples	Ref SN BE01	INOTEC before T	CTIF IE before T	W37-20 before T	W37 before T
Fineness index	46	49	46	46	46
Distribution 50-70-100 (%)	95,03	85,27	89,71	86,21	86,90
Distribution 200-270-bottom (%)	0,18	1,30	1,10	0,64	0,42
Residual aggregates (% sieve 6+12+20)	0,00	0,24	0,28	0,46	0,30
Theoretical specific surface (cm2/g)	159	169	157	161	159
Breakage of sand grains observed under the optical microscope (high/low/not)	No	Low	Low	Low	Low
Aggregates observed under optical microscope (yes/no)	No	Yes	Yes	Yes	Yes
Presence of fines (no/low/significant)	Low	Significant	Significant	Significant	Significant
Grain shape observed under the light microscope (general trend: spherical/angular)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains observed under the optical microscope (general trend: smooth/rough)	Smooth	Smooth+Rou	Smooth+Rou	Smooth+Rou	Smooth+Rou
Amount of black grains (general tendency: no/low/significant)	No	Low	Low	Low	Low
Quantity of light-coloured grains with black spots (general tendency: not/low/significant)	No	Significant	Significant	Significant	Significant
Amount of light-coloured, unstained grains (general trend: no/low/significant)	Significant	No	No	No	No
Electrical conductivity of sand (µS/cm)	500 - 520	907	1357	1045	957
pH of the sand	8,30 - 8,40	10,07	10,36	9,70	9,79
Acid demand of sand (ml HCl)	1,2 - 2,0	28	38,1	16,2	15,5
Samples retained for leaching test		X	X	X	X
UPDATED on November 26th 2021					

EDS analyses carried out to identify the elements present in the sands to be treated:

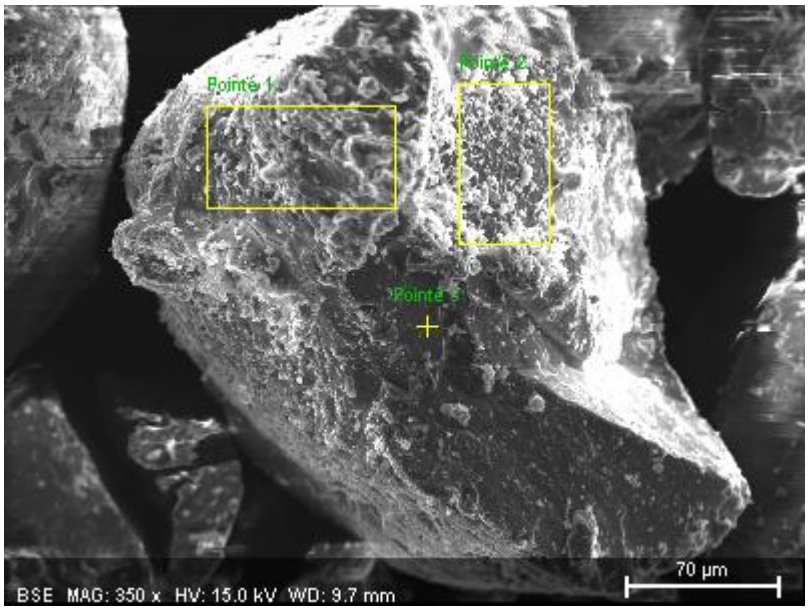
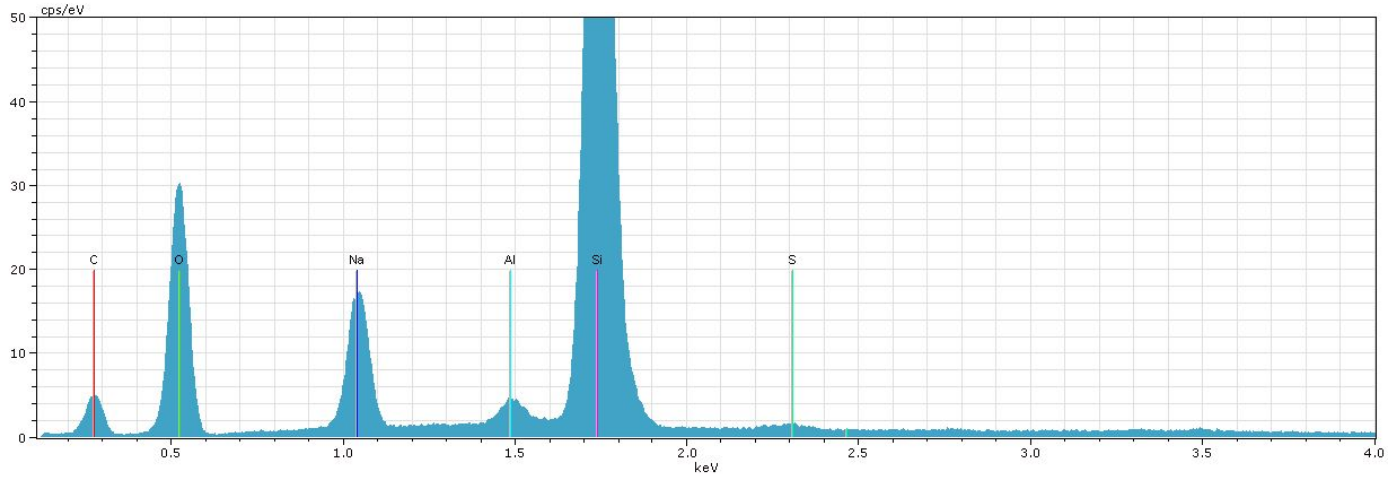
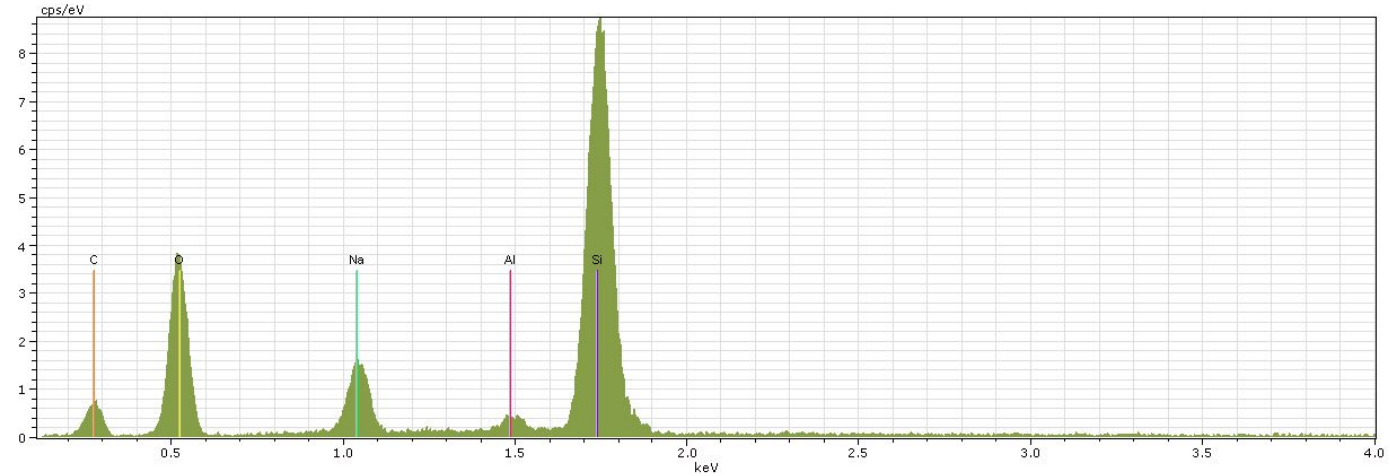


Photo of the sand to be treated, marked CTIF IE, with the analysis zones " marked 1, marked 2, marked 3 ".

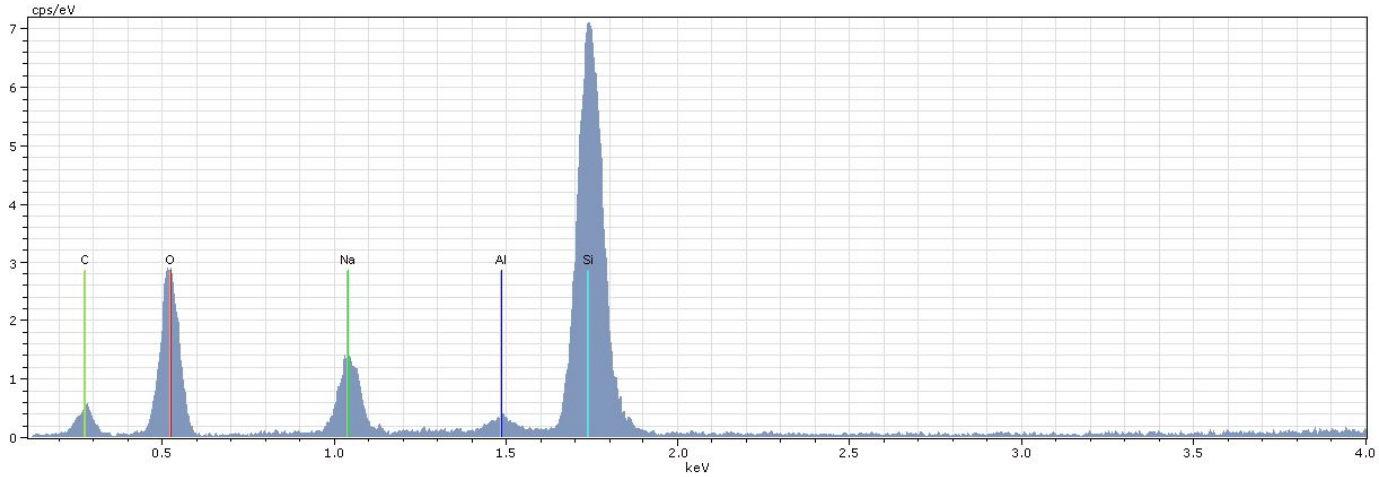


EDS analysis results: CTIF IE photo to be processed "marked 1"



EDS analysis results: CTIF IE photo to be treated "marked 2"

EDS analyses carried out to identify the elements present in the sands to be treated: cont'd



EDS analysis results: CTIF IE photo to be treated "marked 3"

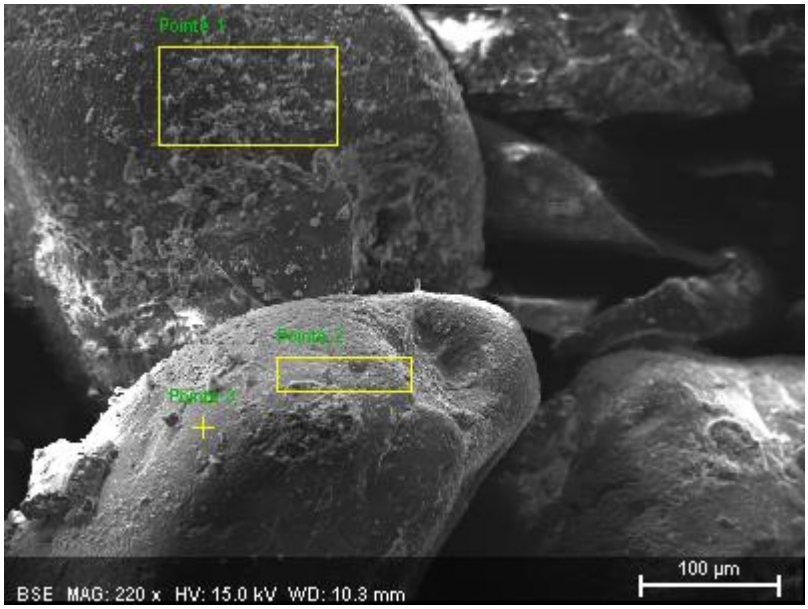
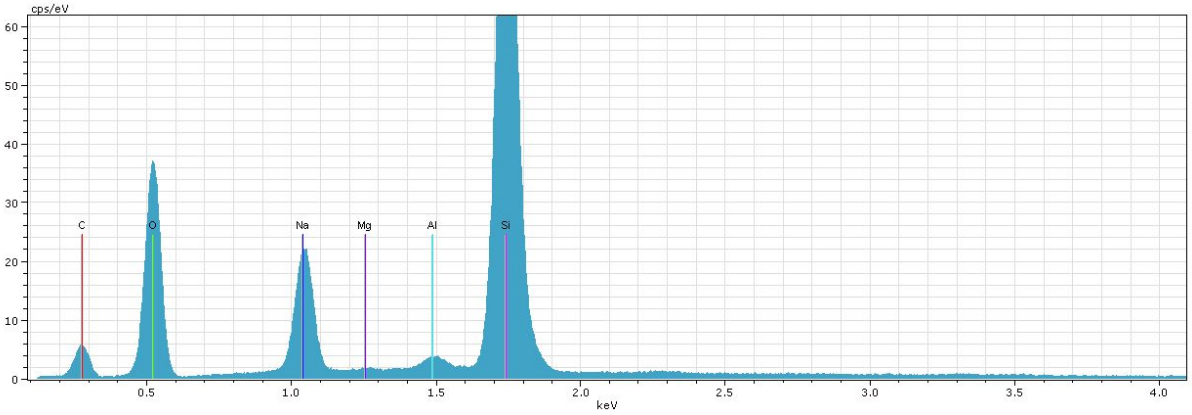
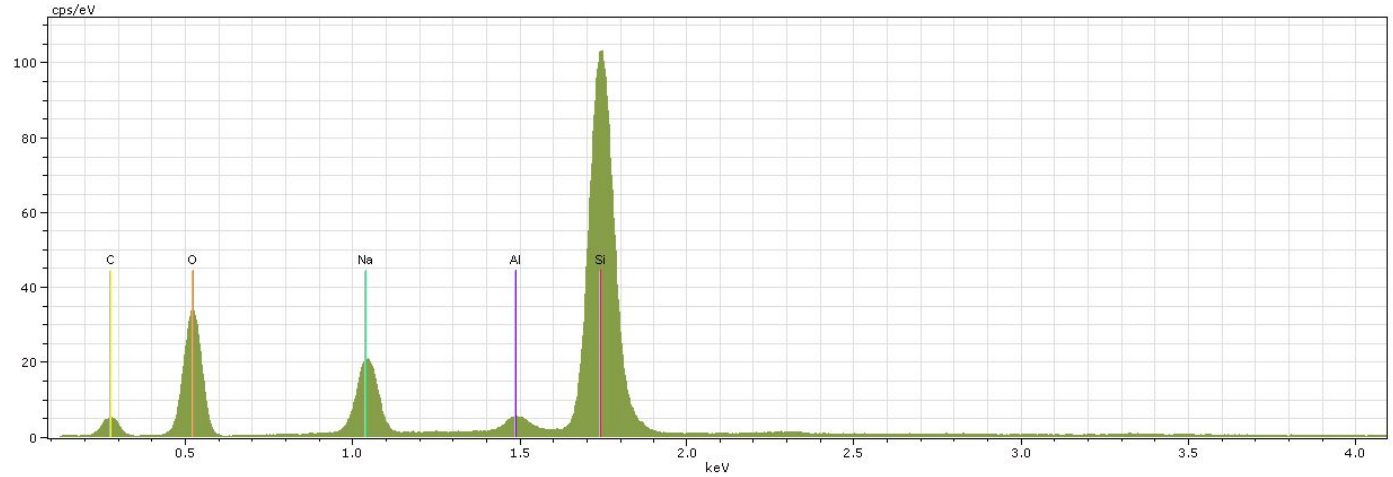


Photo of the sand to be treated, marked INOTEC, with the analysis zones " marked 1, marked 2, marked 3 ".

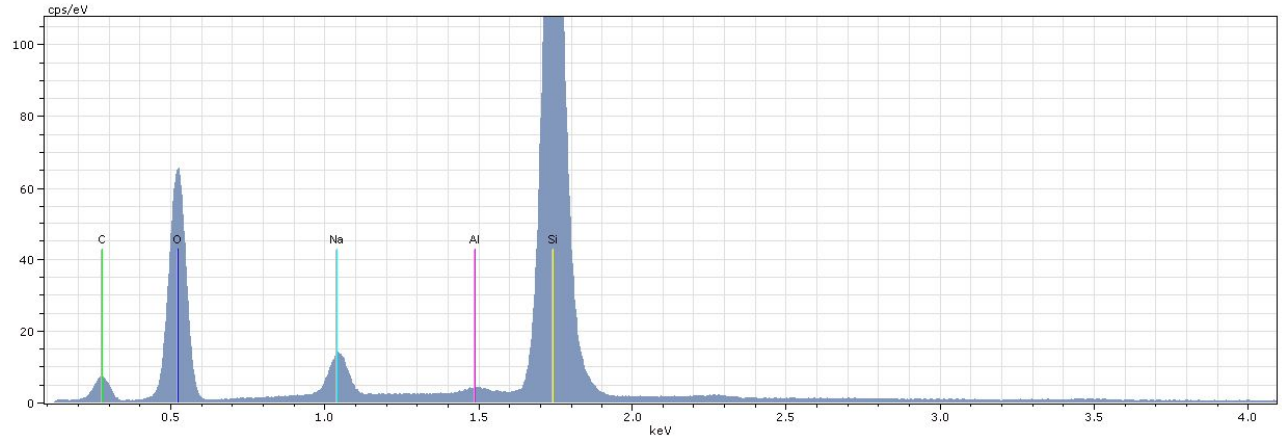


EDS analysis results: INOTEC photo to be treated "marked 1"

EDS analyses carried out to identify the elements present in the sands to be treated: Cont'd



EDS analysis results: INOTEC photo to be treated "marked 2"



EDS analysis results: INOTEC photo to be treated "marked 3"

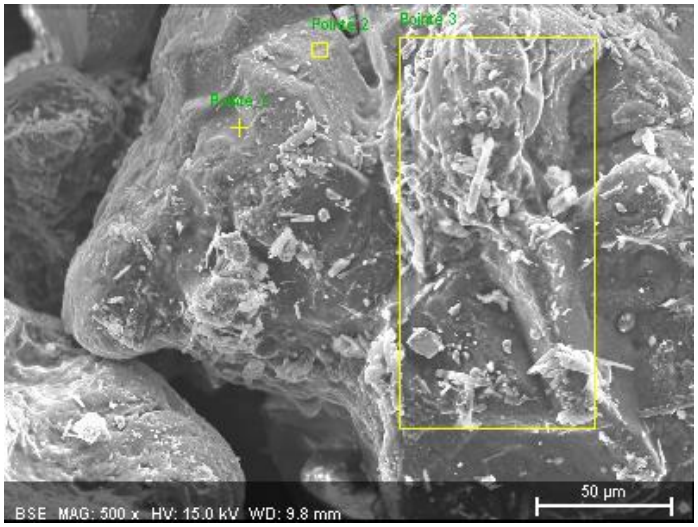
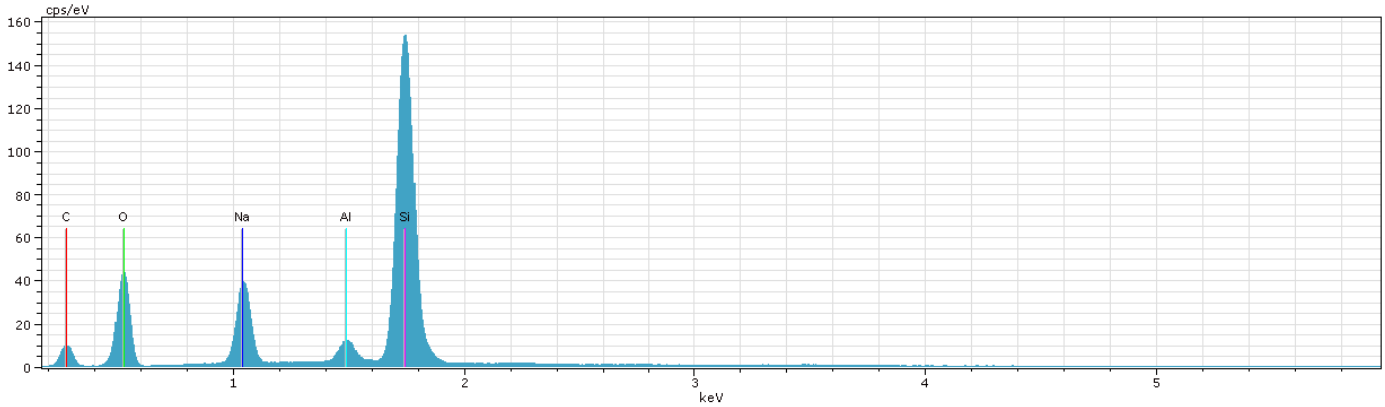
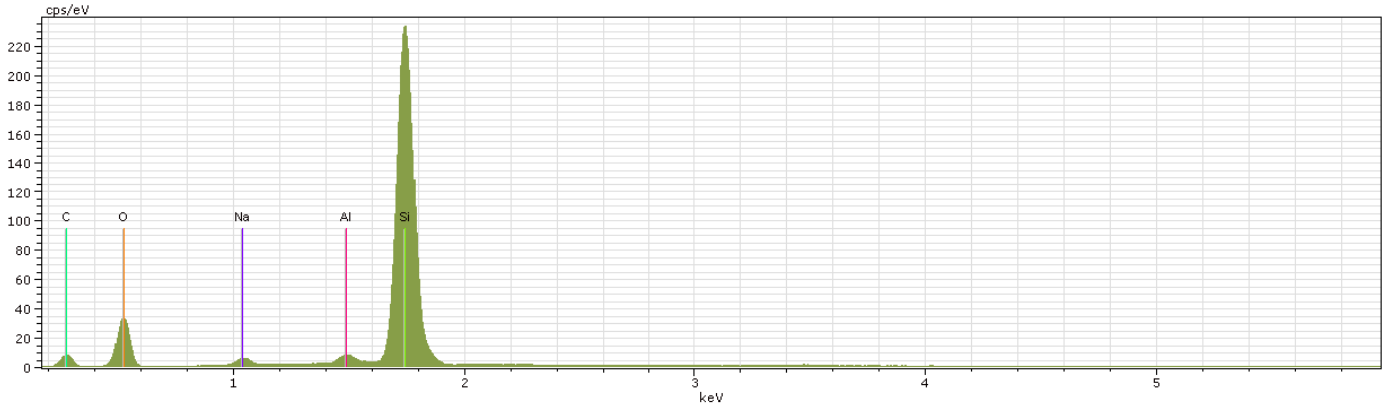


Photo of the sand to be treated marked GEOPOL W37-20, with the analysis zones " marked 1, marked 2, marked 3 ".

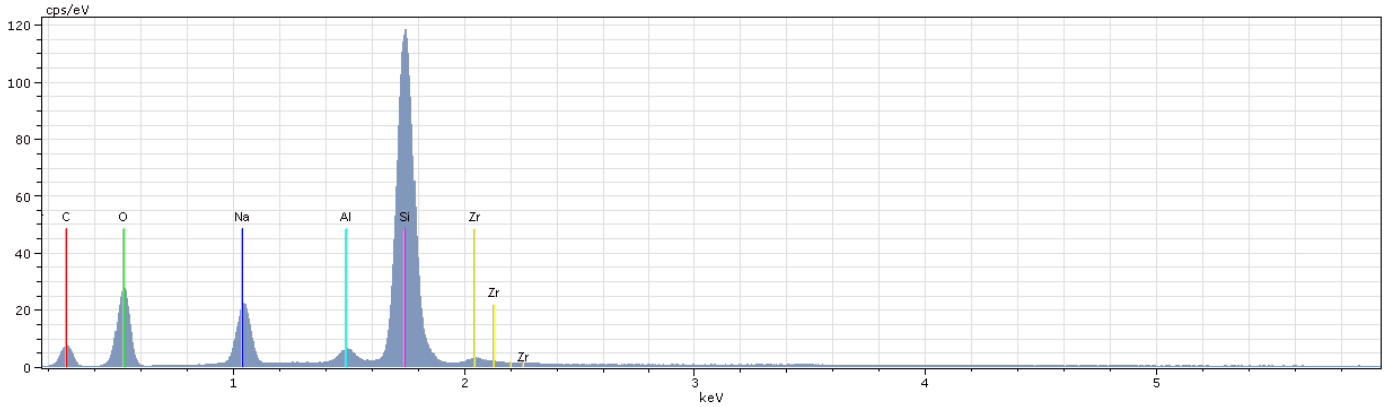
EDS analyses carried out to identify the elements present in the sands to be treated: Cont'd



EDS analysis results: Geopol W37-20 photo to be treated "marked 1"



EDS analysis results: Geopol W37-20 photo to be treated "marked 2"



EDS analysis results: Geopol W37-20 photo to be treated "marked 3"

EDS analyses carried out to identify the elements present in the sands to be treated: Cont'd

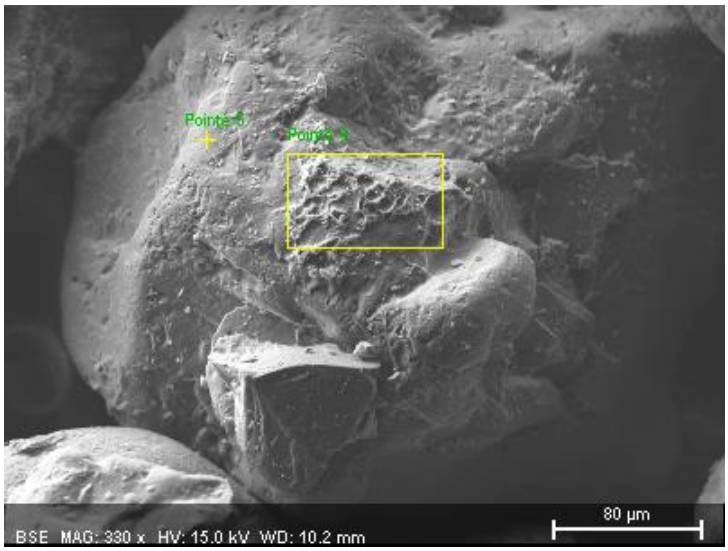
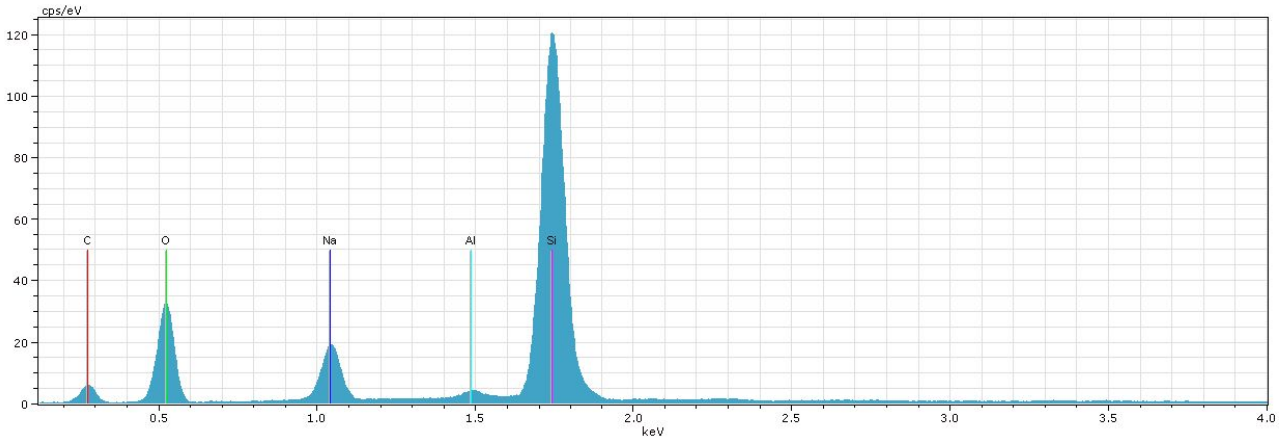
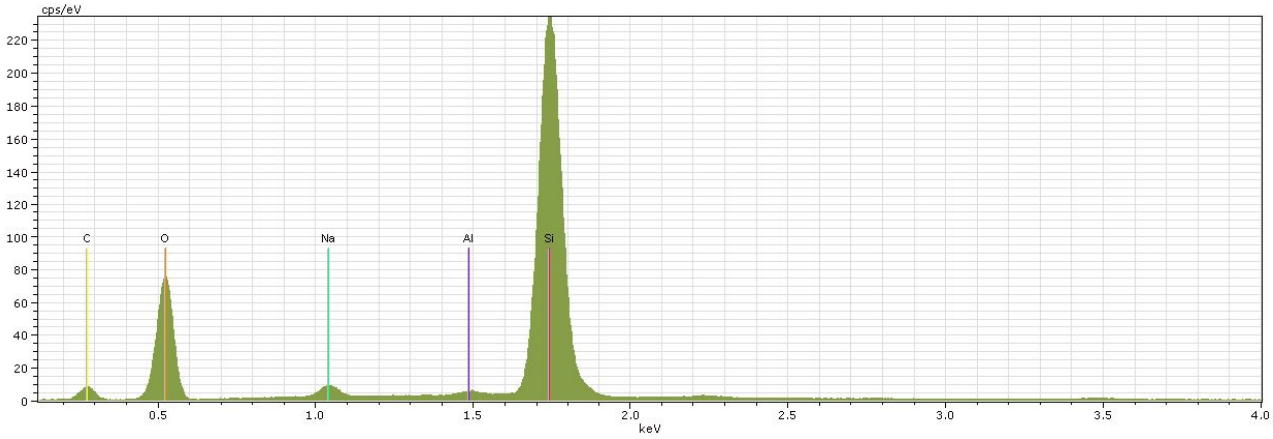


Photo of the sand to be treated marked PEAK W37, with the analysis zones " marked 4, marked 5 ".



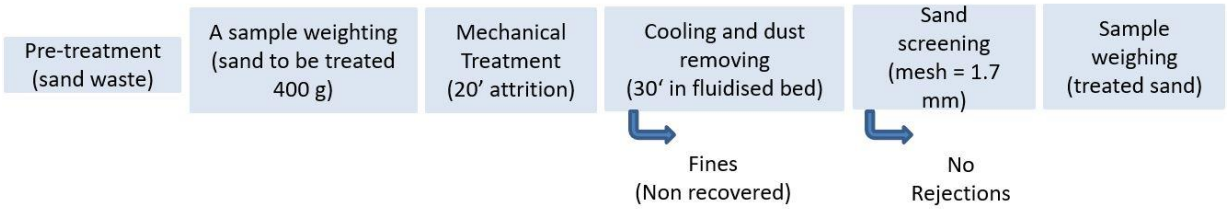
EDS analysis results: PEAK W37 photo to be treated "marked 4"



EDS analysis results: PEAK W37 photo to be treated "marked 5"

2.1. Description of the processes and treatments implemented at the CTIF's platform

Mechanical treatment process



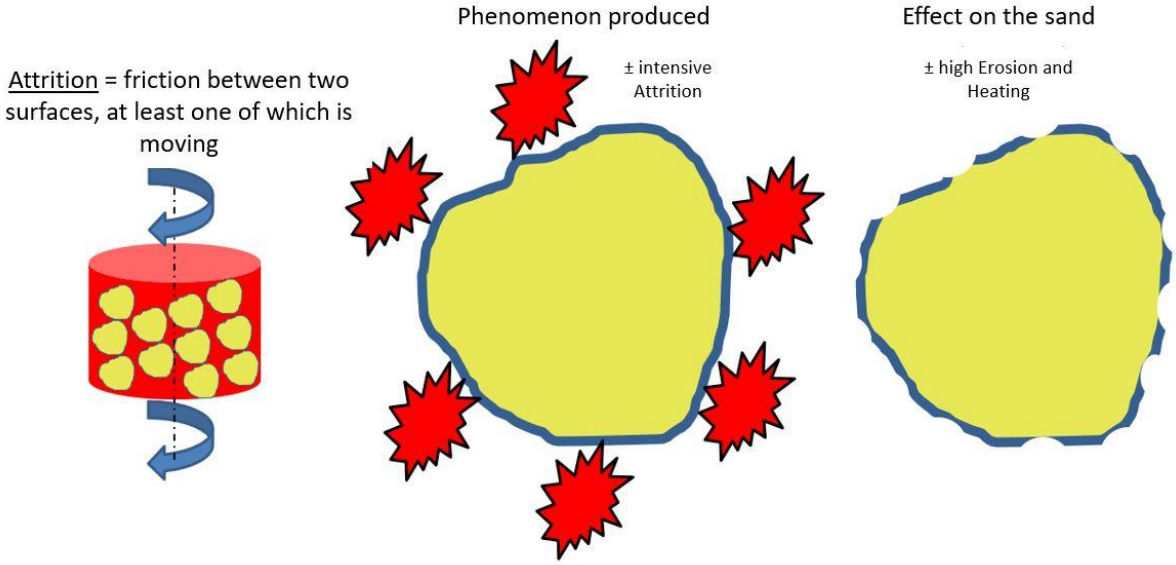
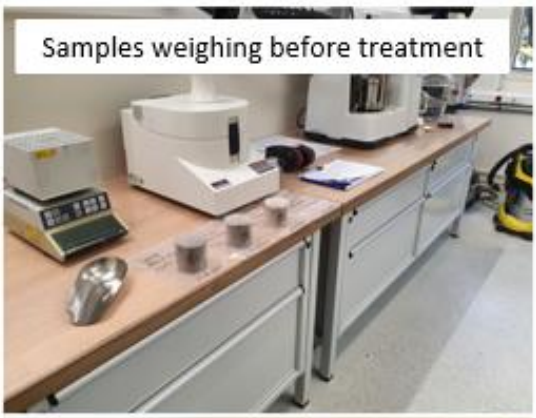


Illustration of the mechanical treatment process



Hydromechanical treatment process

Principle of the hydromechanical treatment

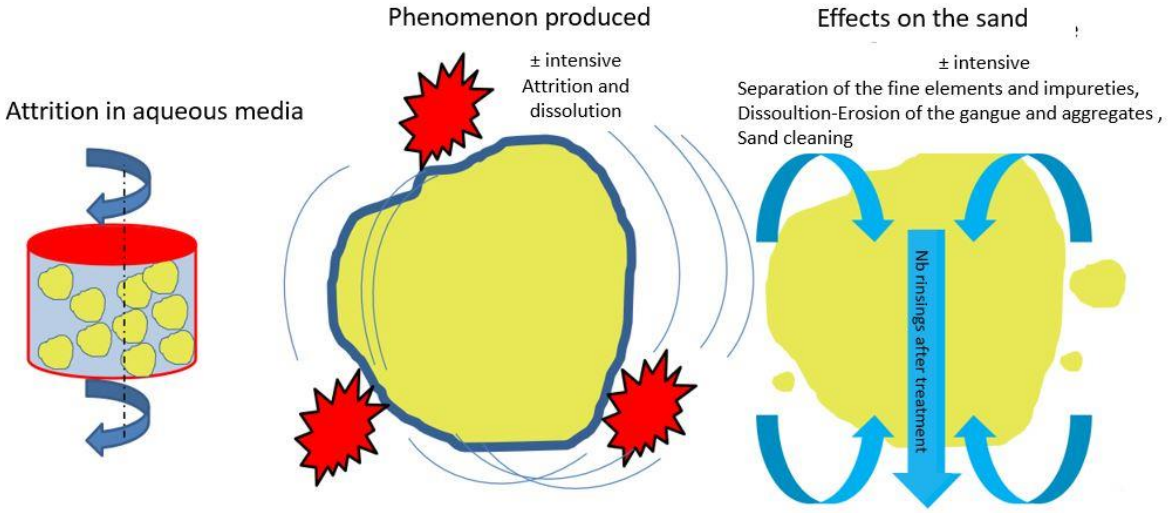


Illustration of the hydromechanical treatment process

Samples weighing before treatment

Sand moistening before treatment

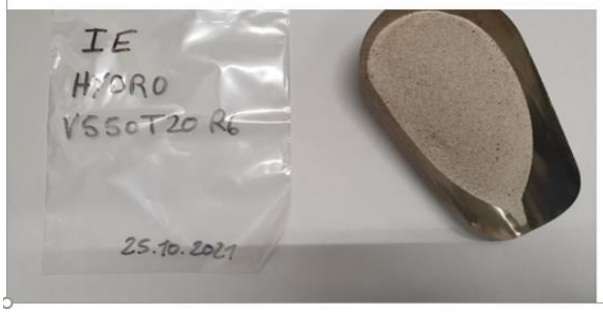
Hydromechanical treatment (20')

Sand before draining and rinsing (6)

Sand CTIF IE after rinsing

Drying and dust removing (30')

Screening and weighing after treatment



Ultrasonic Treatment process

Principle of ultrasound treatment

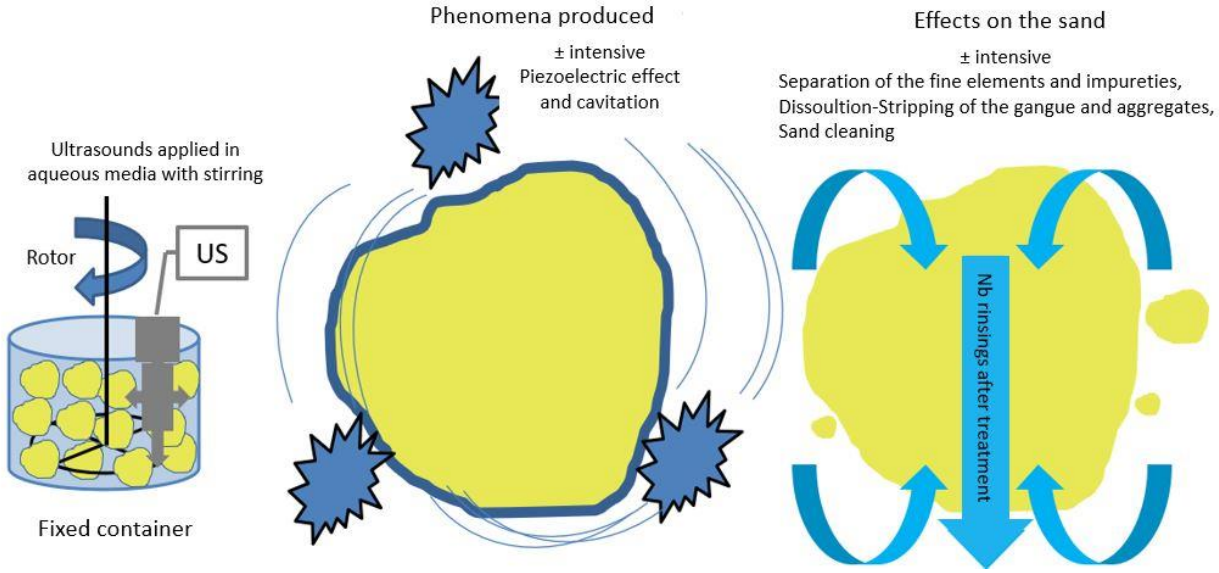
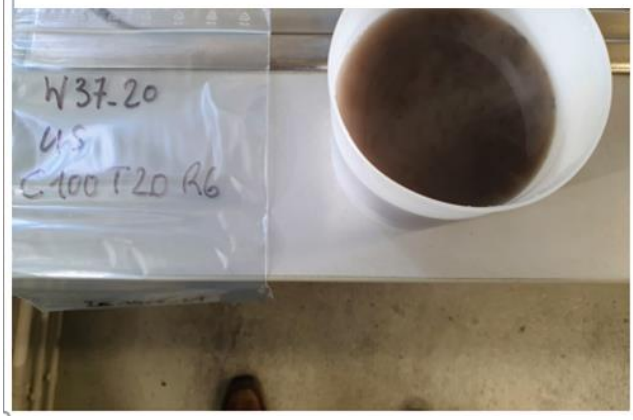


Illustration of the ultrasound treatment process

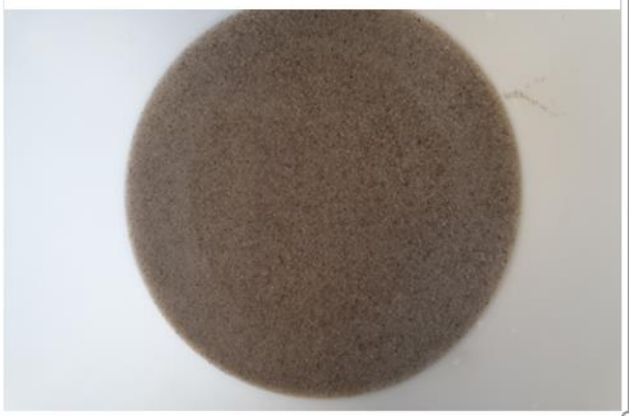
Weighing of the samples before treatment

Sand moistering and US treatment (20')

Sand GEOPOL W37-20 after treatment



Sand GEOPOL W37-20 after rinsing (6)



Drying and dust removing (30')

Sand screening and weighing after treatment

2.2. Summary of the mechanical treatment tests

Table 5: results of the sand characterization after mechanical treatment

Laboratory checks on the sand samples	Ref SN BE01	INOTEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	50	49	52	55
Distribution 50-70-100 (%)	95,03	92,00	94,68	90,27	90,75
Distribution 200-270-bottom (%)	0,18	0,92	1,04	1,89	2,28
Absence of residual aggregate (%)	0,00	0,00	0,00	0,08	0,04
Theoretical specific surface (cm2/g)	159	176	170	184	195
Breakage of sand grains observed under the light microscope (high/low/no)	no	low	low	significant	significant
Aggregate removal observed under optical microscope (yes/no)	no	yes	yes	yes	yes
Amount of fines produced by the treatment (no/low/significant)	no	significant	significant	significant	significant
Grain shape observed under light microscope (general trend: spherical/angular)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains observed under the light microscope (general trend: smooth/rough)	smooth	smooth+Rug	smooth	smooth	smooth
Amount of black grains (general tendency: not/low/significant)	no	significant	low	low	low
Quantity of light-coloured grains with black spots (general tendency: not/low/significant)	no	significant	significant	significant	significant
Amount of light-coloured unstained grains (general trend: not/low/significant)	significant	no	low	low	low
Electrical conductivity of treated sand (µS/cm)	500 - 520	863	1262	997	842
pH of the treated sand	8,30 - 8,40	10,01	10,17	9,57	9,44
Acid demand of treated sand (ml HCL)	1,2 - 2,0	27,5	35,9	20,9	17,1
Samples retained for leaching test		X	X	X	X
Updated on 26/11/2021					

Initial findings: (see illustrations on pages 21 to 46)

- Grain breakage for the GEOPOL W37-20 and PEAK W37 sands,
- The production of fines is significant in all cases,
- For all the treated sand samples, conductivity, pH and acid demands are not in conformity with the new sand reference BE01,
- All sand samples are not well cleaned.

Explanations:

In order to compare the effects of the mechanical treatment with the hydromechanical and ultrasonic treatments, the settings of the mechanical module were set at V550T20 + 30 min of dedusting.

- To reduce grain breakage in GEOPOL W37-20 and PEAK W37 sands, the rotation speed of the module and the treatment time should be adjusted (e.g. set to V550T15 or V500T20),
- The 30 minute dedusting time was not sufficient to reduce the fines content,
- The mechanical treatment does not clean the inorganic sand well: the production of fines is high (dry attrition phenomenon), and a large quantity of residual gangue remains stuck to the surface of the grains (temperature rise phenomenon).

Note: after mechanical treatment, no clear unstained grain is found in INOTEC sand: this difference in behaviour compared to other sands is perhaps due to the nature, composition and/or quality of the binder and additives used for this process.

2.3. Summary of the hydromechanical treatment tests

Table 6: results of the sand characterization after hydromechanical treatment

Laboratory checks on the sand samples	Ref SN BE01	INOTEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	49	47	48	49
Distribution 50-70-100 (%)	95,03	92,64	95,42	94,68	93,94
Distribution 200-270-bottom (%)	0,18	0,14	0,04	0,00	0,06
Absence of residual aggregate (%)	0,00	0,04	0,00	0,04	0,08
Theoretical specific surface (cm2/g)	159	172	160	169	172
Breakage of sand grains under the light microscope (significant/low/no)	no	low	low	low	low
Aggregate removal observed under optical microscope (yes/no)	no	yes	yes	yes	yes
Amount of fines produced by the treatment (no/low/significant)	no	low	low	low	low
Grain shape observed under the optical microscope (general trend: spherical/angular)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains under the optical microscope (general trend: smooth/rough)	smooth	smooth	smooth	smooth	smooth
Amount of black grains (general trend: no/low/significant)	no	low	low	low	low
Quantity of light-coloured grains with black spots (general trend: no/low/significant)	no	significant	low	low	low
Amount of clear unstained grains (general trend: no/low/significant)	significant	significant	significant	significant	significant
Electrical conductivity of treated sand (µS/cm)	500 - 520	523	516	507	511
pH of treated sand	8,30 - 8,40	8,78	8,73	8,72	8,45
Acid demand of treated sand (ml HCl)	1,2 - 2,0	5,8	2,2	0,6	1,5
Samples retained for leaching test		X	X	X	X
Updated on 26/11/2021					

Initial findings: (see illustrations on pages 21 to 46)

- No breakage of the sand grains in all cases,
- All the parameters checked are in conformity with the reference sand BE01,
- The sand is well cleaned in all cases,
- Only the INOTEC sand has a slightly higher acid demand.

Explanations :

- The phenomena produced and the effects generated by the treatment are particularly effective in cleaning inorganic sands,
- The slightly high acid demand for INOTEC sand can be reduced by optimising the settings of the treatment module (rotation speed, treatment time, number of rinses).

2.4. Summary of the ultrasonic treatment tests

Table 7: results of the characterisation of the sands after ultrasonic treatment

Laboratory checks on the sand samples	Ref SN BE01	InoEC	CTIF IE	GEOPOL W37-20	PEAK W37
Fineness index	46	50	47	49	50
Distribution 50-70-100 (%)	95,03	93,02	96,10	94,14	93,98
Distribution 200-270-bottom (%)	0,18	0,18	0,06	0,04	0,10
Absence of residual aggregate (%)	0,00	0,04	0,04	0,06	0,12
Theoretical specific surface (cm2/g)	159	176	162	171	175
Casse grains de sable observée au microscope optique (significant/low/no)	no	low	low	low	low
Sand grain breakage observed by optical microscope (significant/low/no)	no	yes	yes	yes	yes
Aggregate removal observed under optical microscope (yes/no)	no	low	low	low	low
Amount of fines produced by the treatment (no/low/significant)	Spherical	Sph+Ang	Sph+Ang	Sph+Ang	Sph+Ang
Appearance of grains under the optical microscope (general trend: smooth/rough)	smooth	smooth	smooth	smooth	smooth
Amount of black grains (general trend: no/low/significant)	no	low	low	low	low
Quantity of light-coloured grains with black spots (general trend: no/low/significant)	no	significant	low	low	low
Quantity of clear unstained grains (general trend: no/low/significant)	significant	low	significant	significant	significant
Electrical conductivity of treated sand (µS/cm)	500 - 520	525	521	515	518
pH of treated sand	8,30 - 8,40	8,76	8,77	8,79	8,58
Acid demand of treated sand (ml HCL)	1,2 - 2,0	7,5	4,5	1,5	1,6
Samples retained for leaching test					
Updated on 26/11/2021					

Initial findings: (see illustrations on pages 21 to 46)

- No breakage of the sand grains in all cases,

- All the parameters checked are in conformity with the reference sand BE01,

- The sand is well cleaned in all cases,

- Only the INOTEC sand has a slightly high acid demand and a low quantity of clear unstained grains.

- The acid demand of the CTIF IE sand is also a little high.

Explanations:

- The phenomena produced and the effects generated by the treatment are particularly effective in cleaning inorganic sands (with, however, poorer characterisation results of the treated sands, compared to the hydromechanical treatment process),

- The acidic demands that are still somewhat high for INOTEC and CTIF IE sands can be reduced by optimising the settings of the treatment module (treatment time and rinses).

Illustration related to the summaries of inorganic sand treatment tests

Photo optical microscope CTIF's sand IE to be treated: overview

Photo optical microscope INOTEC sand to be treated: overview

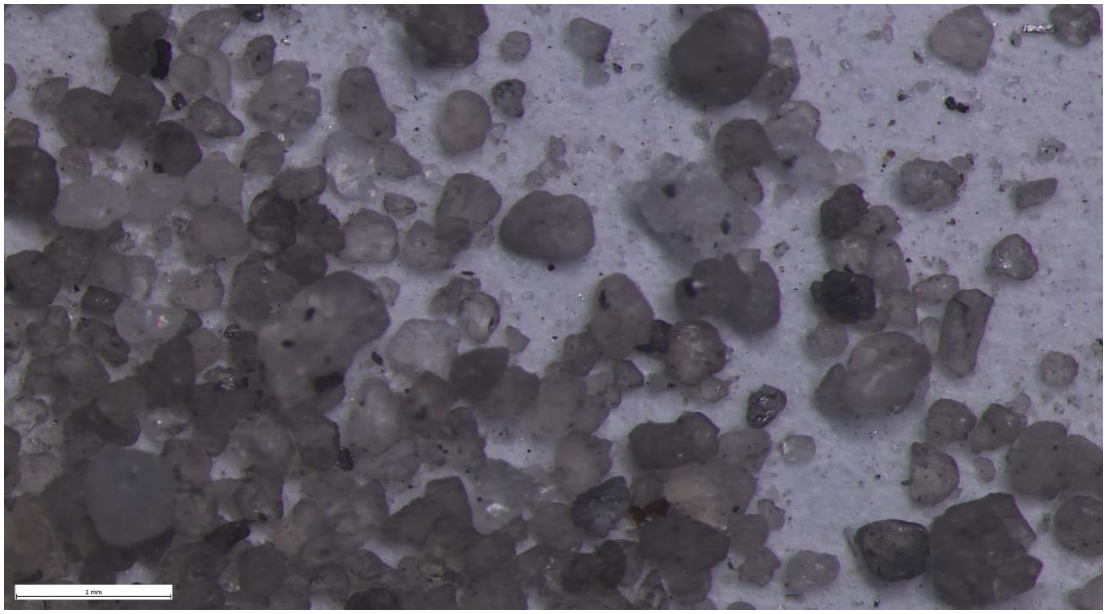


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope GEOPOL W37-20 sand to be treated: overview

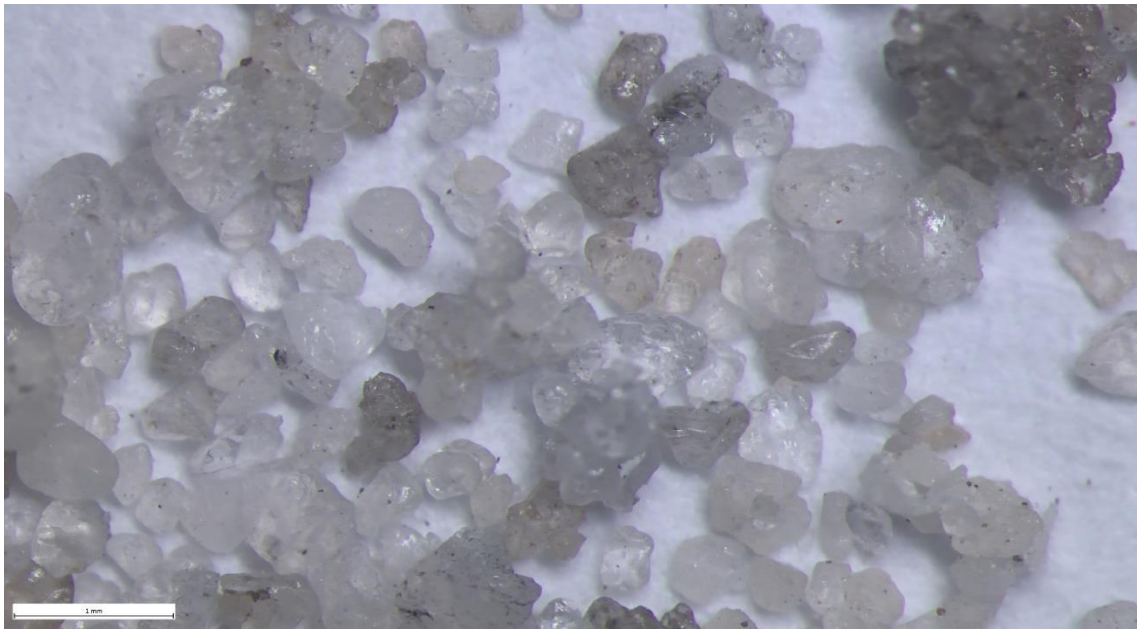


Photo - optical microscope PEAK W37 sand to be treated: overview

Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope sand new reference BE01: overview

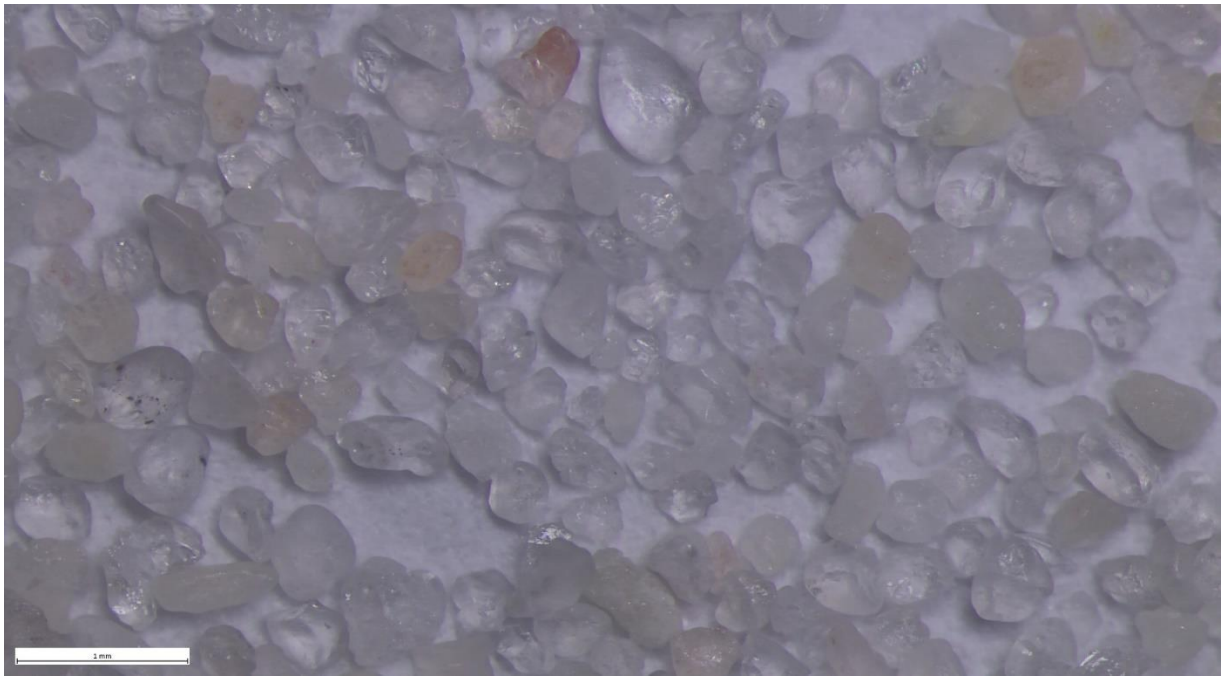


Photo - MEB new sand reference BE01: appearance of the grains

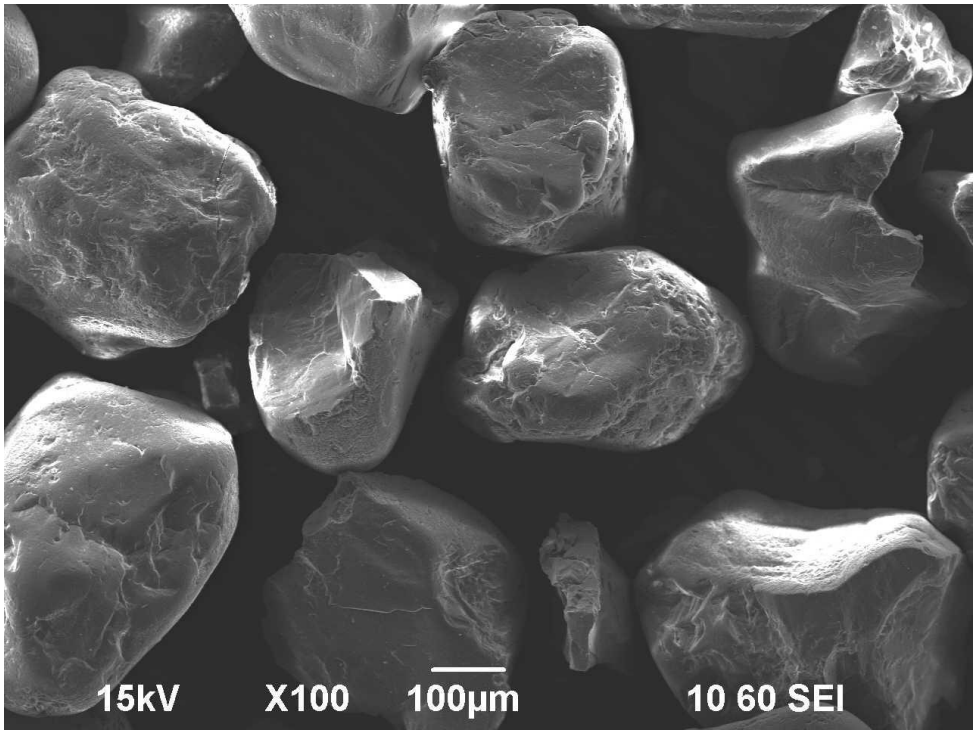


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo MEB new sand reference BE01: appearance of a broken grain (extraction and cleaning conditions)

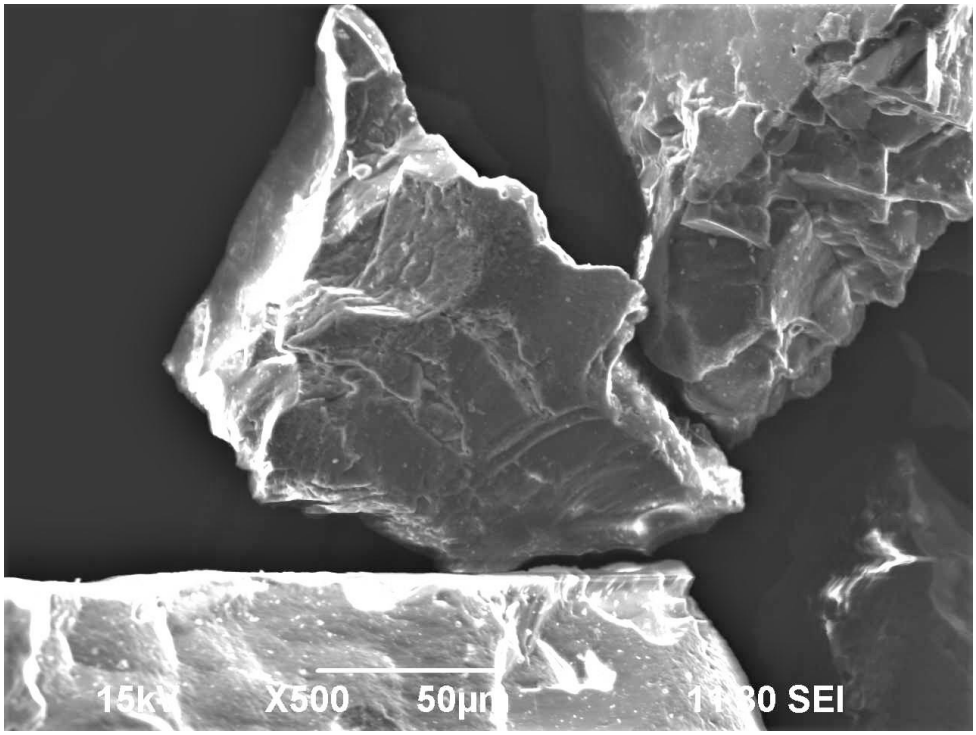


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope sand CTIF IE mechanically treated: overview

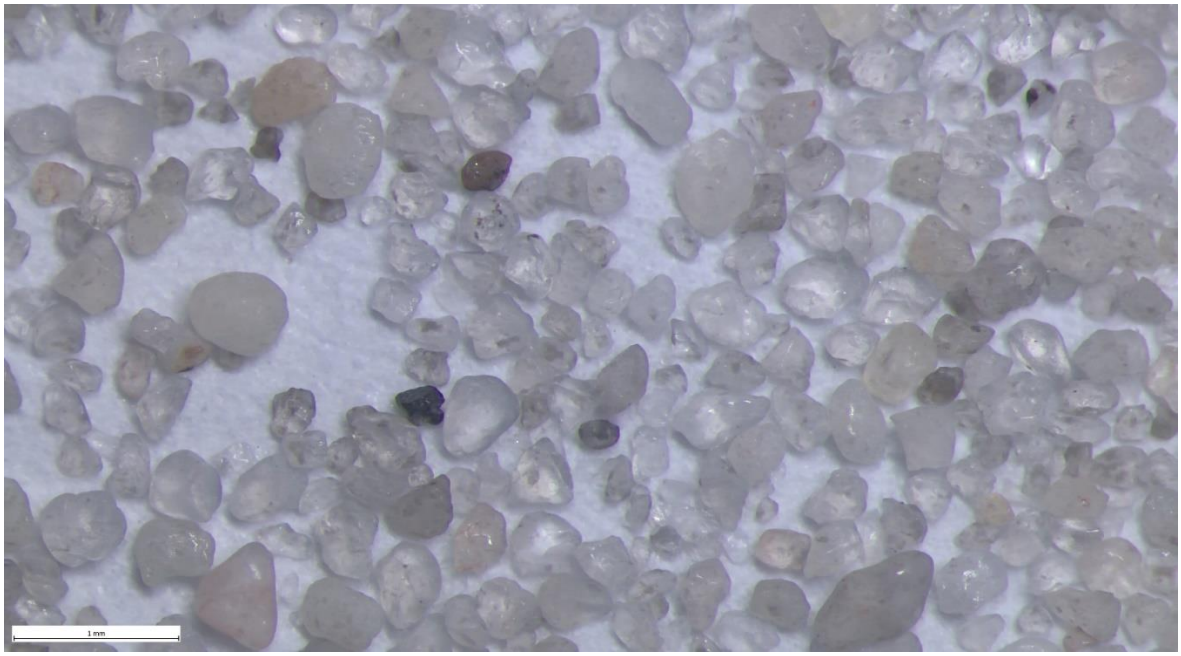


Photo - optical microscope sand INOTEC mechanically treated: overview

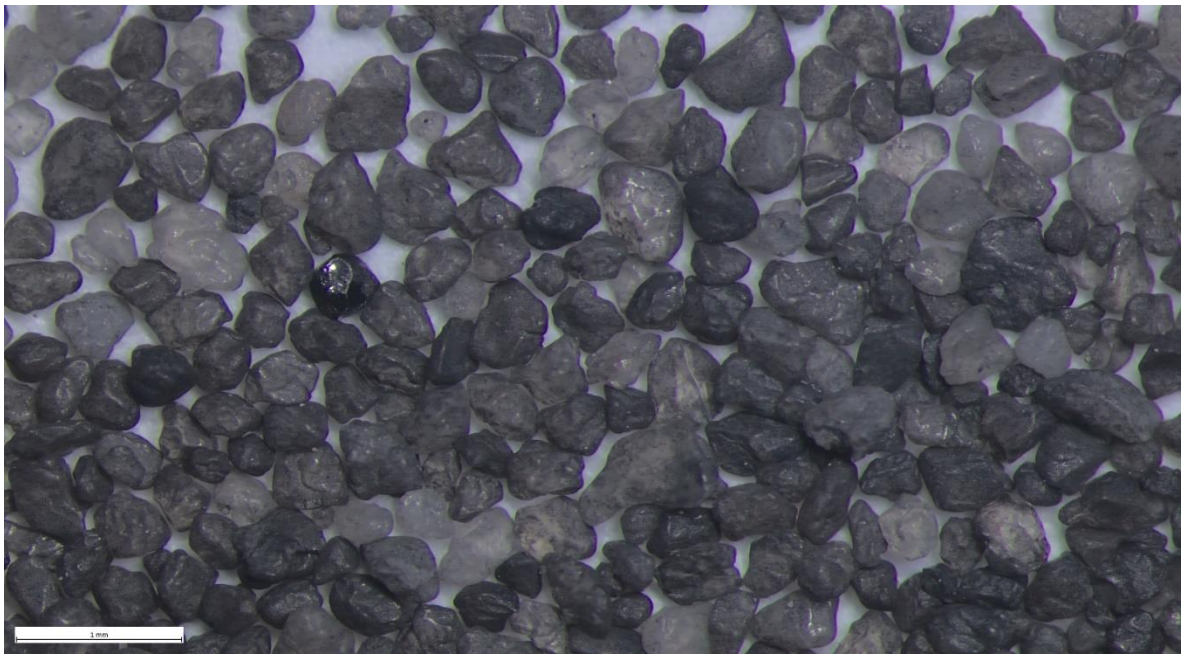


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope Geopol W37-20 mechanically treated sand: overview

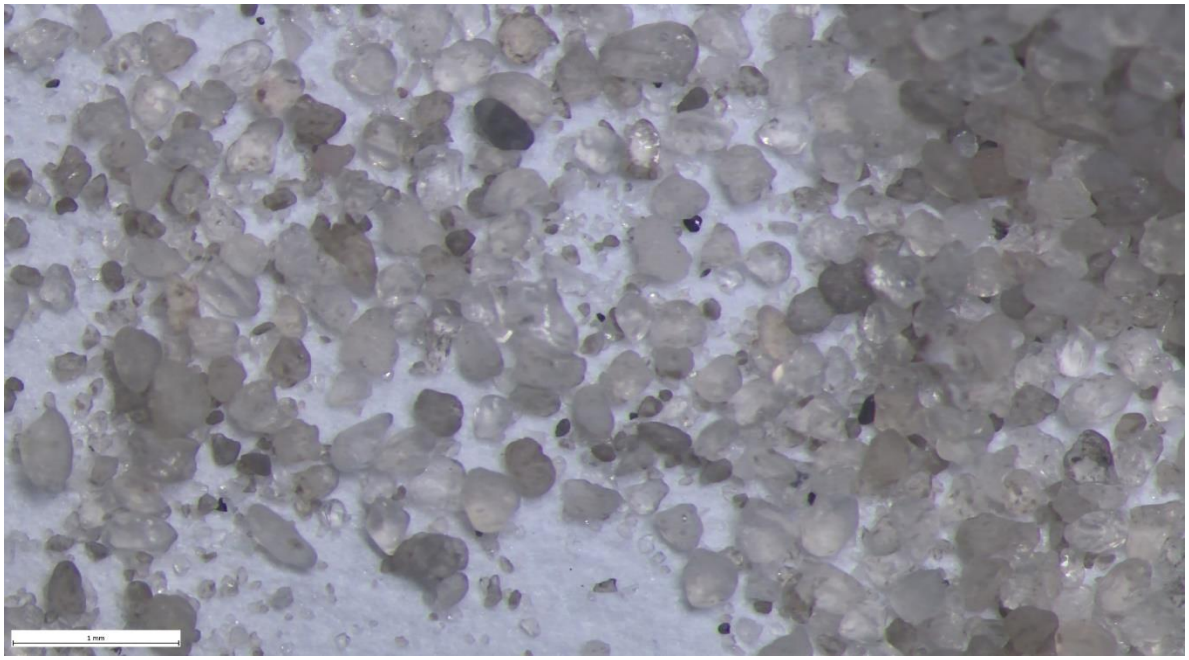


Photo - Optical microscope PEAK W37 sand mechanically treated: overview

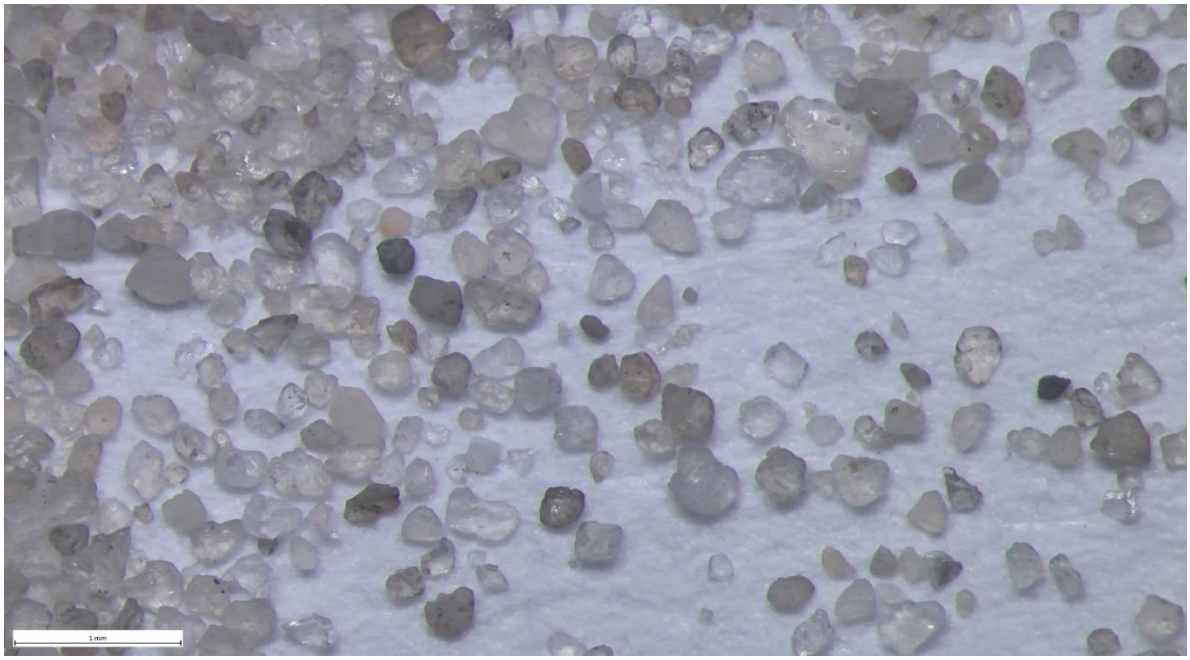


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Optical microscope photo of hydromechanically treated CTIF IE sand: overview

Photo optical microscope of hydromechanically treated INOTEC sand: general view

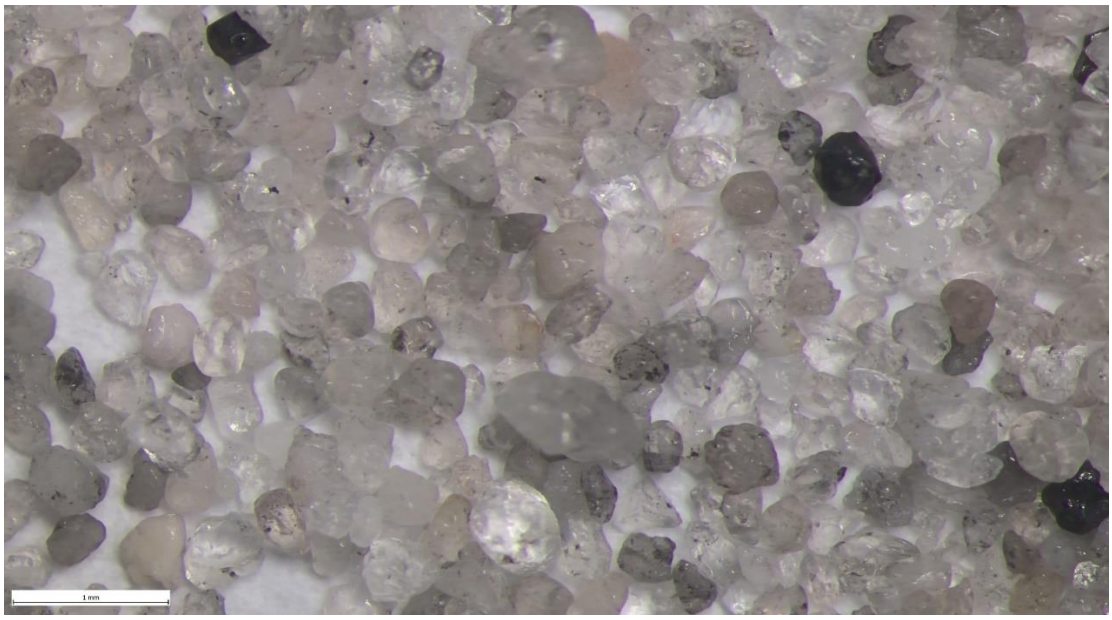
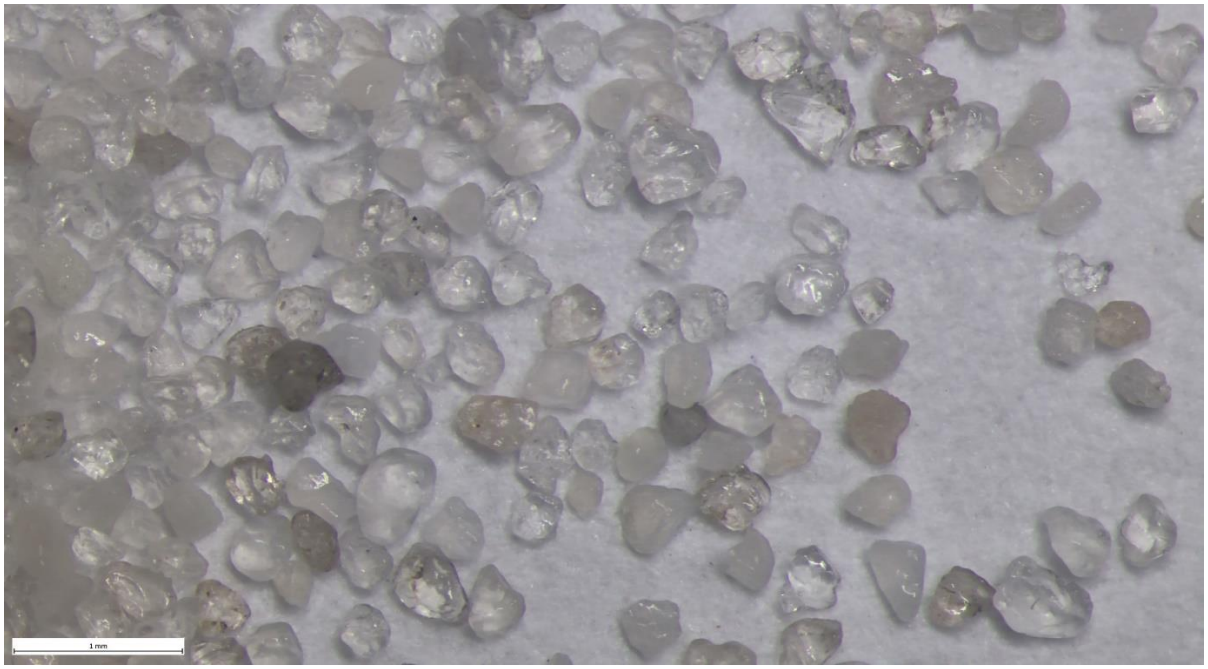


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope of sand GEOPOL W37-20 hydromechanically treated: overview



Optical microscope photo of hydromechanically treated PEAK W37 sand: overview

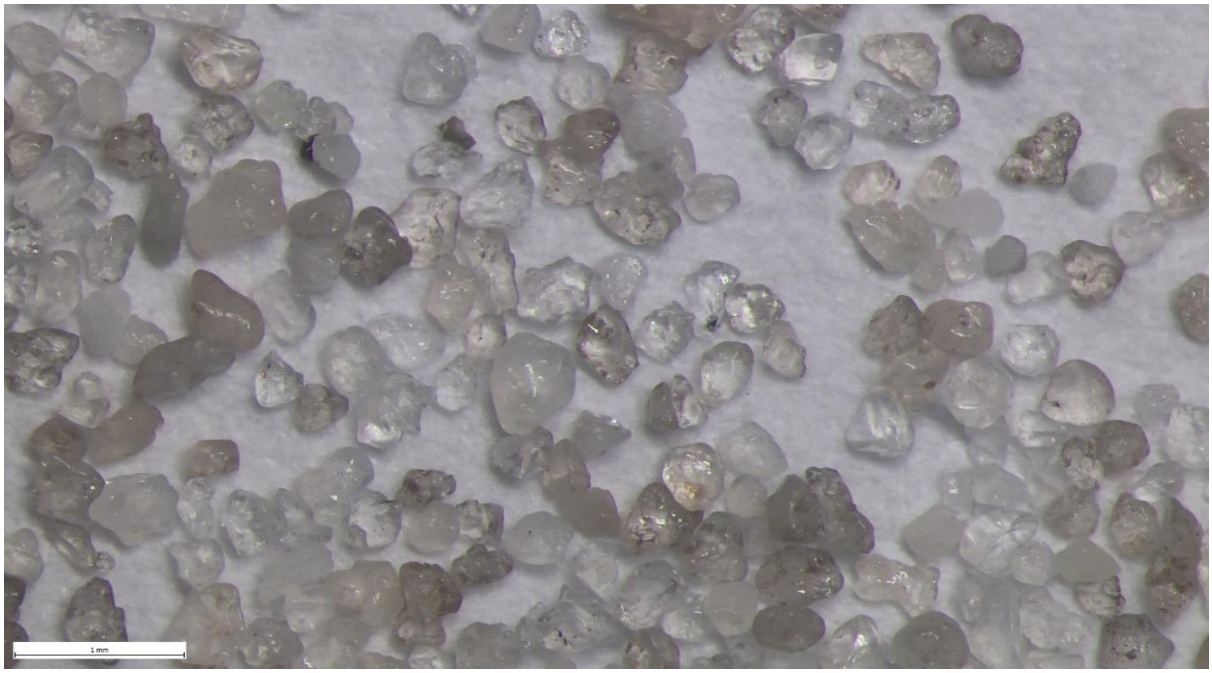


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - optical microscope ultrasonically treated CTIF IE sand: overview

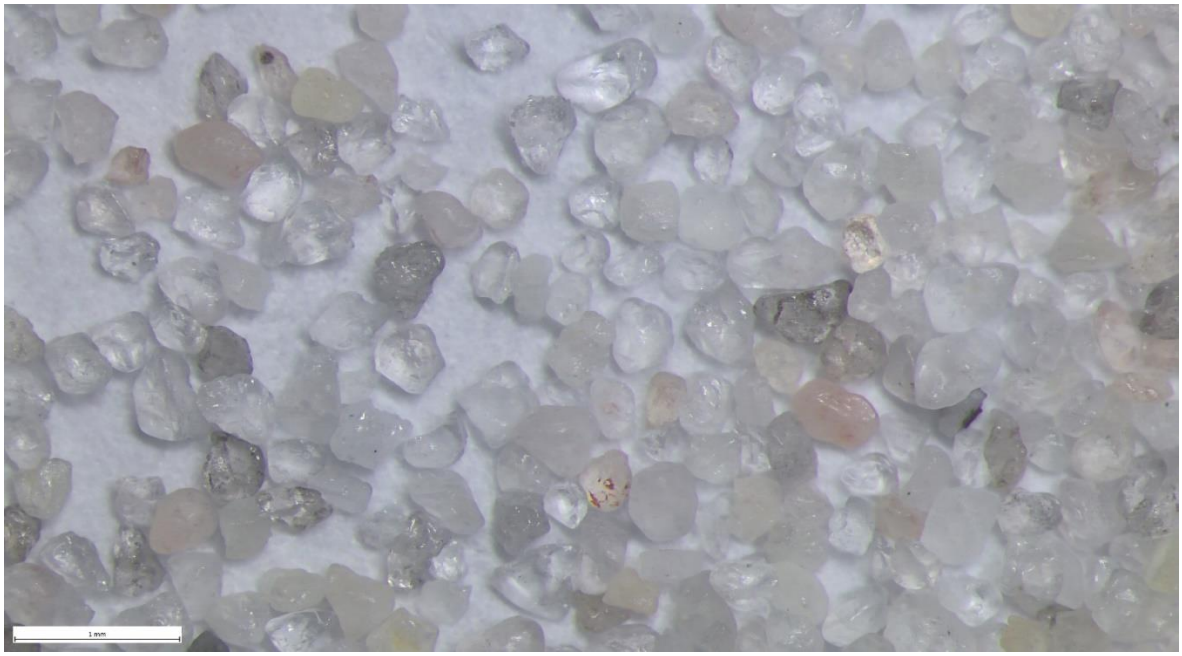


Photo - Optical microscope Ultrasonically treated INOTEC sand: overview

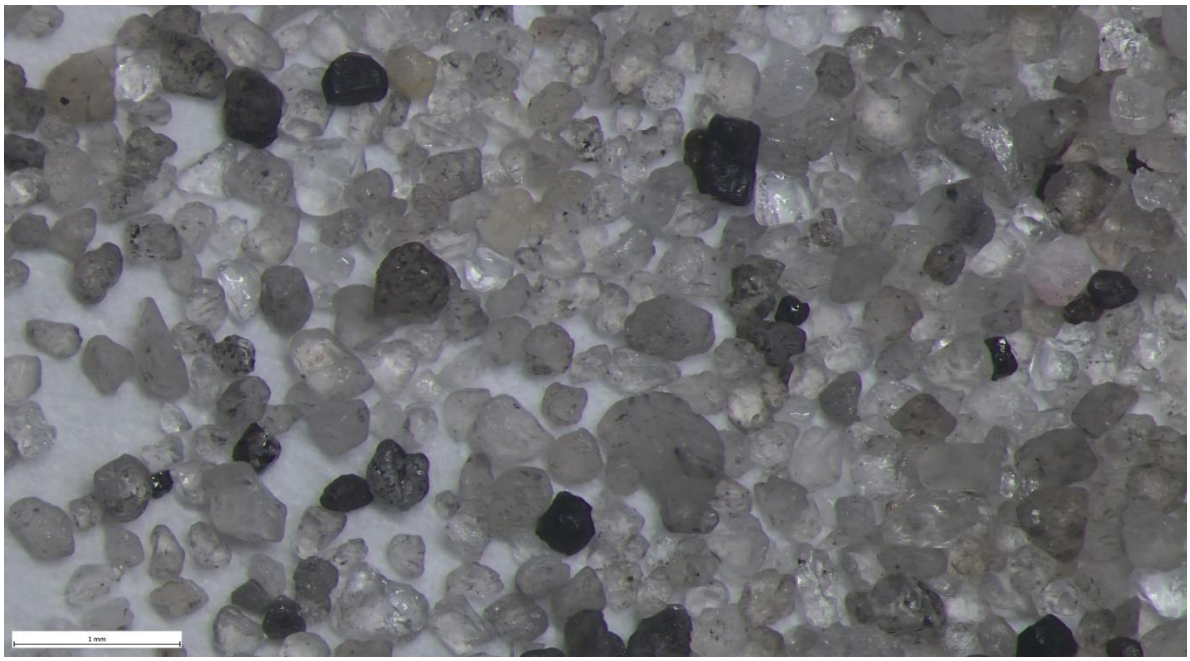


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - Optical microscope Ultrasonically treated GEOPOL W37-20 sand: overview

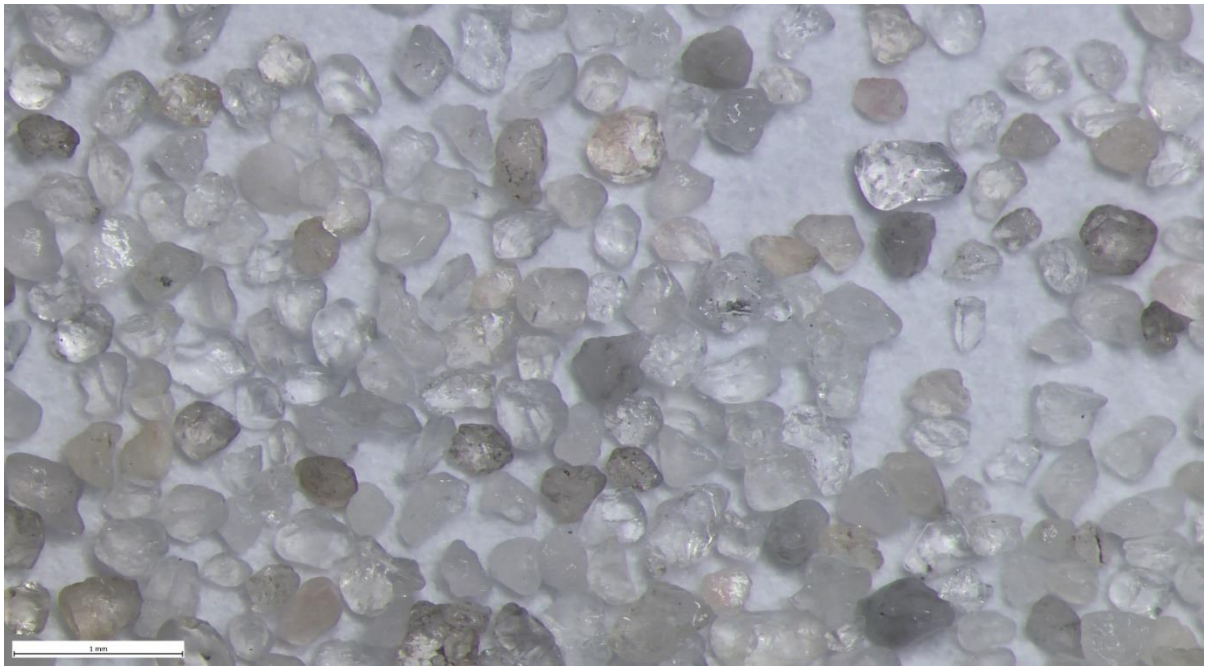


Photo - Optical microscope Ultrasonically treated PEAK W37 sand: overview

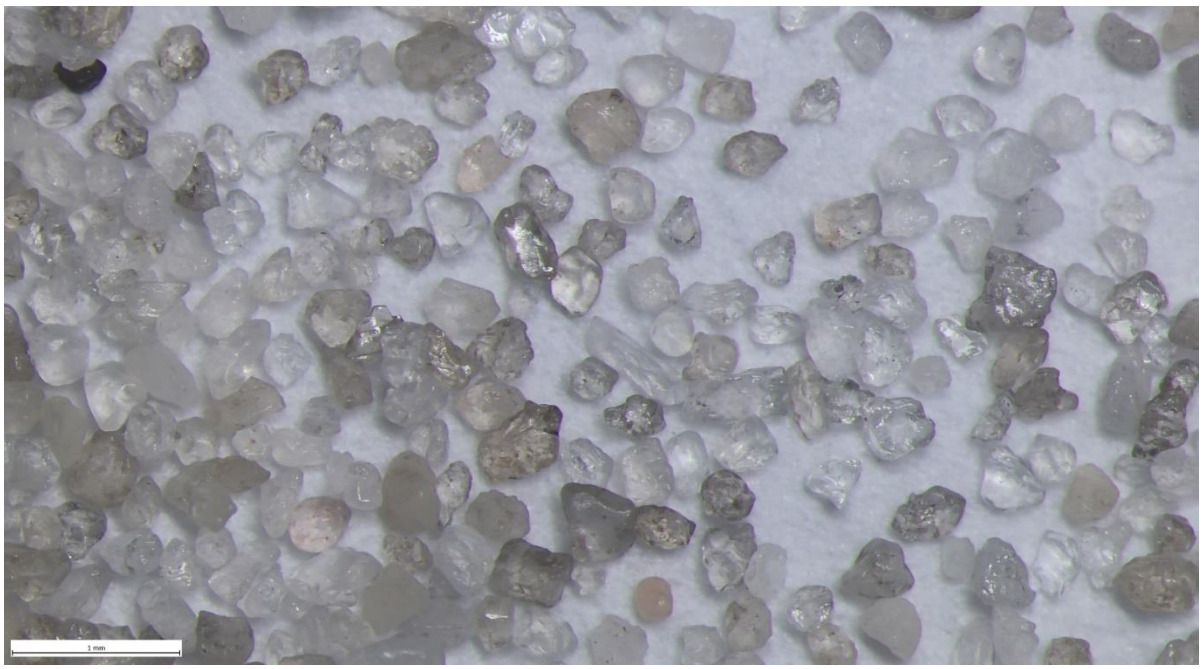


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo - SEM sand CTIF IE to be treated: overview

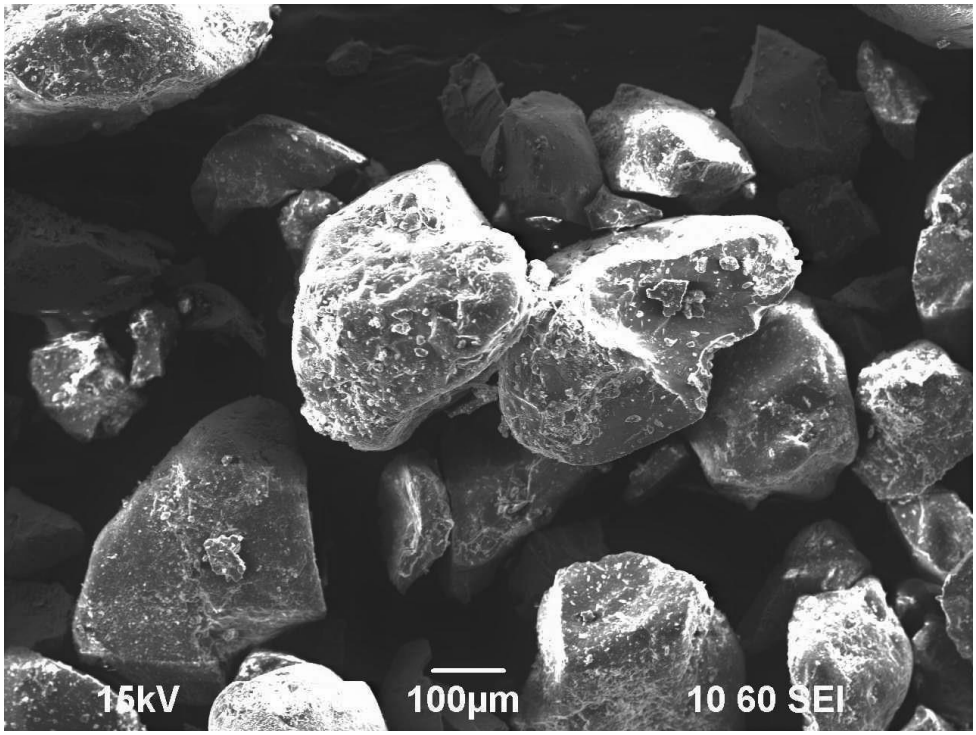


Photo SEM sand INOTEC to be treated: overview

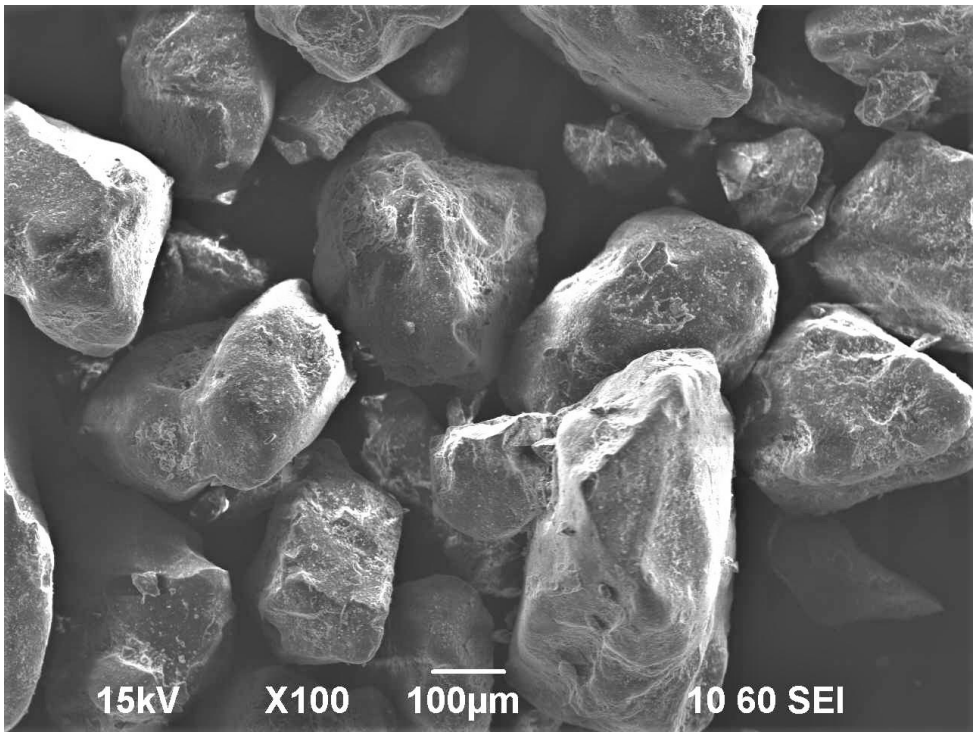


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo MEB sand GEOPOL W37-20 to be treated: overview

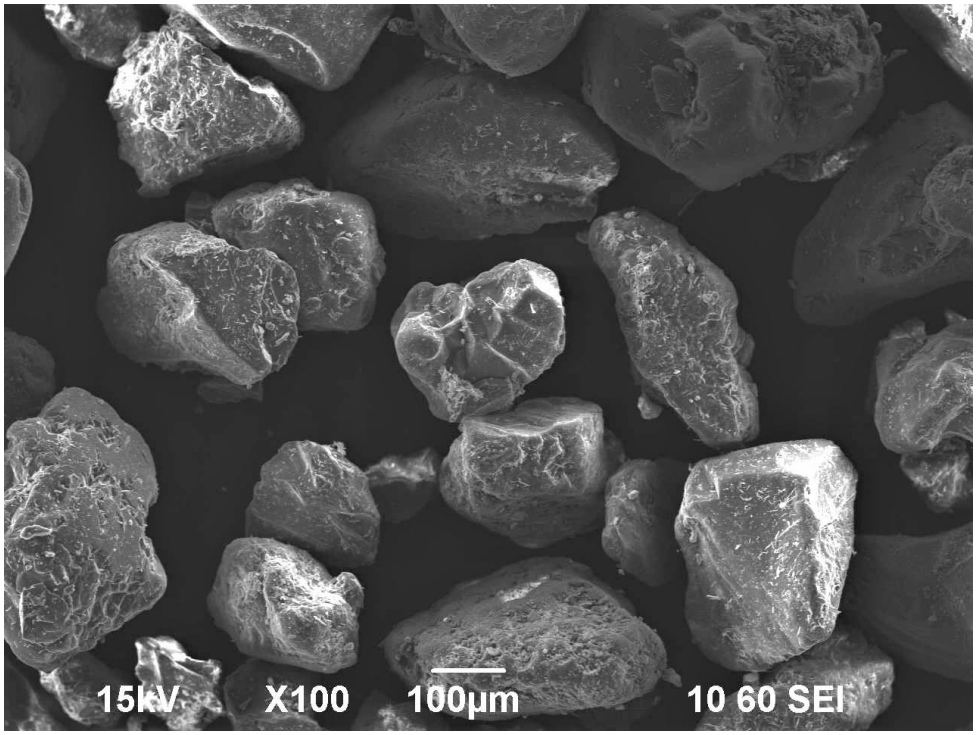


Photo MEB sand PEAK W37 to be treated: overview

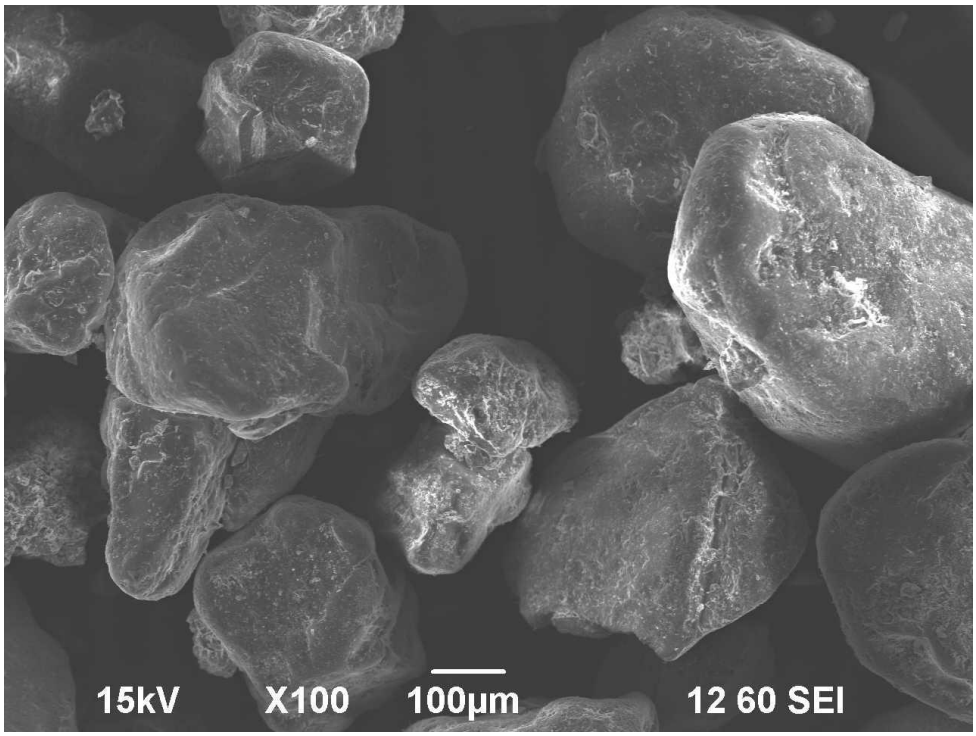


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo MEB sand CTIF IE mechanically treated: overview

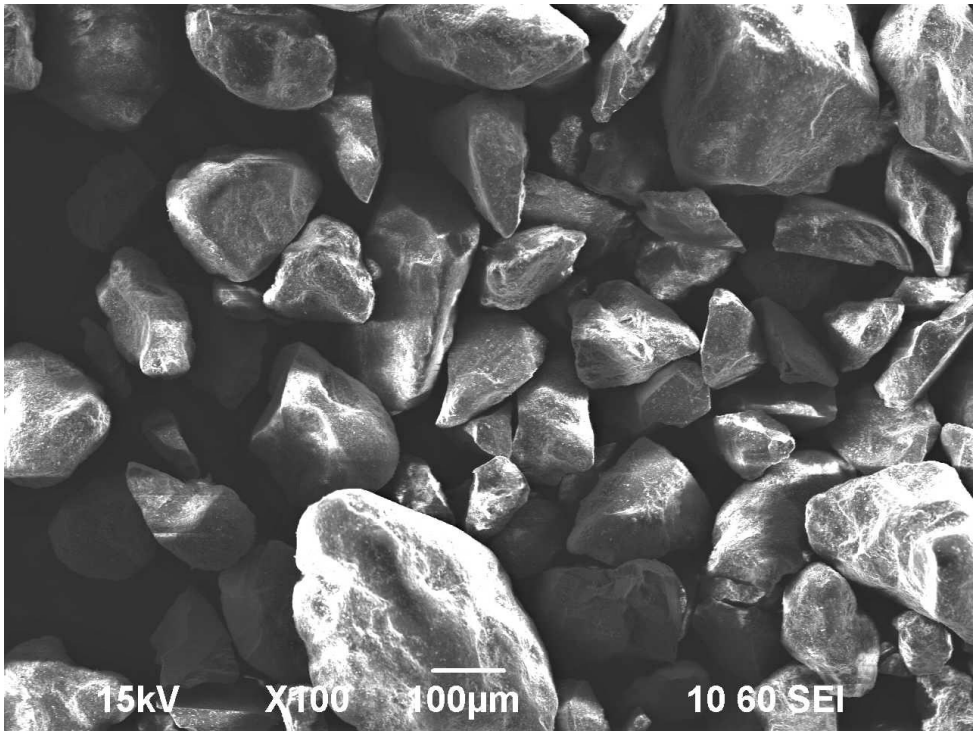


Photo MEB sand INOTEC mechanically treated: overview

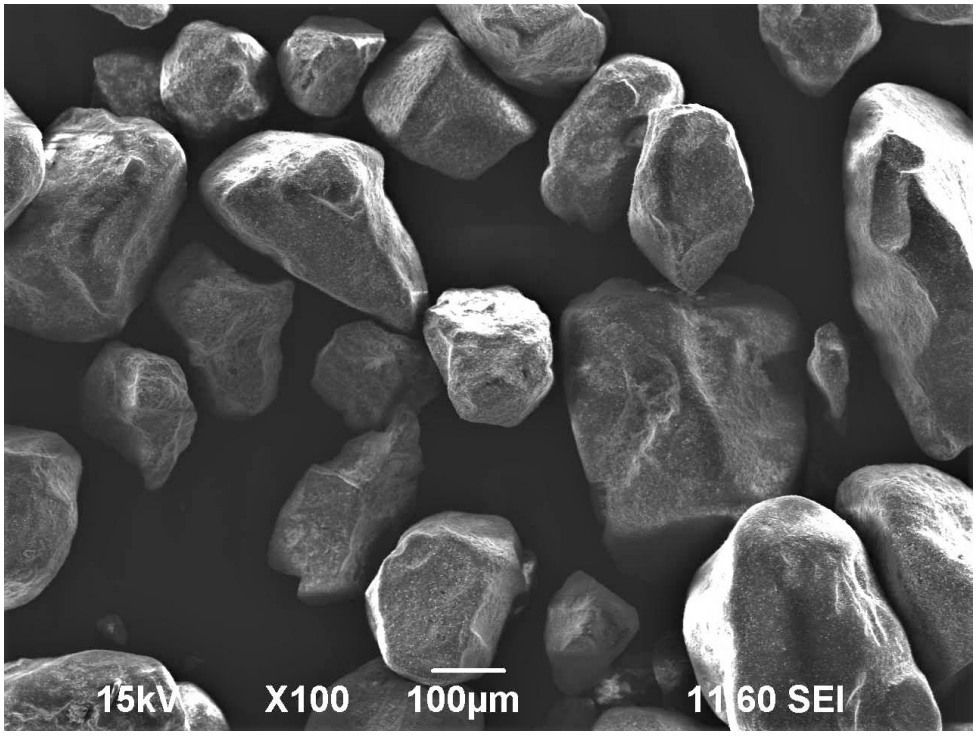


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo MEB sand GEOPOL W37-20 mechanically treated: overview

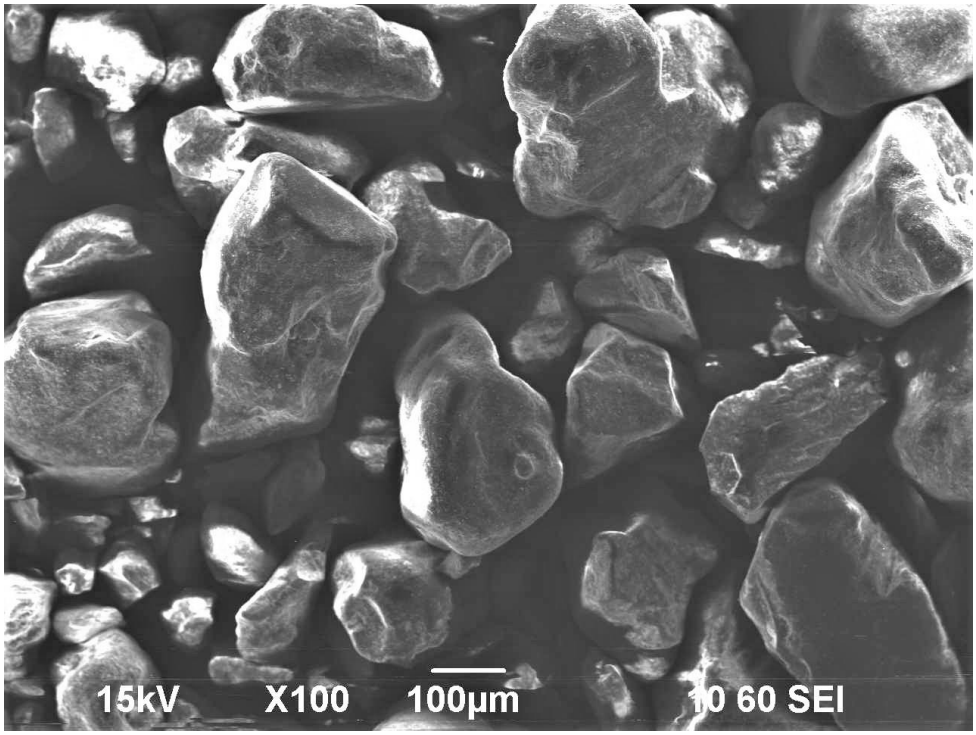


Photo MEB sand PEAK W37 mechanically treated: overview

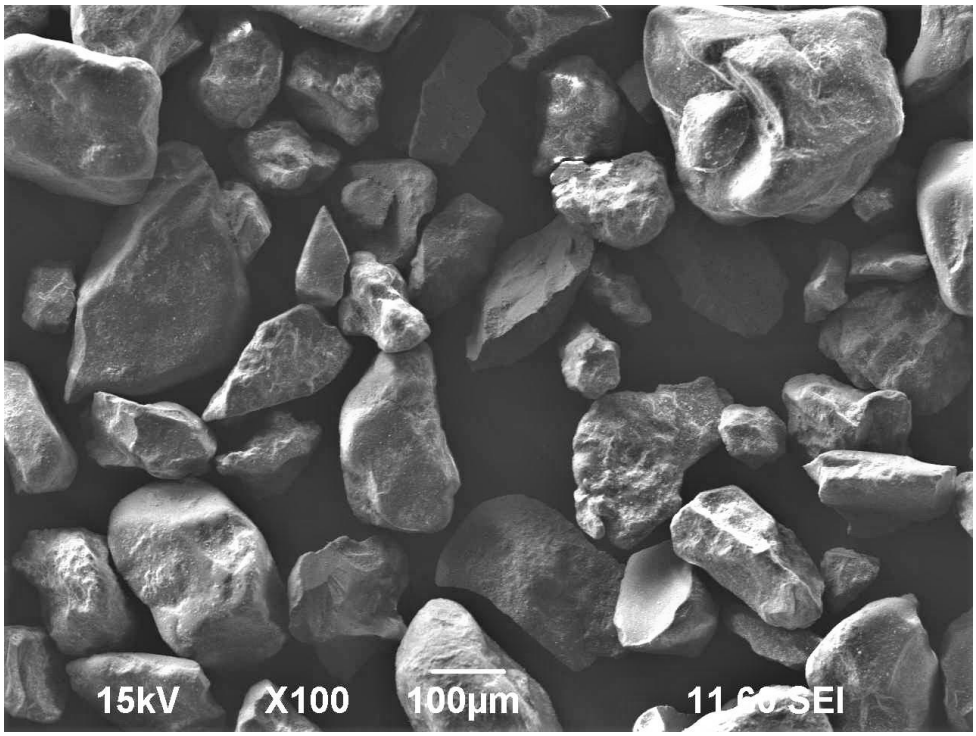


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo SEM sand CTIF IE treated by the hydromechanical process: overview

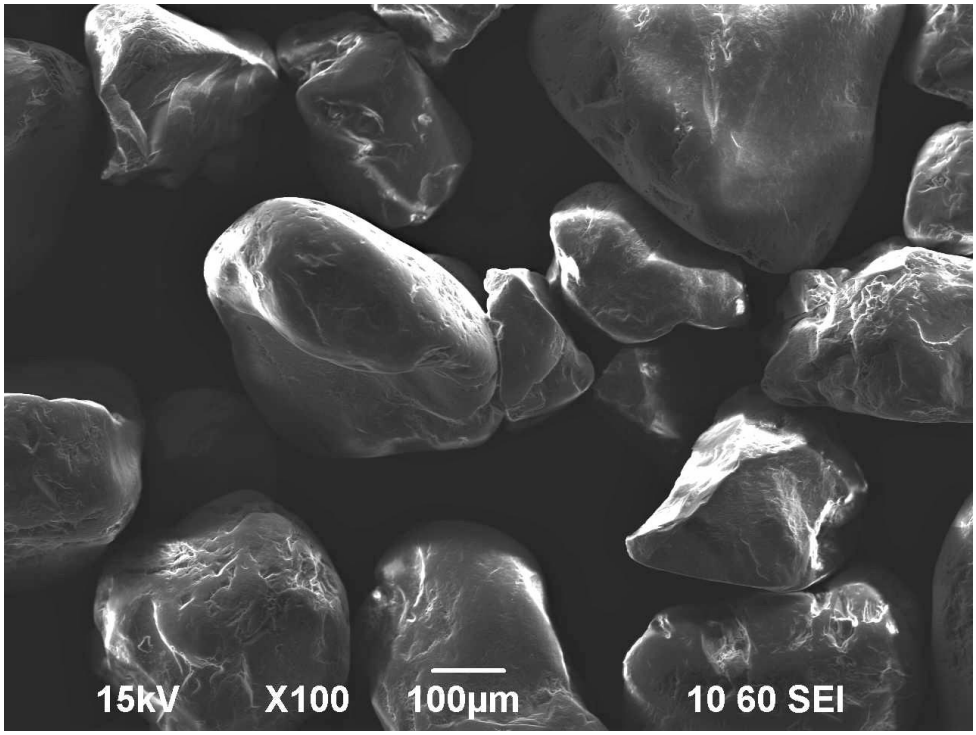


Photo MEB sand INOTEC treated by the hydromechanical process: overview

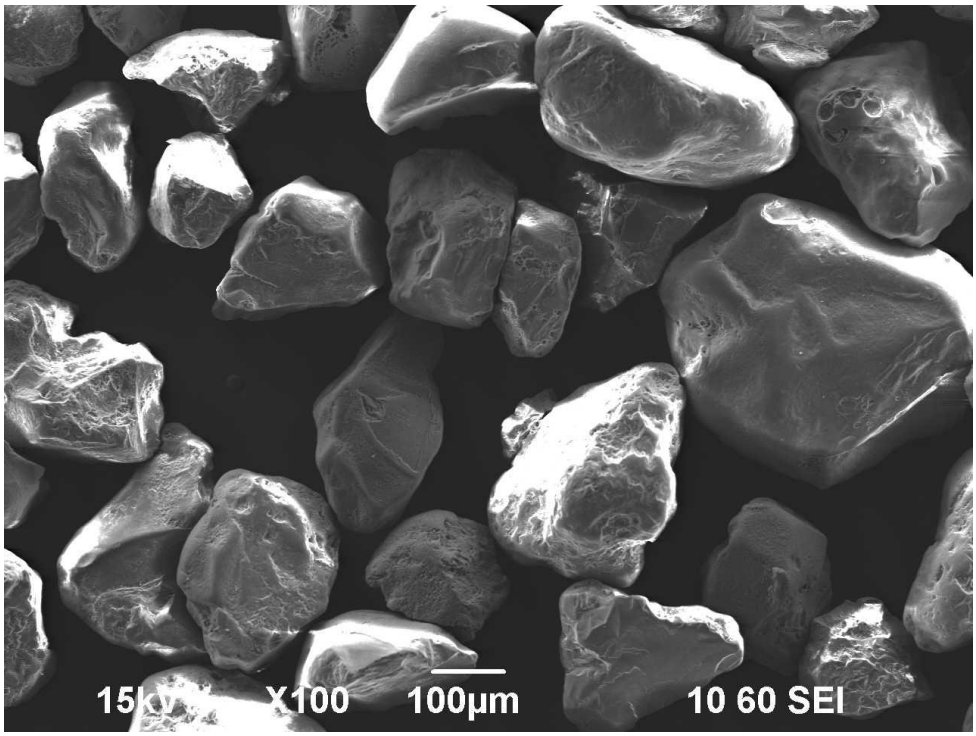


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

Photo MEB sand GEOPOL W37-20 treated by the hydromechanical process: overview

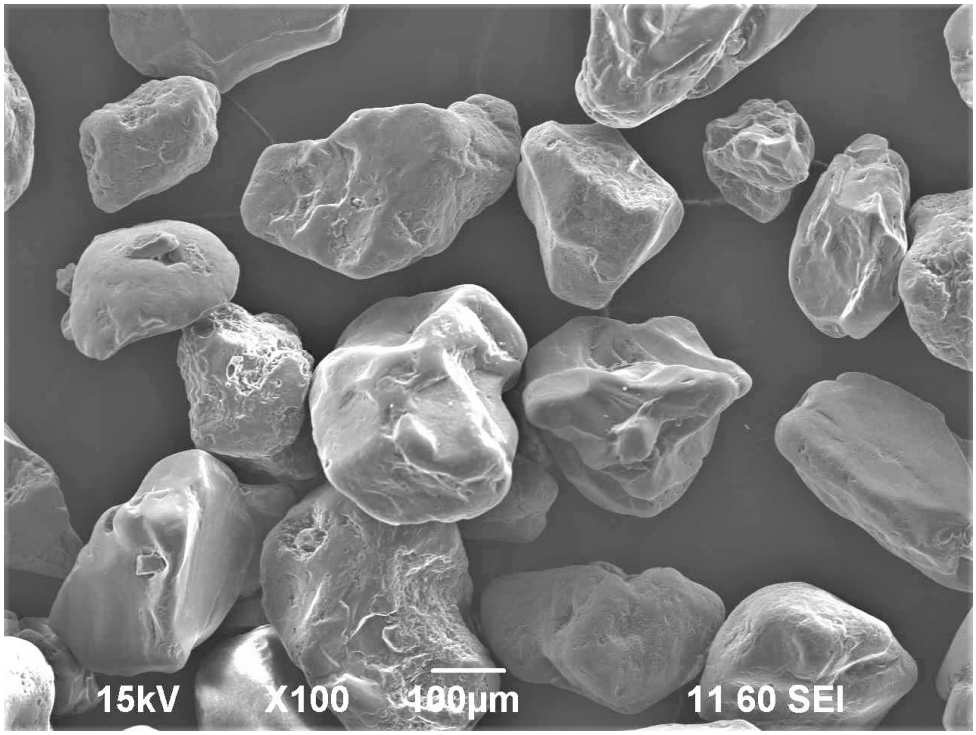


Photo MEB sand PEAK W37 treated by the hydromechanical process: overview

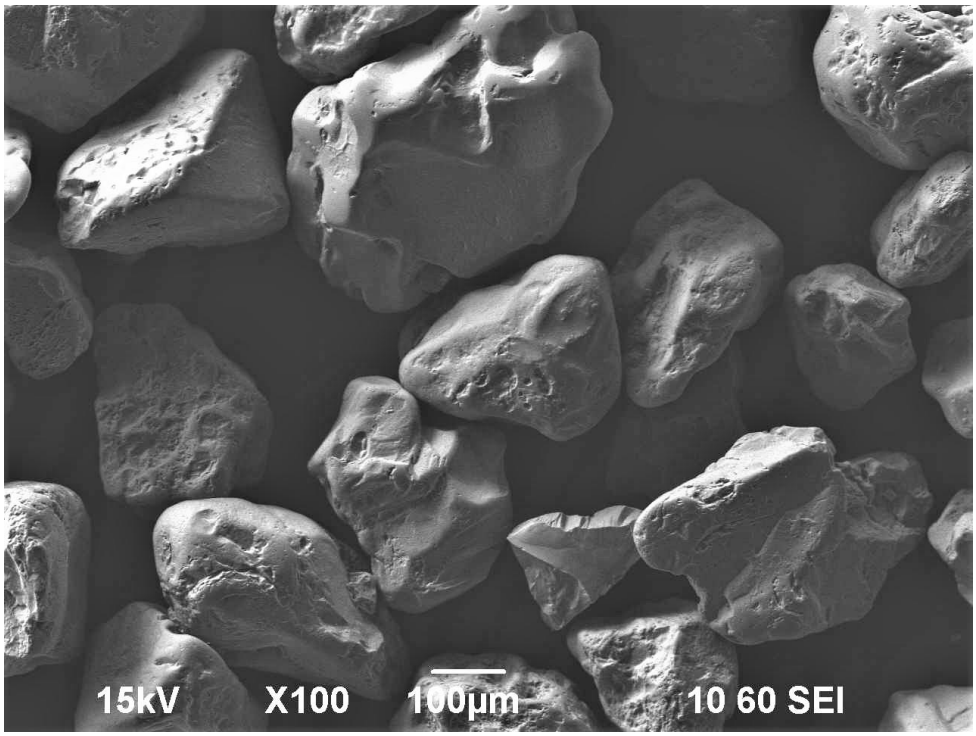
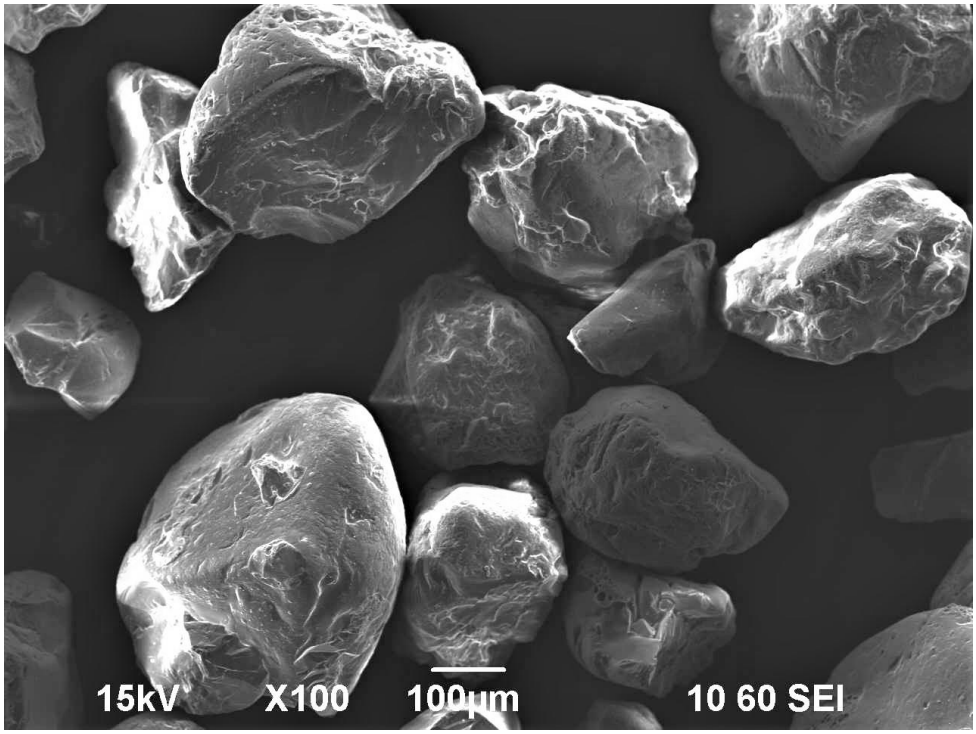


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of ultrasonically treated CTIF IE sand: general view



SEM photo of INOTEC ultrasonically treated sand: general view

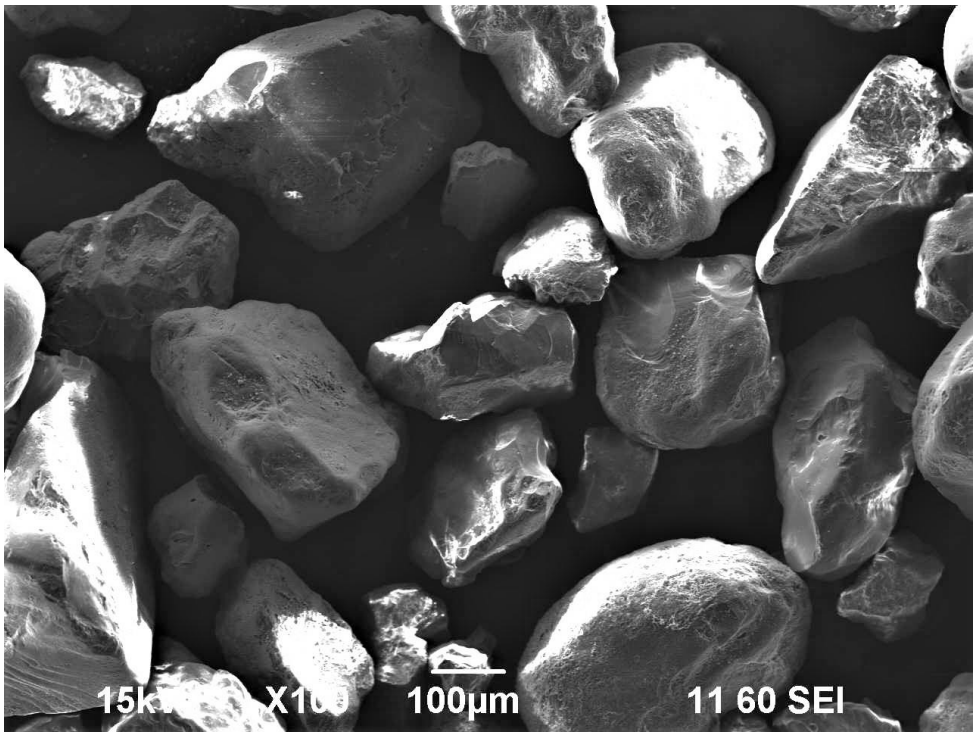
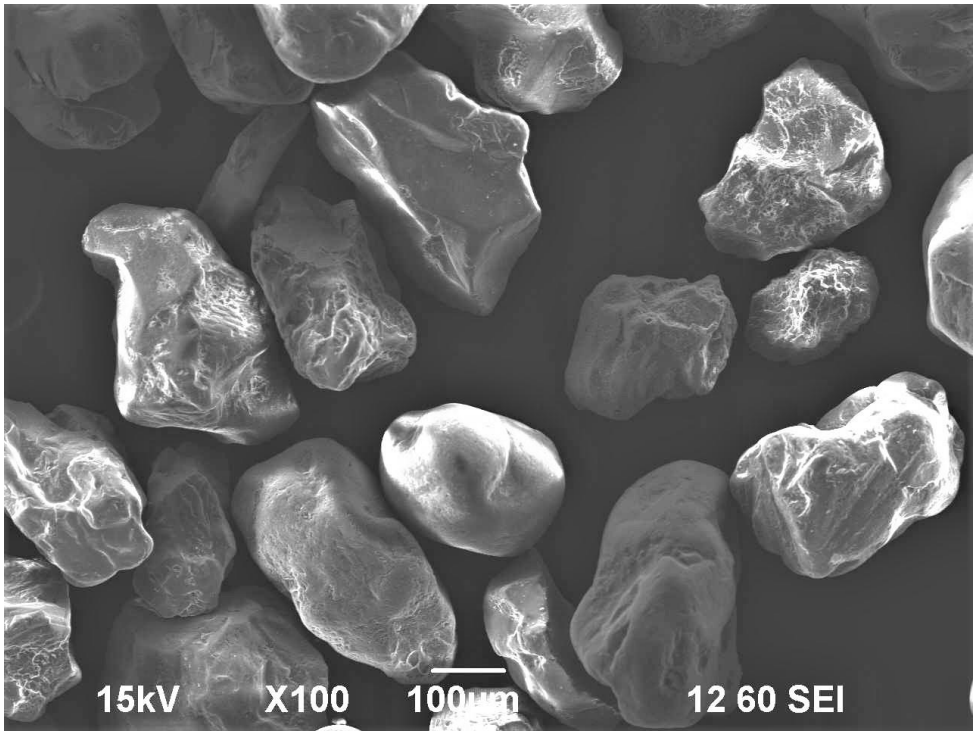


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM Photo - sand GEOPOL W37-20 ultrasonically treated: overview



SEM photo - sand PEAK W37 ultrasonically treated: overview

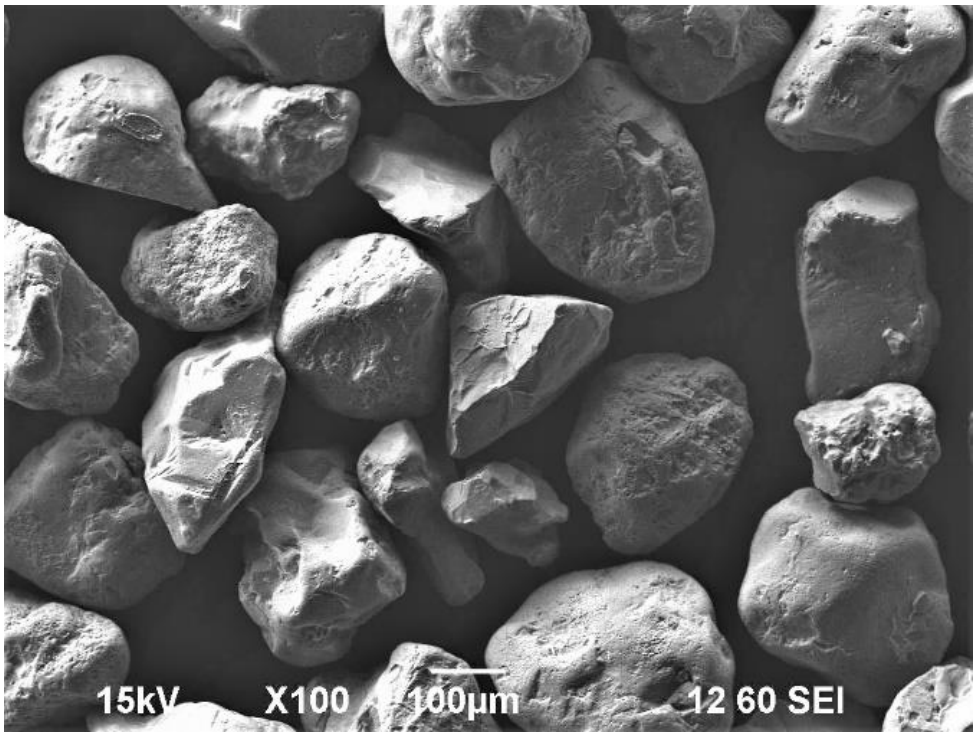
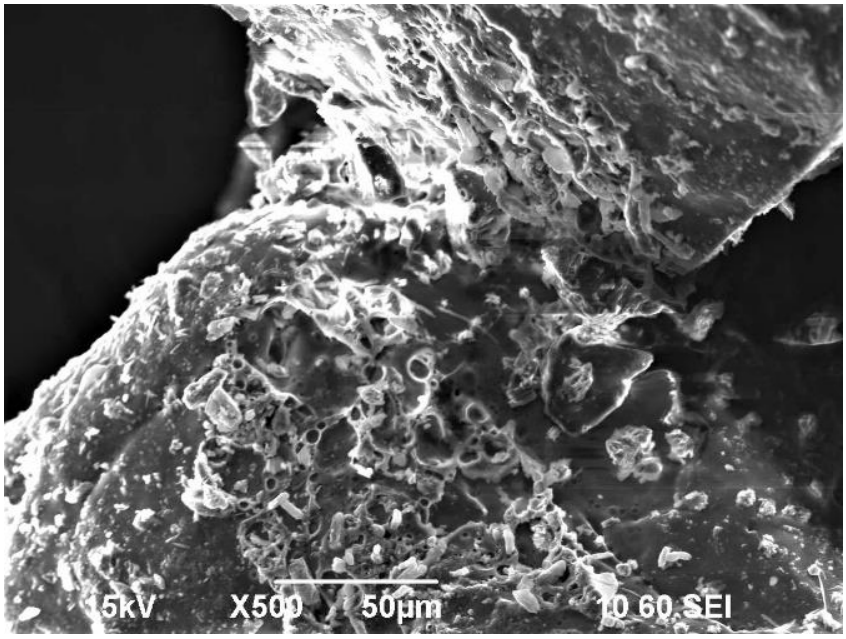


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of CTIF IE sand to be treated: view of a chemical bridging and appearance of the residual gangue



SEM photo of INOTEC sand to be treated: view of a chemical bridging and appearance of the residual gangue

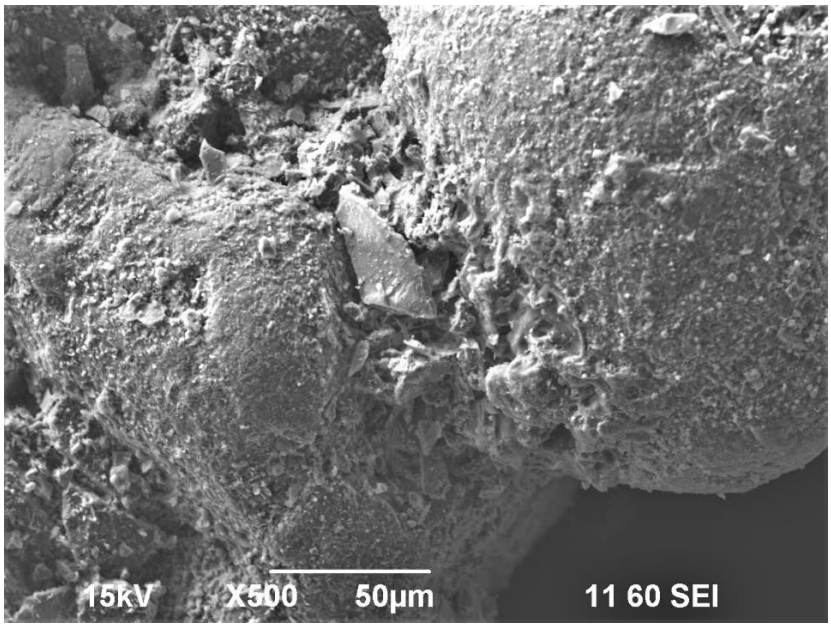
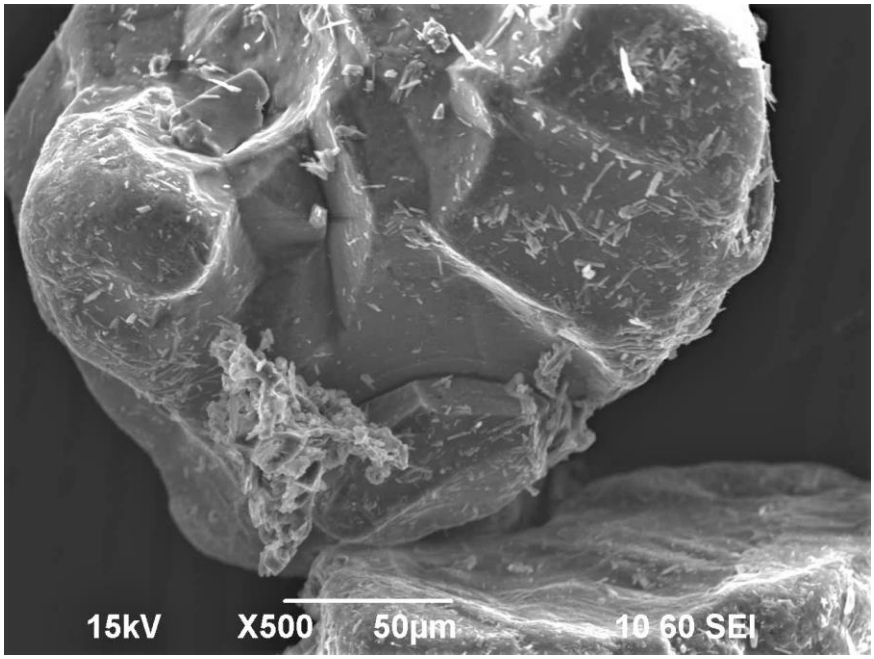


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of GEOPOL W37-20 sand to be treated: view of chemical bridging and appearance of the residual gangue



SEM photo of PEAK W37 sand to be treated: view of a chemical bridging and appearance of the residual gangue

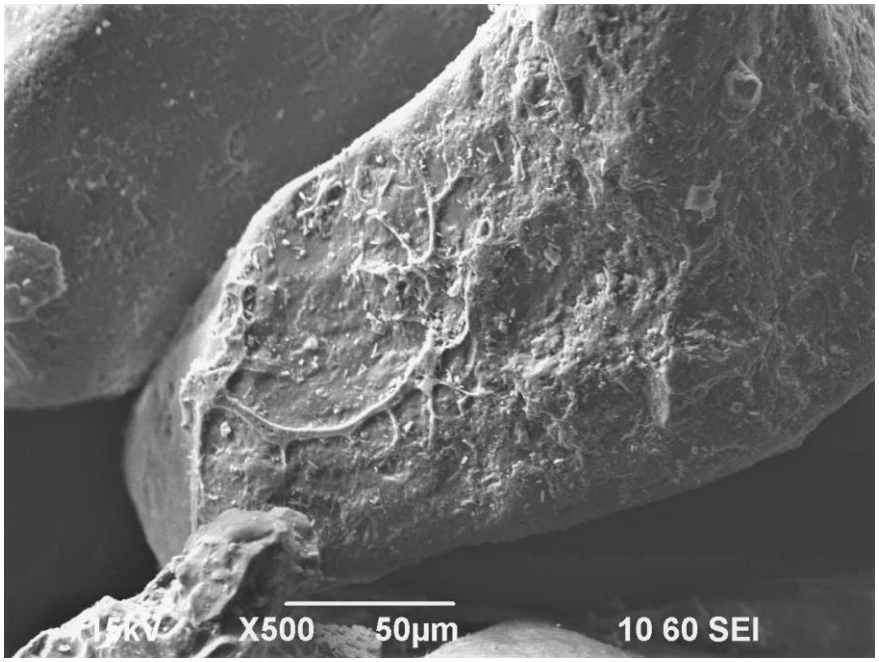
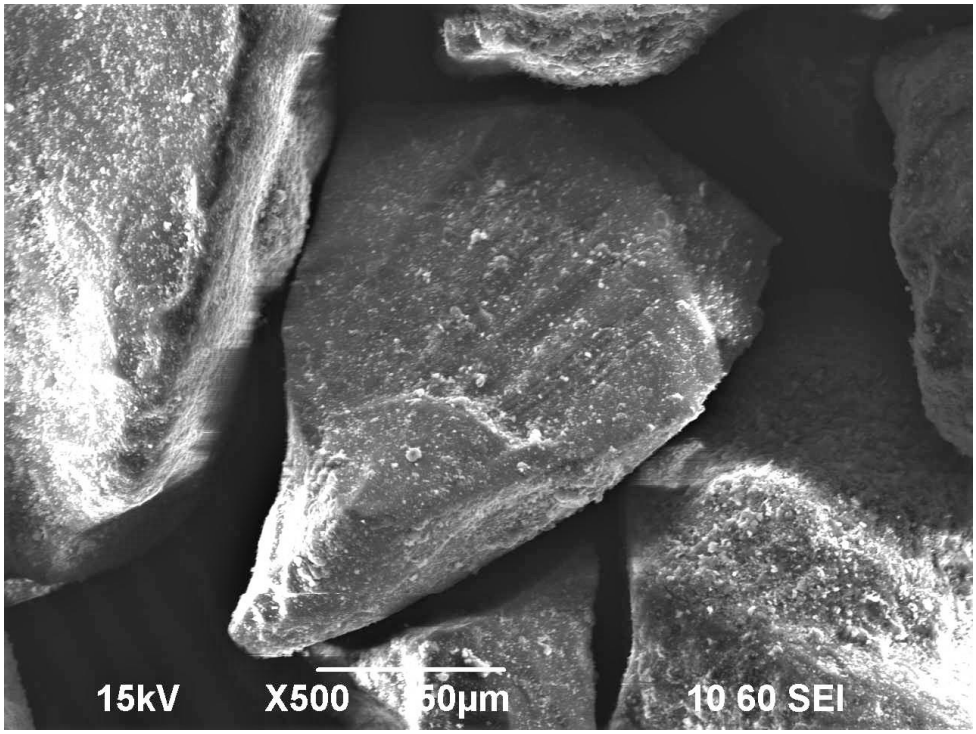


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of mechanically treated CTIF IE sand: appearance of grains and residual gangue



SEM photo of mechanically treated INOTEC sand: appearance of grains and residual gangue

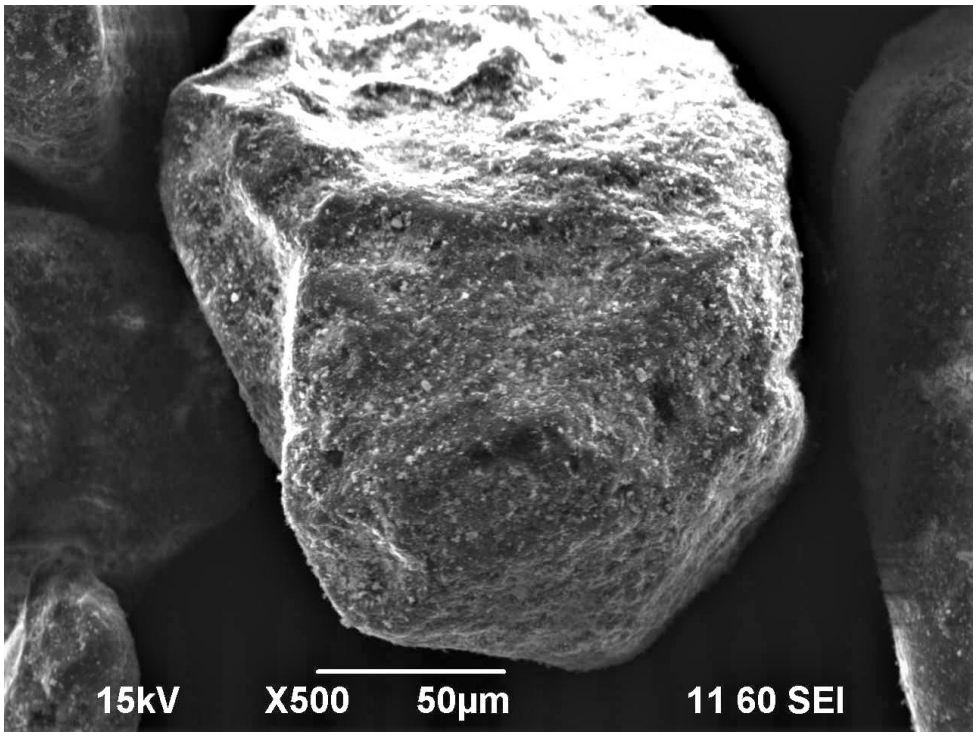
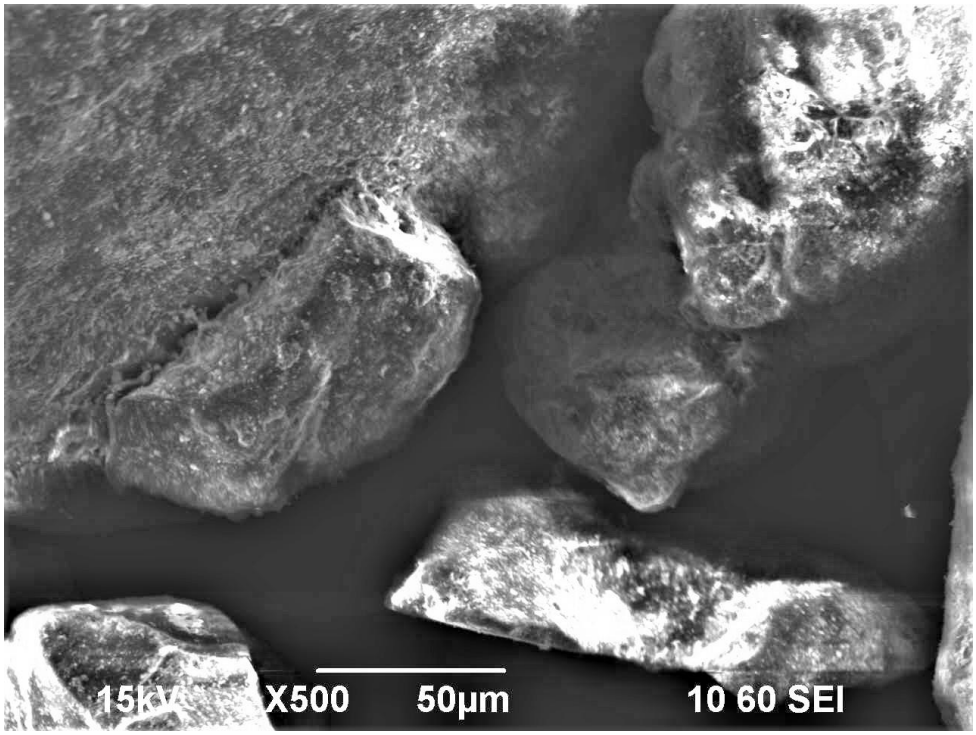


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of mechanically treated GEOPOL W37-20 sand: appearance of grains and residual guangue



SEM photo of mechanically treated PEAK W37 sand: appearance of grains and residual gangue

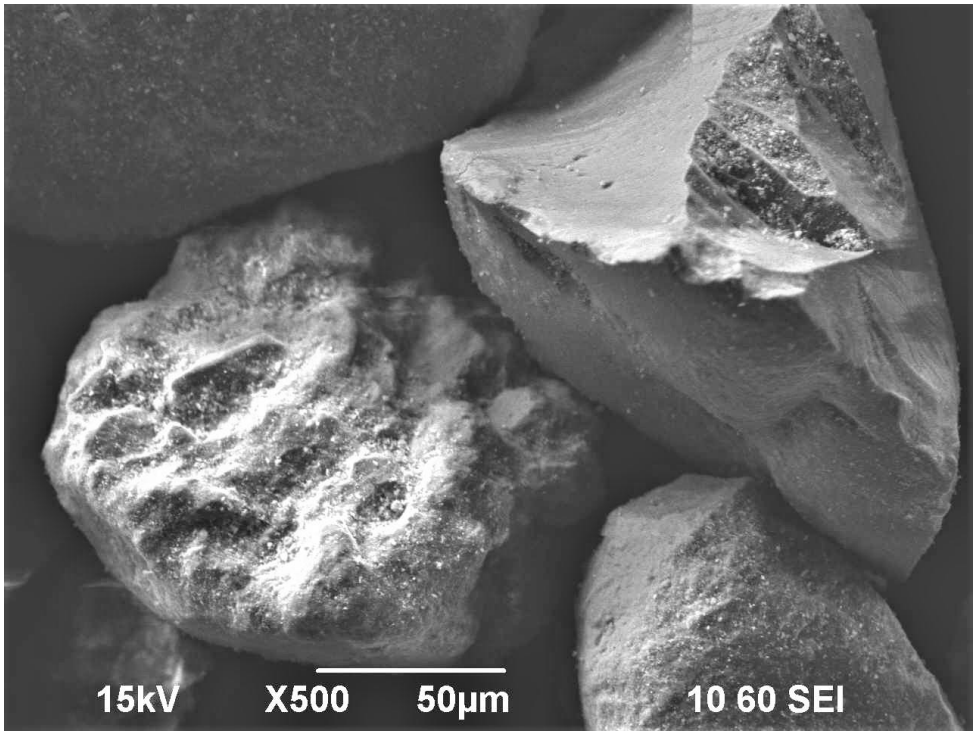
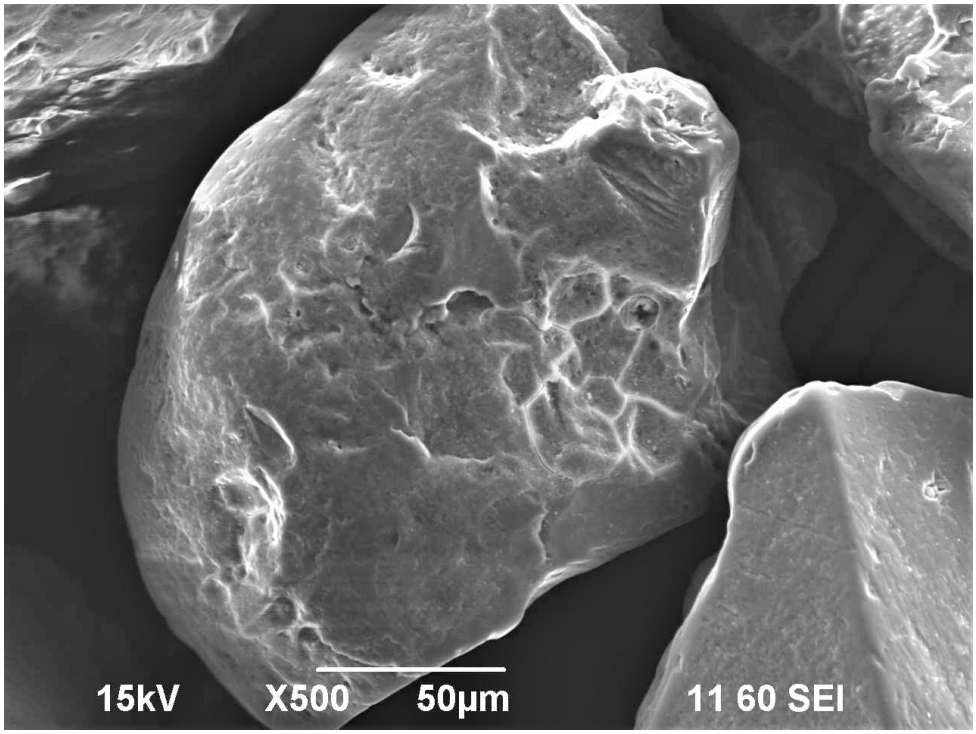


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of hydromechanically treated CTIF IE sand: grain appearance



SEM photo of hydromechanically treated INOTEC sand: appearance of the grains

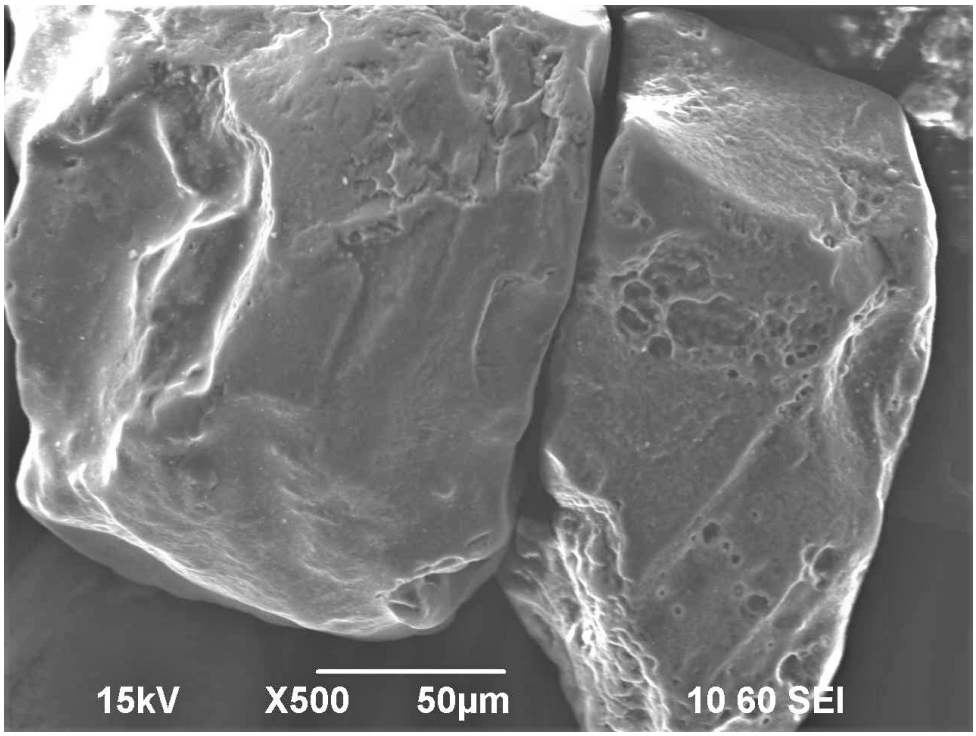
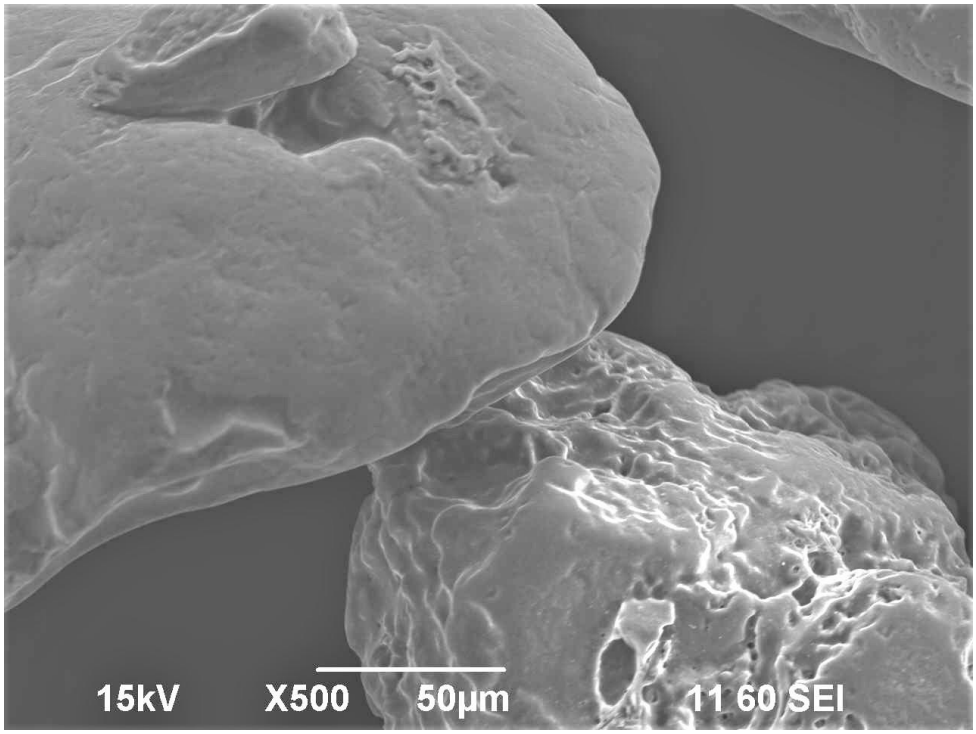


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo GEOPOL W37-20 sand treated by hydromechanical process: grain aspect



SEM photo of hydromechanically treated PEAK W37 sand: grain appearance

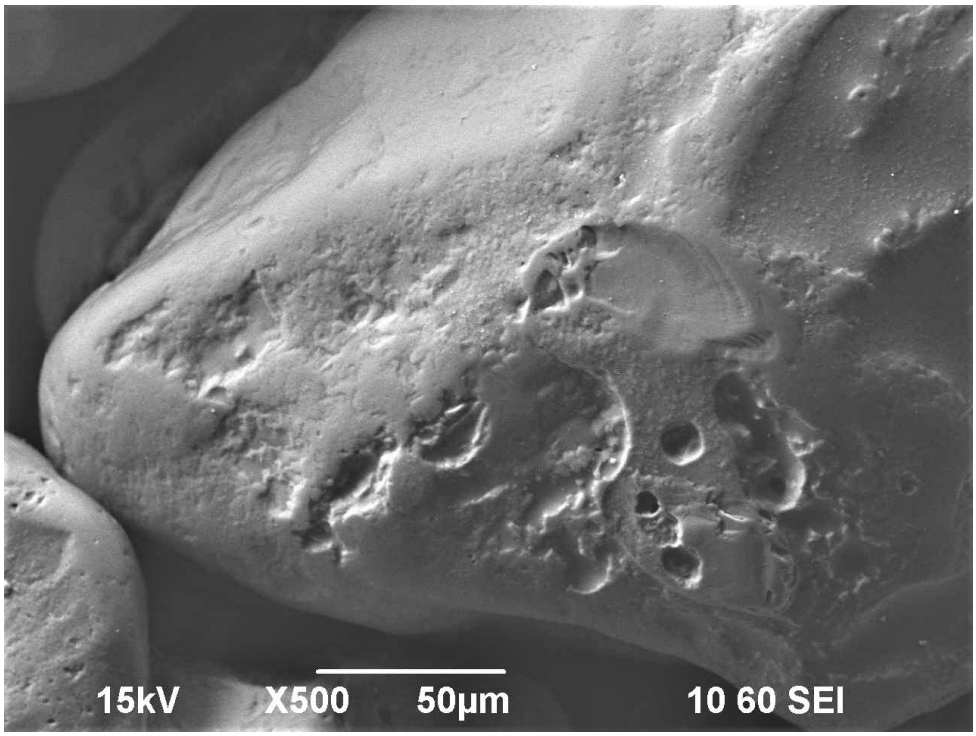
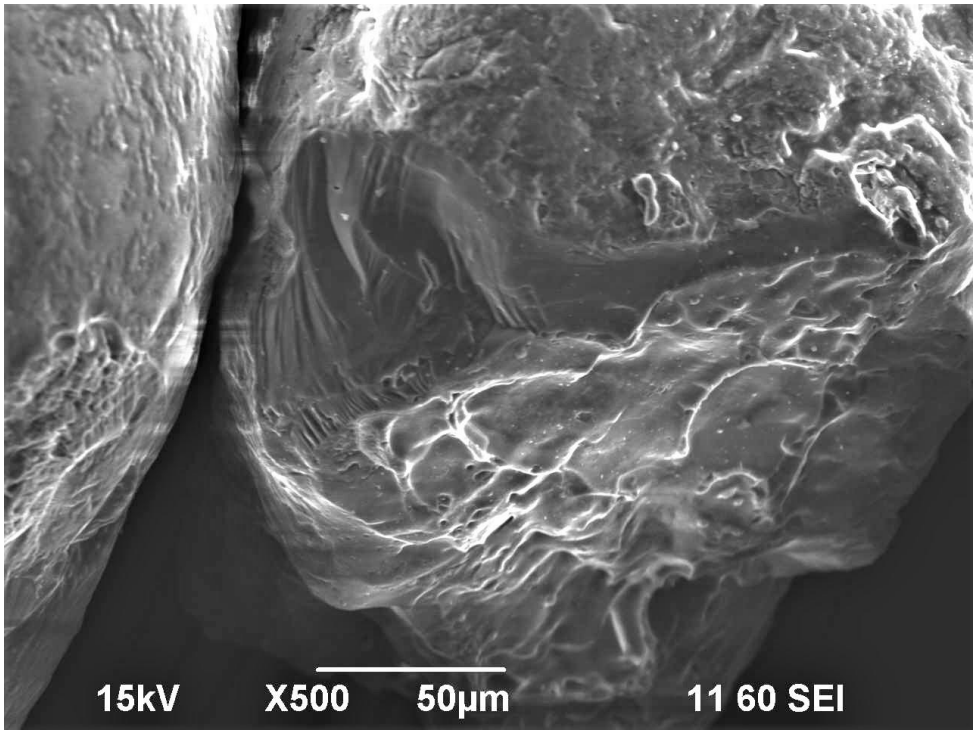


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo of ultrasonically treated CTIF IE sand: grain appearance



SEM photo of INOTEC sand treated by ultrasound: appearance of the grains

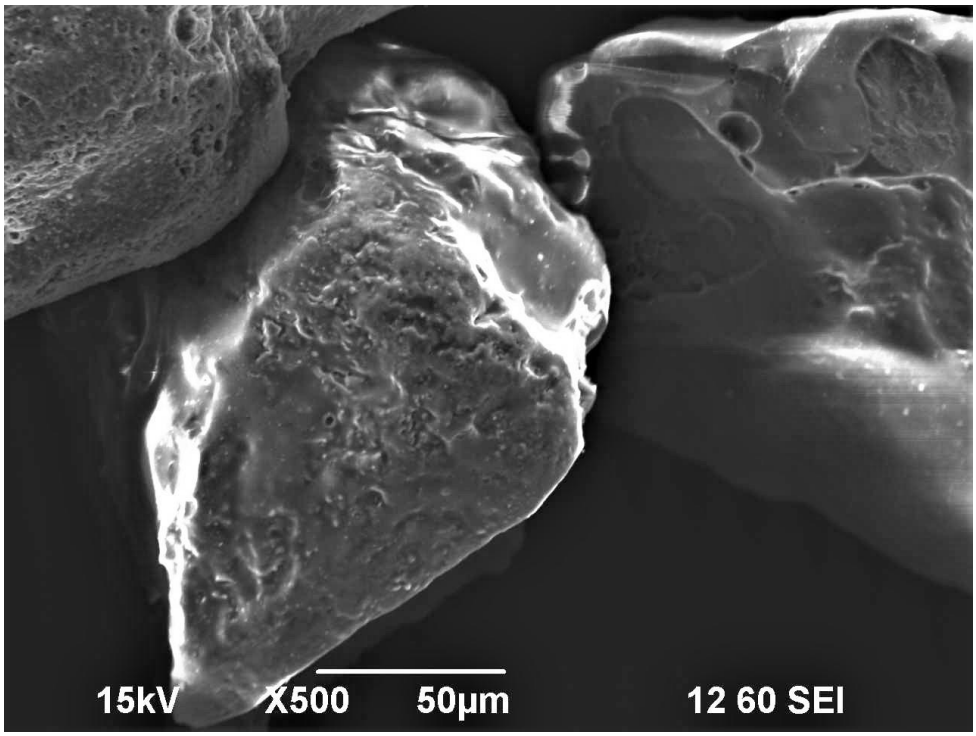
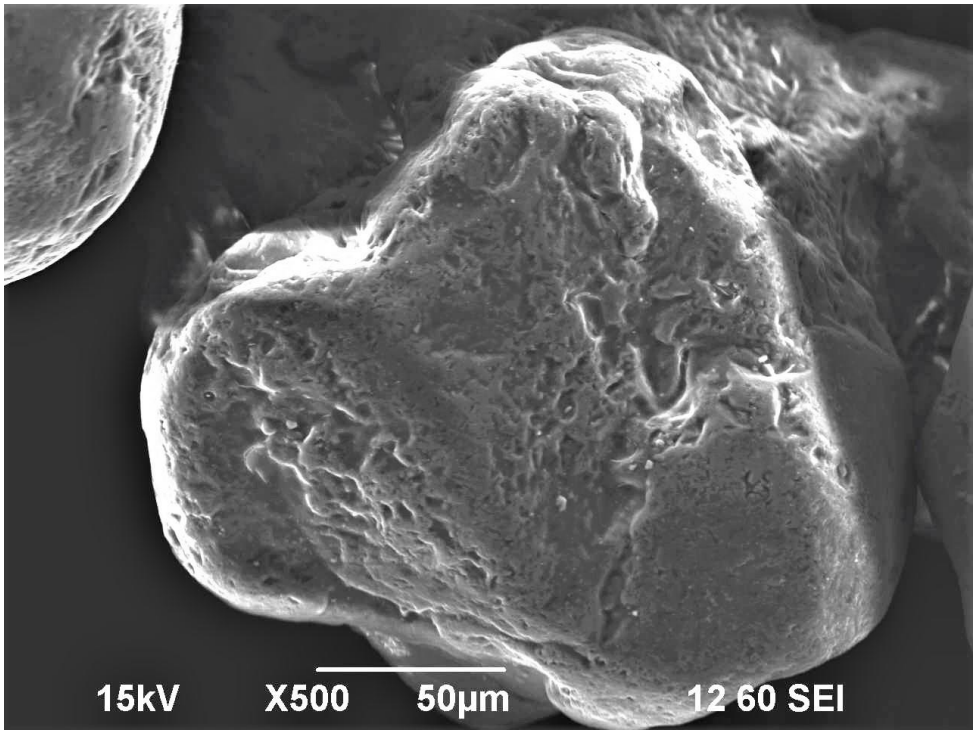
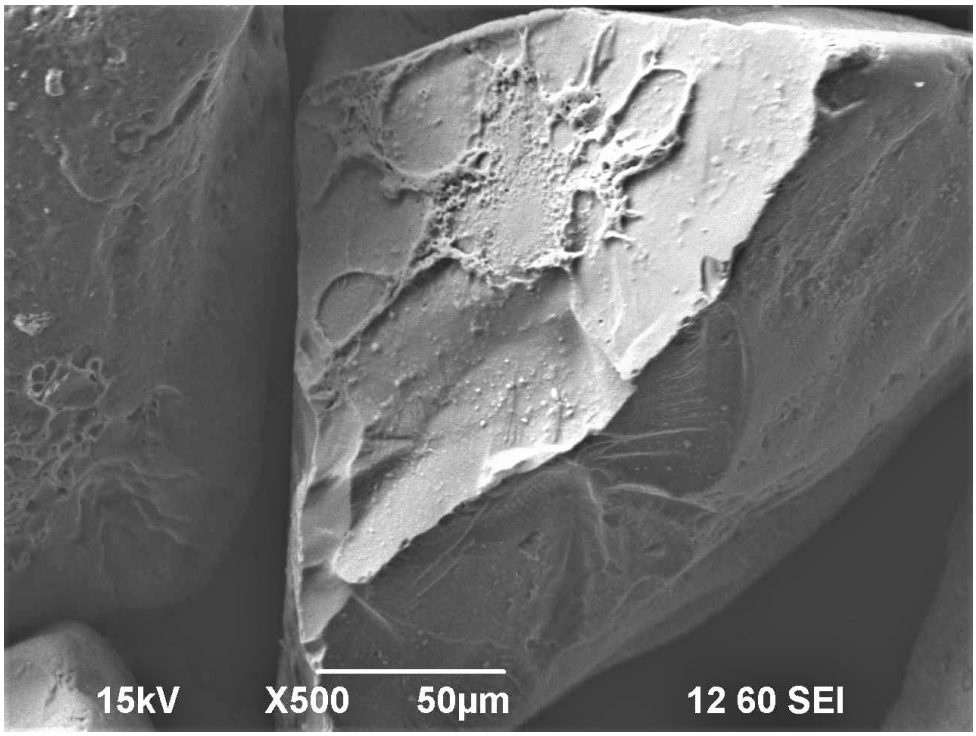


Illustration related to the summaries of the inorganic sand treatment tests (cont'd)

SEM photo GEOPOL W37-20 sand treated by ultrasound: appearance of the grains



SEM photo of ultrasonically treated PEAK W37 sand: grain appearance



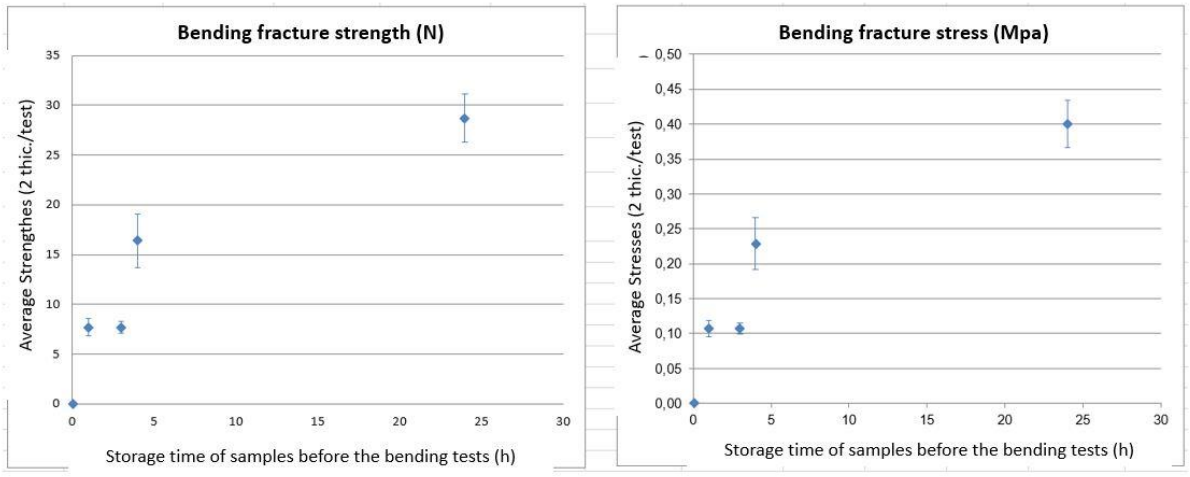
2.5. Reuse test of treated sand and comparison with new reference sand BE01

In order to verify whether the treated sand can produce quality cores without major service life problems, a 7 kg batch of sand marked "CTIF IE" was treated with the hydromechanical process that gave the best results.

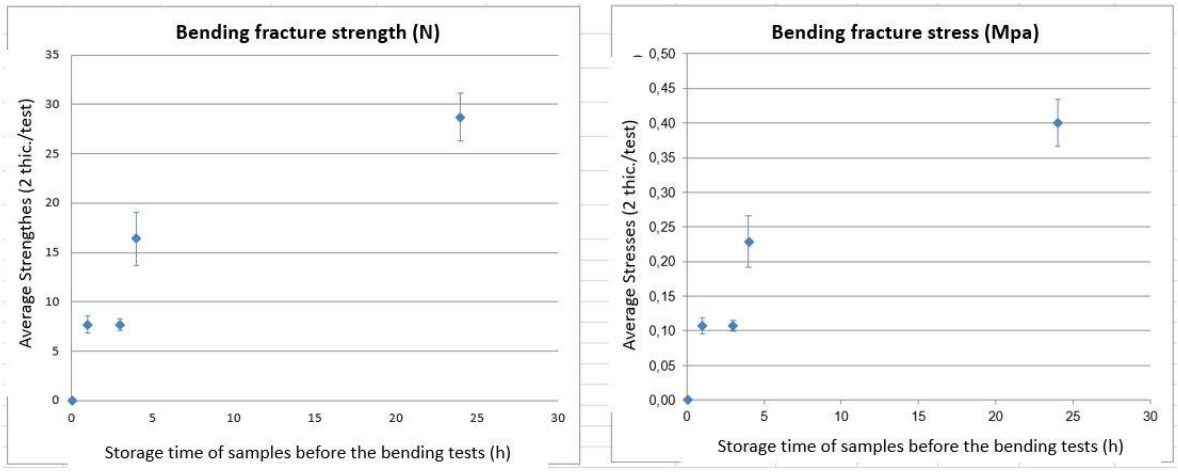
Bending test pieces were made to measure the strength of the cores and to determine the service life of the sand prepared with 100% treated sand, compared to 100% new sand.

<u>Comparison of cores made with treated sand, compared to new sand cores:</u>

With 100% of new sand BE01 : bending fracture stress = 0.400 Mpa

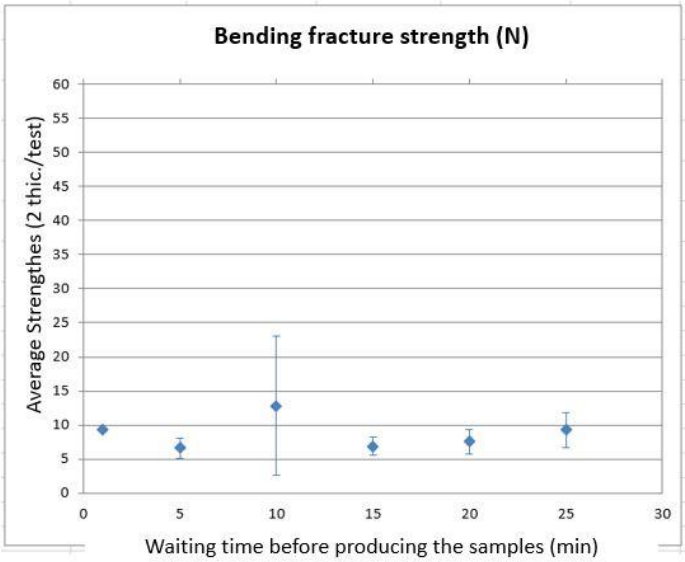


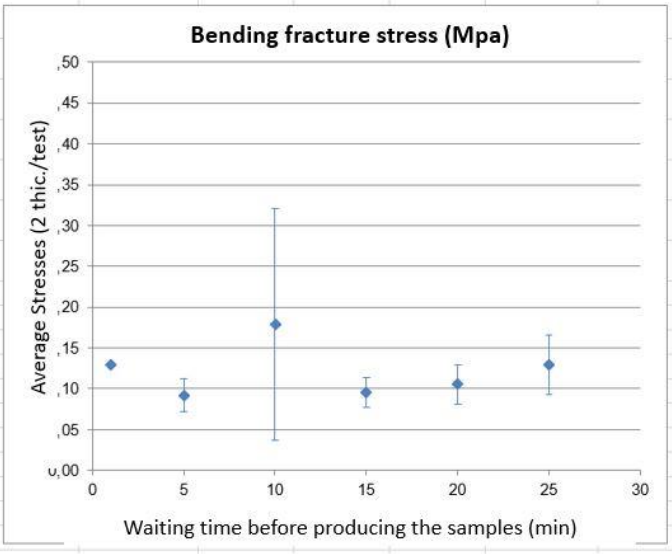
With 100% of CTIF IE sand hydromechanically treated: bending fracture stress = 0.405 Mpa



<u>Comparison of cores made with treated sand, compared to new sand cores</u>: Cont'd

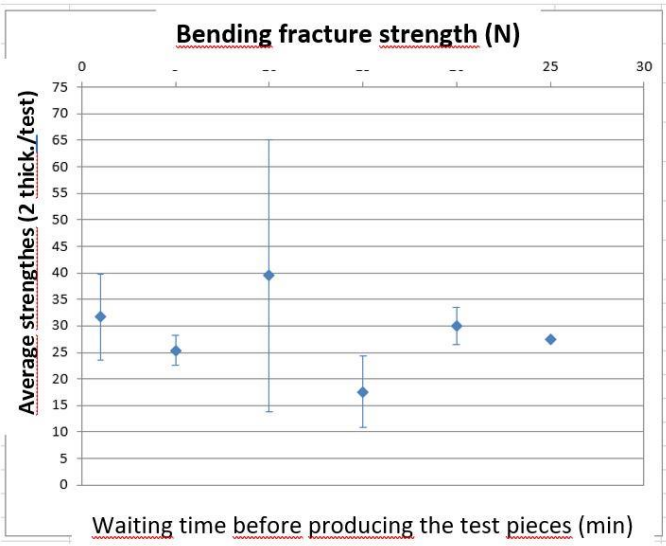
With 100% of new sand BE01 : life of the prepared sand

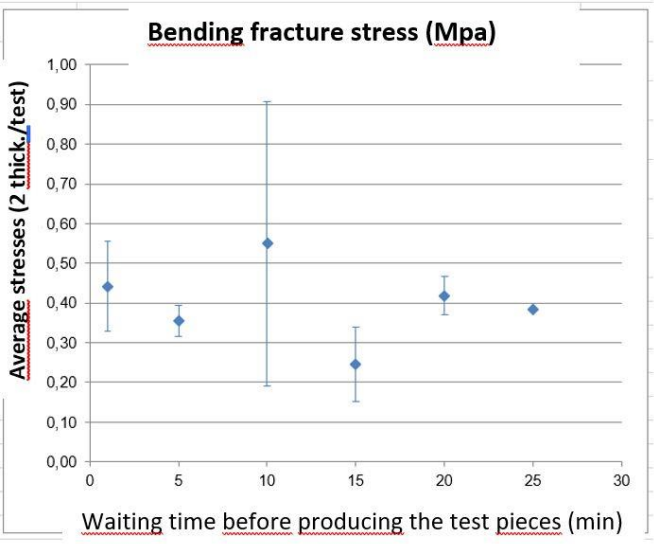




<u>Comment: at T=30mn, hardening of the prepared sand and plugging of the machine's shooting head (unfilled test pieces)</u>

With 100% hydromechanically treated CTIF IE sand: life of the prepared sand





<u>Comment: at T=30mn, hardening of the prepared sand and plugging of the machine's shooting head (unfilled test pieces)</u>

<u>Conclusion</u>: The strength of the cores made with the hydromechanically treated "CTIF IE" sand and the service life of the prepared sand are similar to those obtained with the new reference sand BE01.

This confirms that the hydromechanical treatment of inorganic sand waste is particularly effective for the reuse of treated sand in moulding or core making.

Illustration of bending tests and life tests

Sand preparation: 2.5% resin + 0.30% hardener

Equipment and tools used to produce cores (standardized test pieces)

Illustration of bending tests and life tests: cont'd

Test pieces removing

Measurement of flexural strength of test pieces