LIFE17 ENV/FI/000173

Green Foundry

1/7/2018-30/6/2022

Action B3 Test series of molds, cores and casts produced by inorganic binder systems

DeB3 Quality analyses of test casts carried out in pilot foundries in Green Foundry LIFE project

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Content

1. Introduction

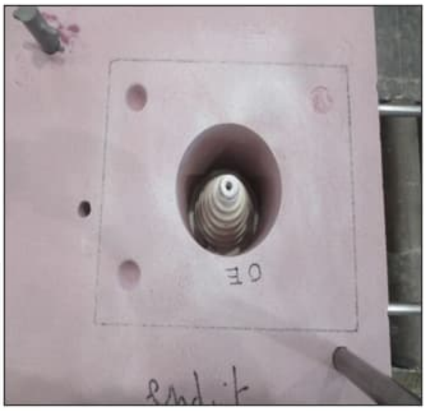
Once the steel parts have been cast by the different partners of the Green Foundry Life project in order to compare the emissions generated in the foundry between organic and inorganic sand, CTIF carried out several works for phase B3 of the project, concerning the impact of inorganic sand on the quality of steel castings:

- Determination of roughness indices of the castings by the different partners,
- Measurement of gas contents (on parts) that can be generated by the sand,
- Structural investigations on samples taken from the parts to check the absence of defects due to exogenous gas generated by the sand.

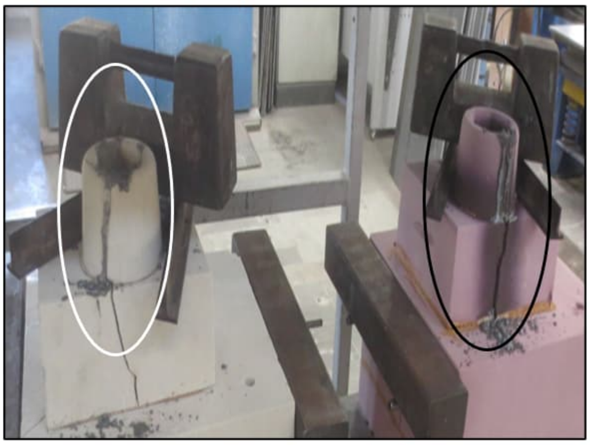
2. Impact of inorganic sand on the quality of steel castings

2.1. Presentation of the steel parts cast by the project partners

Processes used and parts cast by CTIF



Moulds and cores making Mould assembly (120 kg of sand) Mould preparation before
pouring



Steel GS240 pouring (30 kg/mould – casting weight = 12 kg) Inorganic sand ref. « I » Organic sand ref. 0 »

Metal/Sand ratio as a function of the casting thickness: from 4 to 0.20.

Processes used and parts cast by CTIF (cont'd)

CTIF's shaked-out castings

Parts cast by the different partners of the project

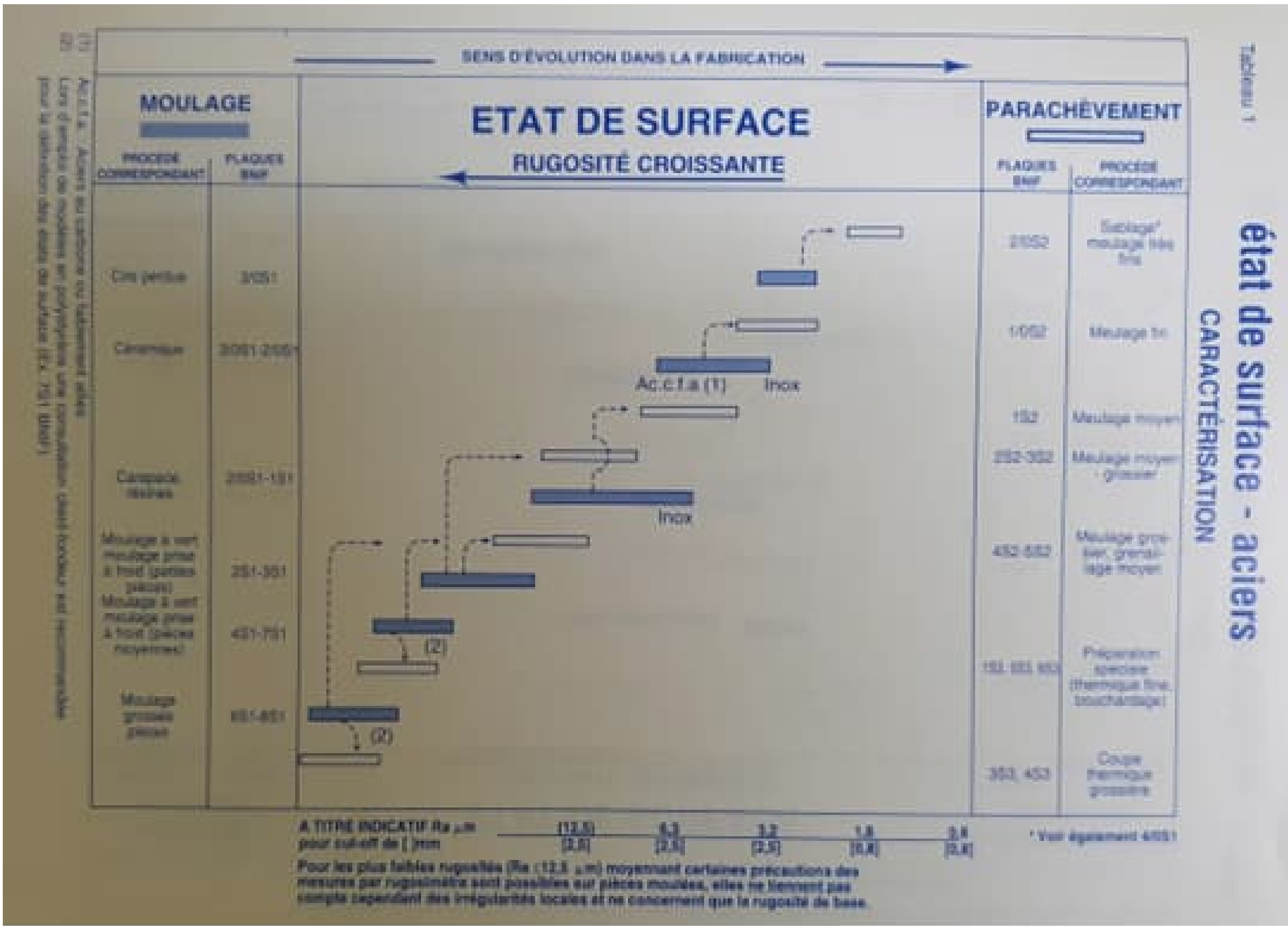
CTIF : Casting made of structural steel standard EN GS240,
INOTEC : Casting made of stainless steel ASTM A747 Cb7-Cu2 (Unified Numbering System 324 J92110),
GEOPOL and PEAK : Castings made of stainless steel ASTM A297 HH (UNS 401 J93503).

2.2. Roughness indexes obtained on steel parts cast with inorganic sands

Method used to check the average roughness index of castings produced by the different partners of the project:

Unlike machined parts, it is relatively complicated to measure the roughness index of castings using mechanical, optical or pneumatic devices, so the inspection was carried out according to the NF1370 standard using visual tactile comparators corresponding to the BNIF's technical recommendation RT No. 359 (Bureau de Normalisation des Industries de la Fonderie).

Characterization of the surface condition of steel parts: extract from the BNIF's RT n°359



<u>Characterization of the surface condition of steel parts</u>: eight tactile visual comparators used, corresponding to the green sand molding and cold setting molding processes (plates 1S1 to 8S1)

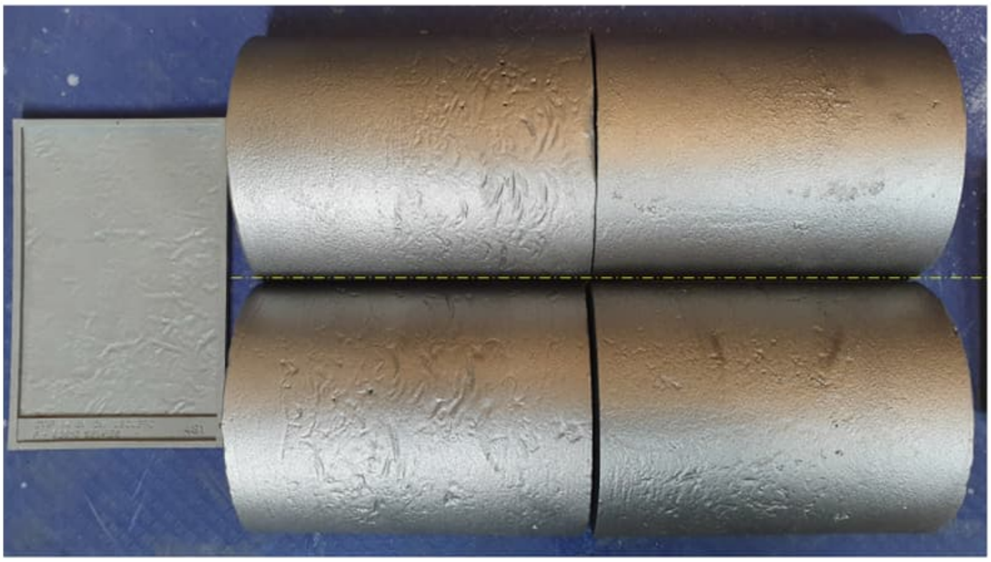
Characterization of the surface condition of steel parts: eight tactile visual comparators used, corresponding to the green sand molding and cold-setting molding processes (1S1 to 8S1) cont'd

Characterization of the surface condition of steel parts: five tactile visual comparators used, corresponding to the finishing of parts by grinding, or grinding and shot blasting (1S2 to 5S2).

Characterization of the surface condition of steel parts: five tactile visual comparators used, corresponding to the finishing of parts by grinding or grinding and shot blasting (1S2-5S2) cont'd

Comparison of the <u>external surfaces</u> of the "organic vs inorganic" CTIF's parts:

The average roughness index of the two parts corresponds to the 4S1 plate.



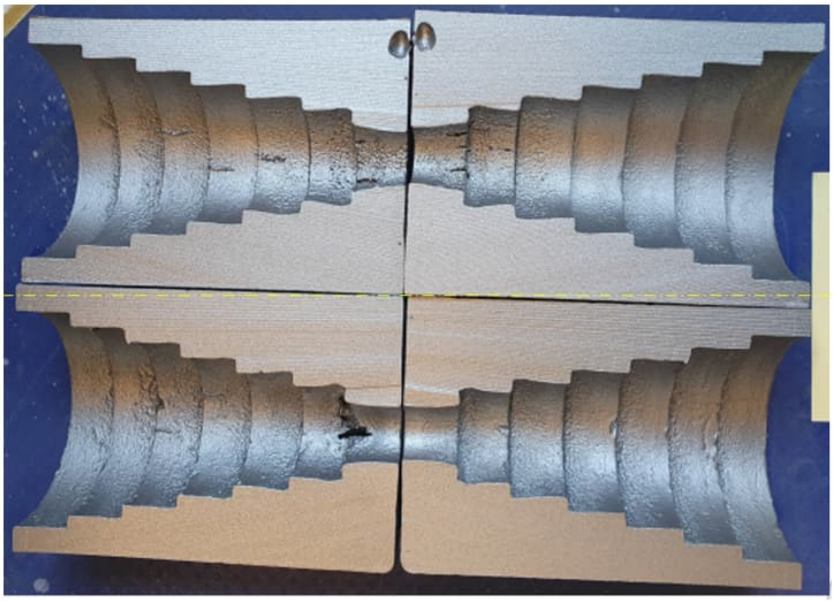
Part cast with organic sand labelled « O »

Part cast with Inorganic sand labelled « I »

Comparison of the <u>internal surfaces</u> of the "organic vs inorganic" CTIF's parts:

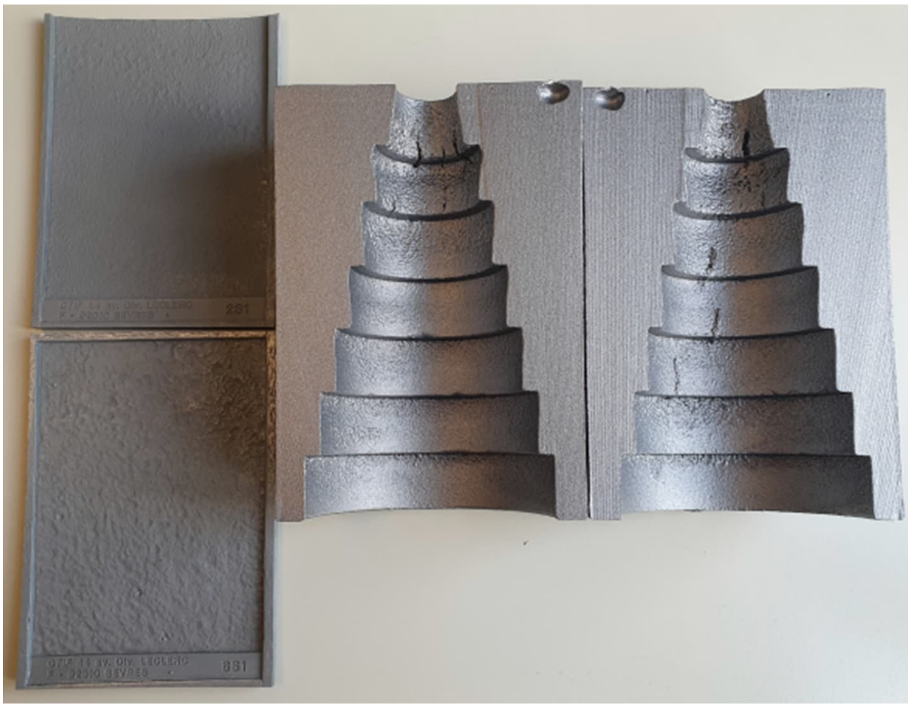
Part cast with organic sand labelled « O »

Part cast with Inorganic sand labelled « I »



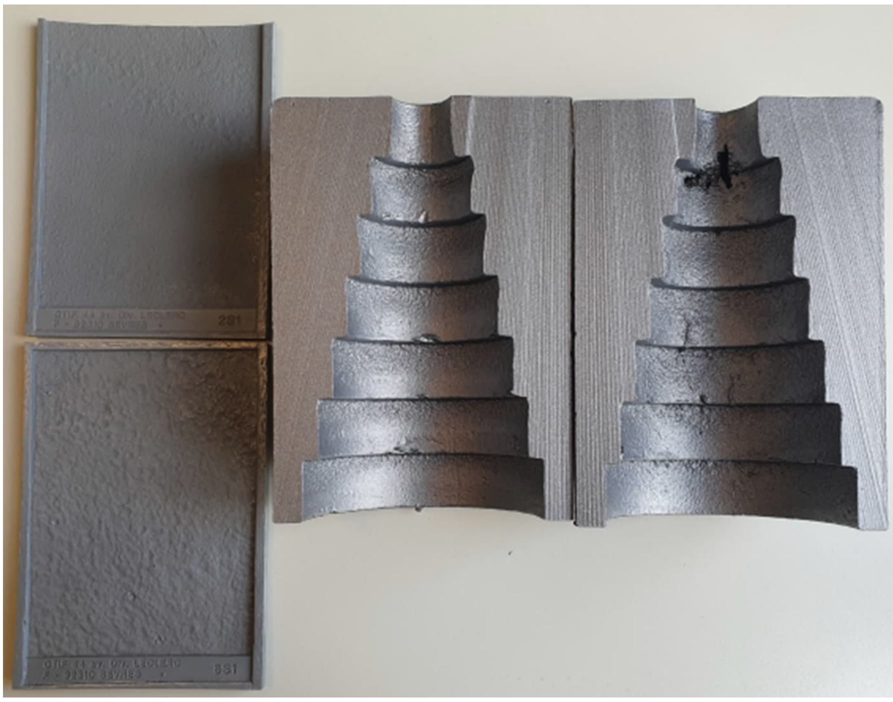
Check performed on the CTIF’s part labelled O:

The roughness index of the surfaces inside the part varies and corresponds to plates 2S1 to 6S1



Check performed on the CTIF’s part labelled I:

The roughness index of the surfaces inside the part varies corresponds to plates 2S1 to 6S1



Note: parts are not ground, surfaces are just sand-blasted.

Check performed on the GEOPOL's part :

The roughness index of moulding surfaces varies and corresponds to plates 2S1 to 6S1

Check performed on the INOTEC's part :

The roughness index of moulding surfaces varies and corresponds to plates 2S1 to 6S1

The average roughness index of the finishing surfaces corresponds to plate 5S2

Check performed on the PEAK's part :

The roughness index of moulding surfaces varies and corresponds to plates 2S1 to 5S1

The average roughness index of the finishing surfaces corresponds to plate 5S2

Roughness indexes of the steel parts cast by the project partners: synthesis of results

The expertise of the steel parts produced by the various project partners with inorganic sands, shows that the quality of the moulding surfaces and finishing surfaces complies with the standard NF1370 and according to the BNIF RT n°359 (see Table 1 below).

The comparison made between the GS240 steel parts produced by CTIF with organic sand ("O" mark) and inorganic sand ("I" mark) also shows that the use of inorganic sand to produce small steel parts seems feasible.

Industrial-scale testing will be required to verify the viability of inorganic binders in ferrous foundries.

Table 1: Roughness Indexes of Steel Parts Cast by the Project Partners

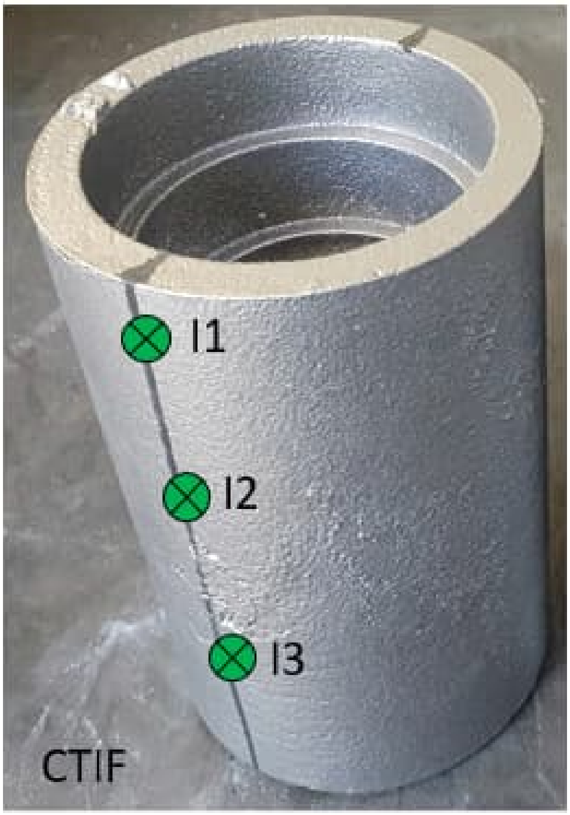
Parts	Roughness indexes measured on **moulding surfaces** **2S1 < standard < 8S1**	Roughness indexes measured on **finishing surfaces** **2S2 < standard< 5S2**	Results obtained compared to standard NF 1370 and the BNIF's RT n°359, for steel parts	
			Casting surfaces	**Finishing surfaces**
CTIF Label O	External surface = 4S1 Internal surfaces = 2S1 to 6S1	*	Compliant with the standard Compliant with the standard	Compliant with the standard Compliant with the standard
CTIF Label I	External surface = 4S1 Internal surfaces = 2S1 to 6S1	*	Compliant with the standard Compliant with the standard	Compliant with the standard Compliant with the standard
GEOPOL	2S1 to 6S1	5S2	Compliant with the standard	Compliant with the standard
INOTEC	2S1 to 6S1	5S2	Compliant with the standard	Compliant with the standard
PEAK	2S1 to 5S1	5S2	Compliant with the standard	Compliant with the standard

* No reference plate corresponding to a simple sandblasting operation

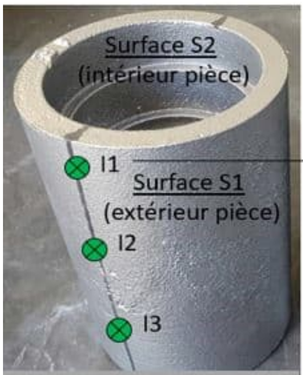
2.3 Gas, C and S contents measured on the steel parts cast with inorganic sand

<u>15 samples taken from the castings to measure the carbon, sulphur and gases N, O, H contents</u>:

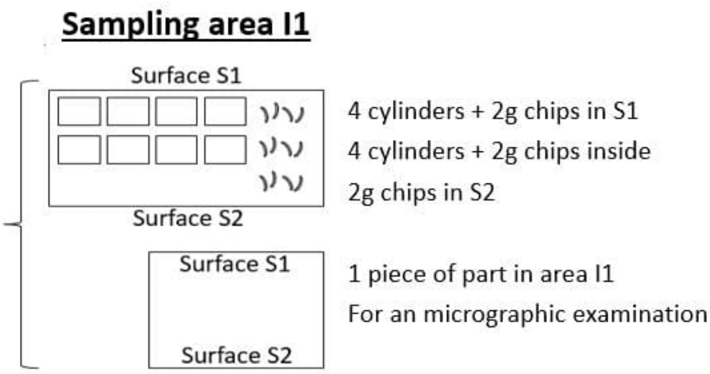
- 6 CTIF's samples taken from 2 parts (inorganic sand I1, I2, I3, and organic sand O1, O2, O3)
- 3 samples taken from ASK's part (Inotec1, Inotec2, Inotec3),
- 3 samples taken from the GEOPOL's casting piece (W37-20/1, W37-20/2, W37-20/3),
- 3 samples taken from the PEAK's casting piece (W37/1, W37/2, W37/3).



12 samplings made on the 15 samples: example for the CTIF's parts



Example of a CTIF's part



Laboratory Expertises

- Determining the C and S contents on chips taken at the surface and inside the samples.
- Determining the N, O and H contents on cylinders taken near the surface and inside the samples.
- Structural investigations performed on each sample to confirm the absence or the presence of defect(s) due to an exogenous gas that can be incriminated to the sand

Table 2: Synthesis of carbon, sulphur and gas content measurements

Samples	Content % C surface	Content % C inside	Content % S surface	Conten % S inside	Content % N surface	Content % N inside	Content % O surface	Content % O inside	Content % H surface	Content % H inside
CTIF O1	0,20	0,21	0,0037	0,0035	0,0080	0,0085	0,0082	0,0082	<0,0001	<0,0001
CTIF O2	0,22	0,22	0,0035	0,0040	0,0080	0,0080	0,0072	0,0062	<0,0001	<0,0001
CTIF O3	0,19	0,21	0,0040	0,0040	0,0080	0,0080	0,0063	0,0085	<0,0001	<0,0001
CTIF I1	0,20	0,21	0,0040	0,0040	0,0080	0,0080	0,0174	0,0075	<0,0001	<0,0001
CTIF I2	0,19	0,21	0,0038	0,0040	0,0080	0,0080	0,0084	0,0065	<0,0001	<0,0001
CTIF I3	0,18	0,21	0,0042	0,0040	0,0080	0,0080	0,0065	0,0106	<0,0001	<0,0001
GEOPOL W37-20/1	0,058	0,049	0,011	0,010	0,0380	0,0380	0,0200	0,0195	0,0008	0,0008
GEOPOL W37-20/2	0,058	0,046	0,011	0,010	0,0385	0,0390	0,0181	0,0206	0,0008	0,0008
GEOPOL W37-20/3	0,058	0,050	0,011	0,010	0,0385	0,0385	0,0179	0,0187	0,0008	0,0008
INOTEC 1	0,045	0,045	0,017	0,016	0,0165	0,0170	0,0085	0,0087	0,0001	0,0002
INOTEC 2	0,053	0,054	0,019	0,020	0,0170	0,0160	0,0089	0,0091	0,0001	<0,0001
INOTEC 3	0,052	0,051	0,019	0,023	0,0175	0,0160	0,0095	0,0087	0,0001	0,0003
PEAK W37/1	0,060	0,050	0,013	0,010	0,0360	0,0390	0,0205	0,0329	0,0007	0,0006
PEAK W37/2	0,054	0,051	0,011	0,010	0,0365	0,0380	0,0173	0,0196	0,0007	0,0009
PEAK W37/3	0,052	0,049	0,011	0,010	0,0365	0,0370	0,0180	0,0196	0,0008	0,0009

Theoretical thresholds for the occurrence of defects: H < 5 ppm, N < 100 ppm or several hundred ppm if high alloying element contents, S < 150 ppm, O < 150 ppm or more if high Cr content.

Exceedance / standard

It seems that the behaviour of the inorganic sands used by the project partners does not have a negative impact, as far the chemical composition of the steels produced is concerned:

- There is no significant difference between the values measured on samples O1, O2 and O3 and the values measured on samples I1, I2 and I3 of CTIF's parts produced with an organic sand and an inorganic sand,
- The comparison of the CTIF's parts also shows that the gradient of the N, O and H gases is stable from the surface to the core of the samples, with very similar values between the organic and inorganic sand (except in the case of the CTIF's I1 sample concerning the surface oxygen content),
- Overall, most of the values in C, S, N, O and H comply with the standards corresponding to the steels elaborated by the project partners, except in the case of INOTEC samples where the sulphur content exceeds 150 ppm.
- However, for the GEOPOL and PEAK samples, a field audit would have been necessary to identify the probable causes of the low carbon contents and the slightly high hydrogen contents (quality of scrap metal? type of melting furnace? methods of elaboration? sand behaviour? (This audit was not originally planned and was not carried out).

2.4 Verification of the absence of defect due to an exogenous gas generated by the inorganic sand

Table 3 : synthesis of structural investigations

Samples	Defect	Comments	Photos	Cause inorg.
CTIF O1	NTR	-	-	-
CTIF O2	NTR	-	-	-
CTIF O3	Cavities	- Blowhole and pinhole related to the fall filling system and poor degassing at the top of the mould. - Micro-shrinkage due to metal shrinkage (defect located in the end-fill area)	O-03-7, O-03 bino 7-1, O-03 bino 8-2 and O-03-4 en pages 24 to 26	No
CTIF I1	Cavity	- Surface pinhole with the presence of iron oxide in the internal cavity: formation of the defect linked to a volume of gas trapped in a thin thickness of the part (with O > 150 ppm in the case of a non-alloyed GS240 steel).	I1-3, I1 bino, MEB I1 BSE-BSE, BSE-O, BSE-C, BSE-Fe, Areass, marked 1 and marked 2	CO peak? O source? Degassing?
CTIF I2	NTR	-	-	-
CTIF I3	Cavities	- Pinhole with the presence of Mn, Al and Si oxides (Mn from FeMn80 introduced 7 minutes before pouring and Al from calming in the ladle 3 minutes before pouring) Formation of the defect due to turbulent filling and dross settling - Micro-shrinkage due to metal shrinkage (defect located in the end-fill area)	I 3-6, I3 bino-6, I3-1 et MEB I3 BSE-BSE, O, Mn, Al and Si in pages 27 to 31	No
GEOPOL W37-20/1	NTR	-	-	-
GEOPOL W37-20/2	Cavity	- Presence of Si and Zr oxides in the cavity (inclusion or settling of dross)	W372-3 and MEB p.32-34	No
GEOPOL W37-20/3	NTR	-	-	-
INOTEC 1	NTR	-	-	-
INOTEC 2	NTR	-	-	-
INOTEC 3	Cavity	- Presence of Si oxide in the cavity (sand inclusion defect in a area with metal penetration probably due to S content > 150 ppm)	Inotec 3-1 and 3-2, and MEB Inotec 3 p. 35-38	No
PEAK W37/1	NTR	-	-	
PEAK W37/2	NTR	-	-	
PEAK W37/3	NTR	-	-	

<u>Blowhole and pinhole detected on the O3 sample of the CTIF's part cast with organic sand:</u>

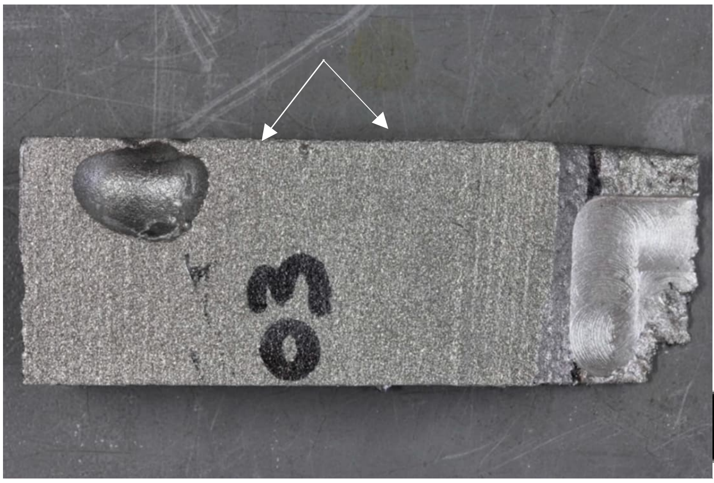
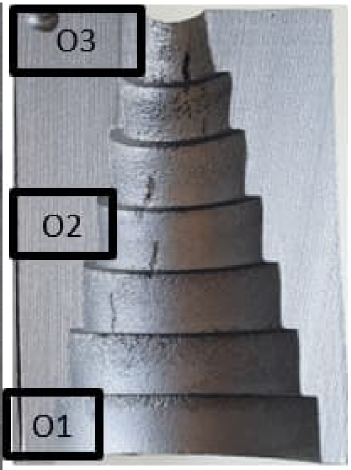


Photo O - 03-7



Position of the samples in relation to the casting

Blowhole and pinhole detected on the O3 sample of the CTIF's part cast with organic sand: cont'd

Blowhole trapped in the part and located at the top of the mould (size 10 x 8 mm)

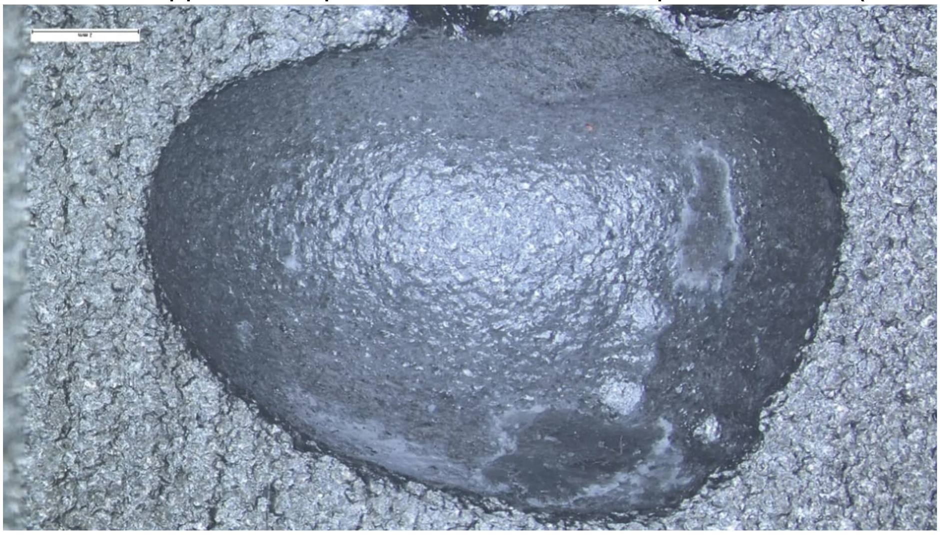


Photo O - 03 bino 7-1

Pinhole trapped in the part and located at the top of the mould (diameter ≈ 1 mm)

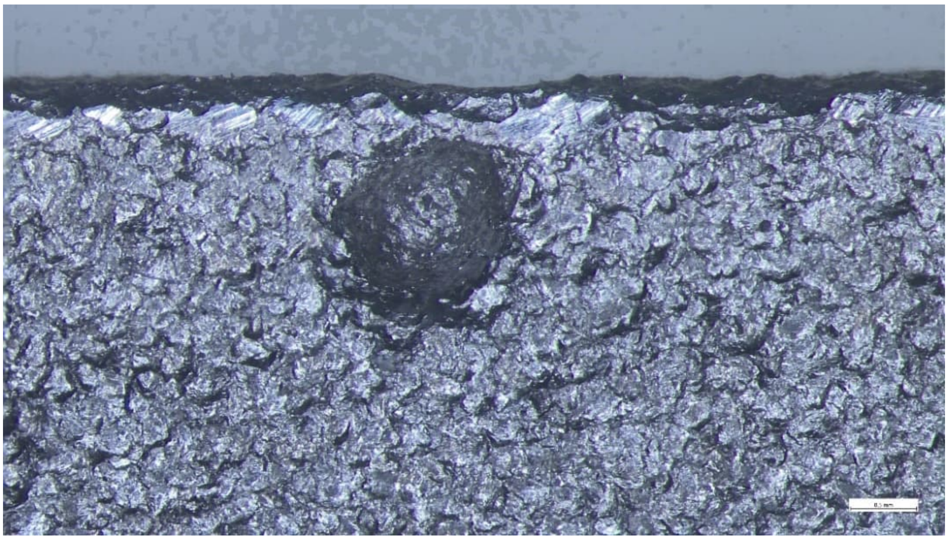


Photo O - 03 bino 8-2

Micro-shrinkage detected on the O3 sample of the CTIF's part cast with an organic sand: cont'd

Micro-shrinkage distributed in the O3 sample

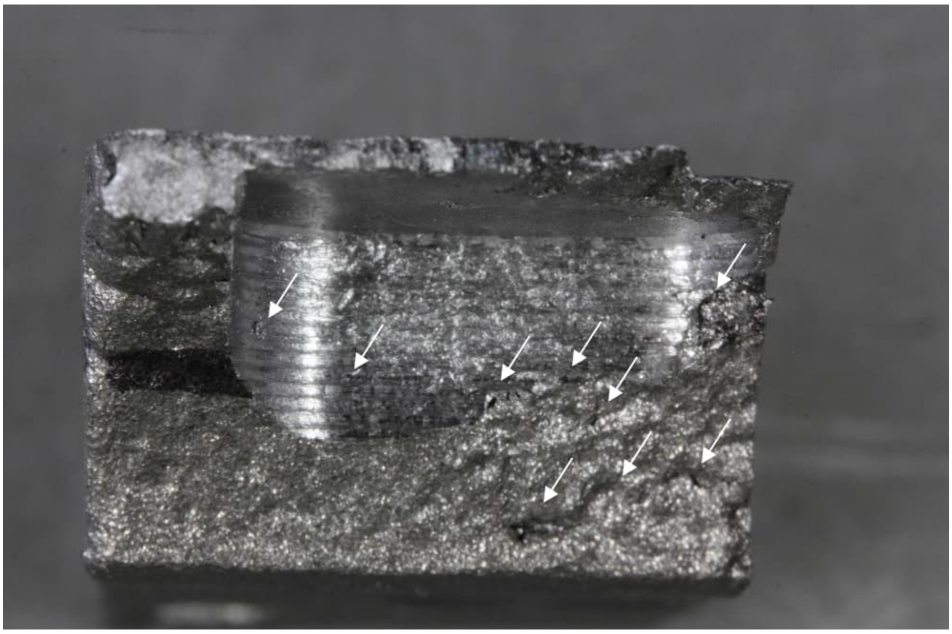


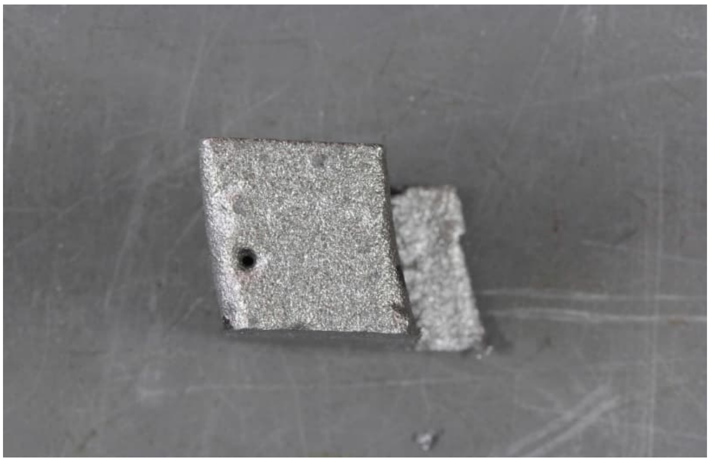
Photo O-03-4

These defects are not attributable to the organic binder, they are mainly due to a turbulent pouring system and poor degassing of the mould in the upper part.

The micro-shrinkage is caused by a feeding failure at the feeder necks.

Pinhole detected on sample I1 of the CTIF's part cast with an inorganic sand:

Pinhole trapped in a thin part of the casting and located in the lower part of the mould



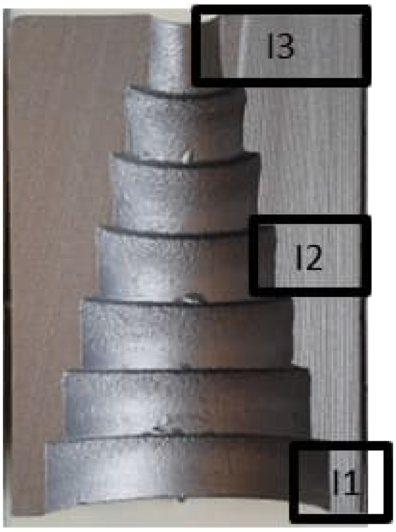


Photo pièce I1-3 Position of the defect in relation to the casting

Pinhole detected on the sample I1 of the CTIF's part cast with an inorganic sand: cont'd

Pinhole trapped in a thin part of the casting and located in the lower part of the mould (diameter ≈ 2 mm)

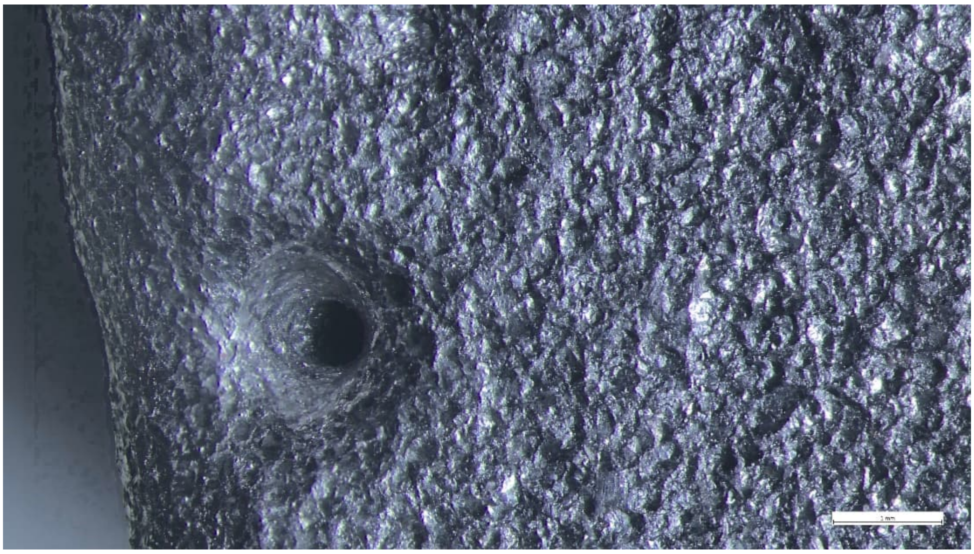


Photo part I1 bino

Identification of an oxide deposit in the cavity

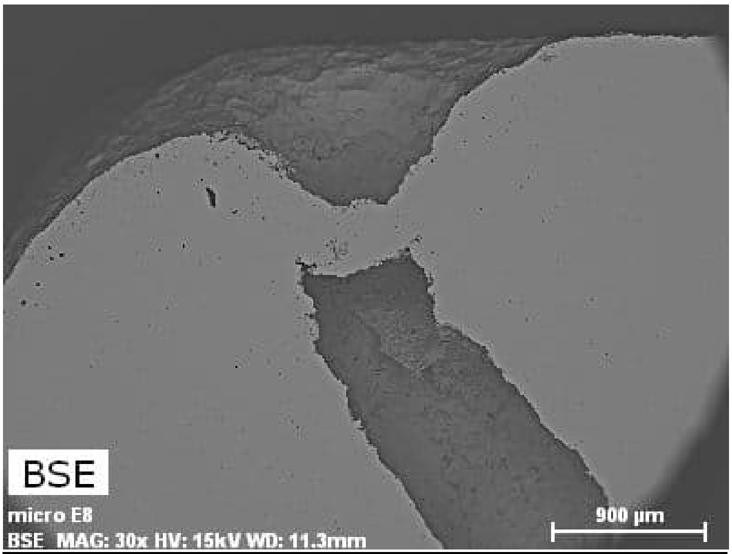
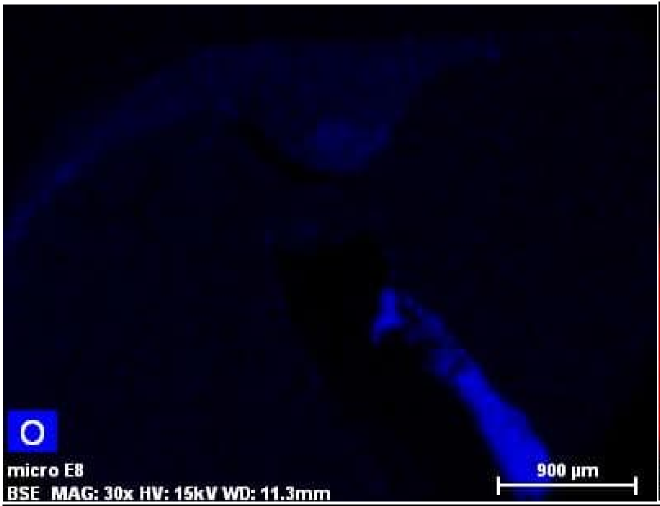
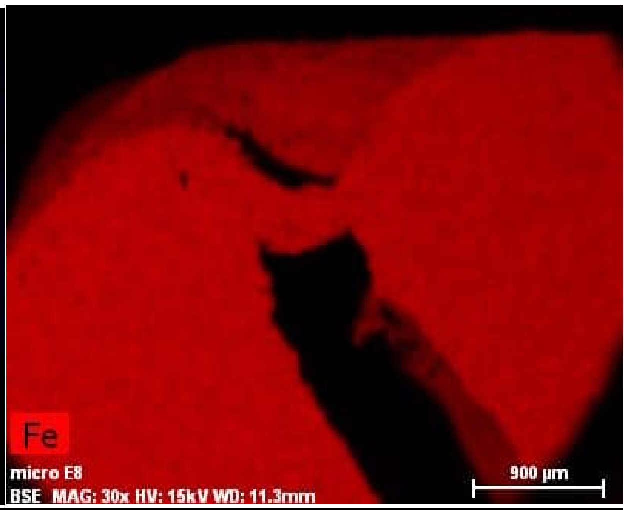


Photo MEB CTIF I1 BSE-BSE

Pinhole detected on the sample I1 of the CTIF's part cast with an inorganic sand: cont'd

Identification of an iron oxide in the cavity





Significant amount of oxygen

Photo MEB I1 BSE-O

Iron presence

Photo MEB I1 BSE-FE

Another element present in the cavity: carbon concentration

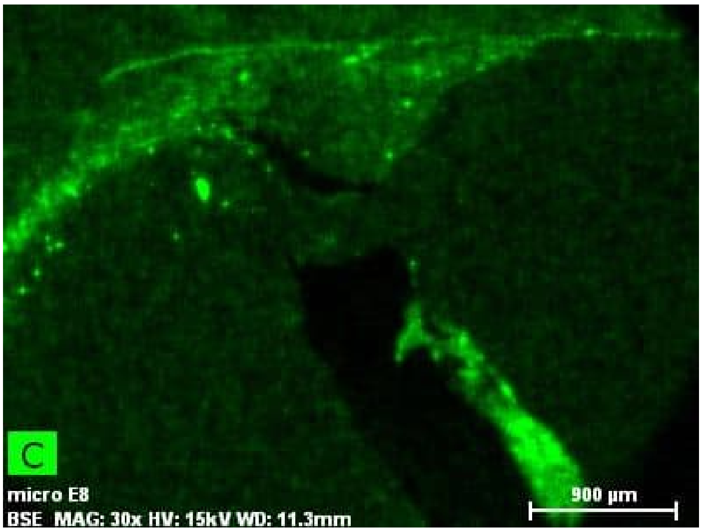


Photo MEB I1 BSE-C

Pinhole detected on the sample I1 of the CTIF's part cast with an inorganic sand: cont'd

Verification by a map of the elements present in the area of the defect

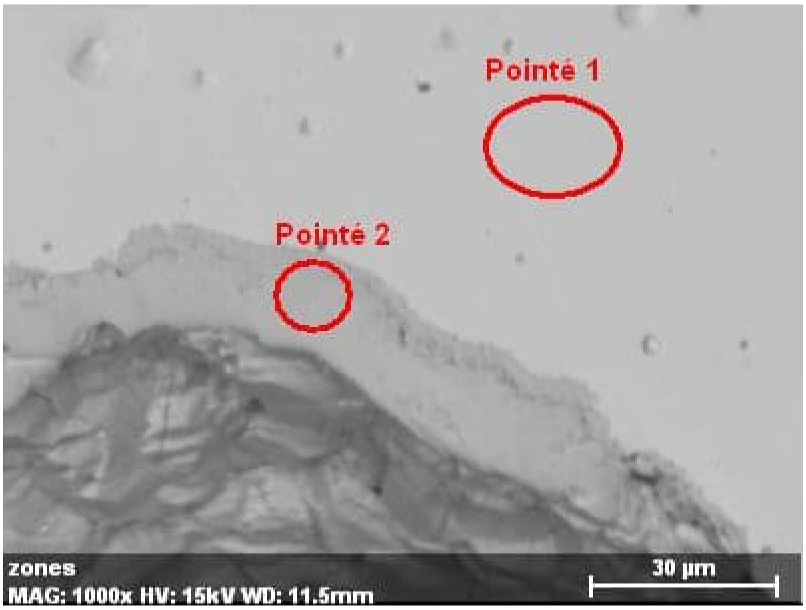


Photo MEB I1 Zones

Iron, carbon, silicon and manganese are present outside the defect: this is normal

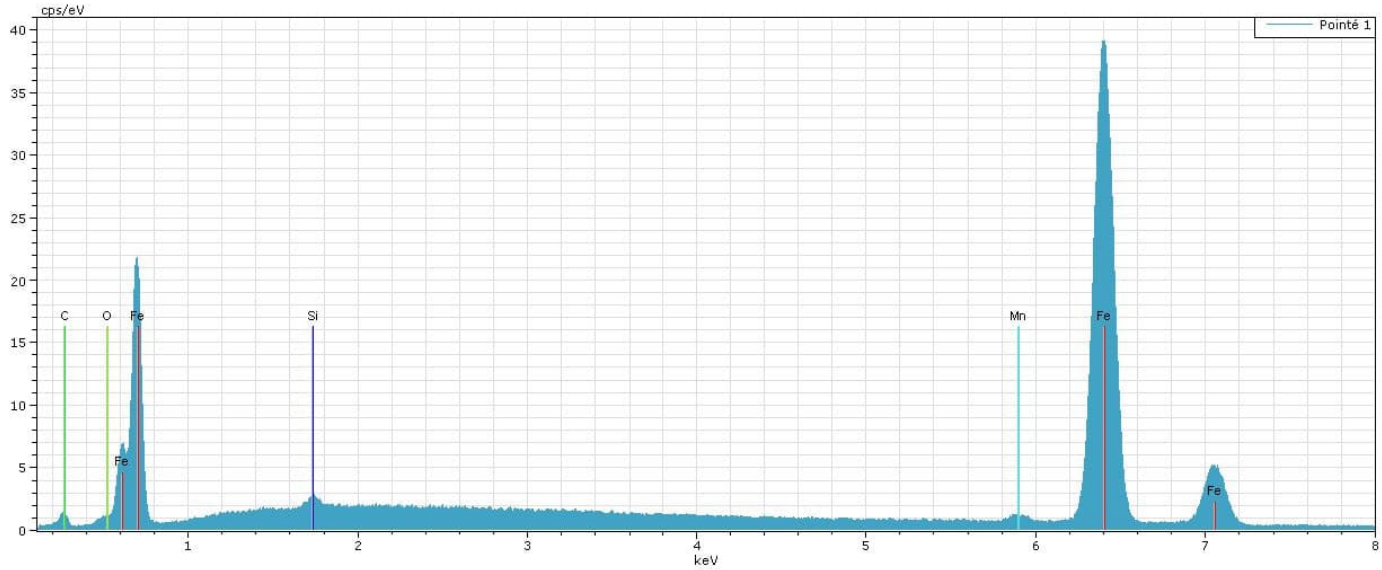


Photo MEB I1 Marked 1

Pinhole detected on the sample I1 of the CTIF's part cast with and inorganic sand: cont'd

Iron, carbon, silicon and manganese are present at the edge of the defect, but with a significant amount of oxygen: this is not normal

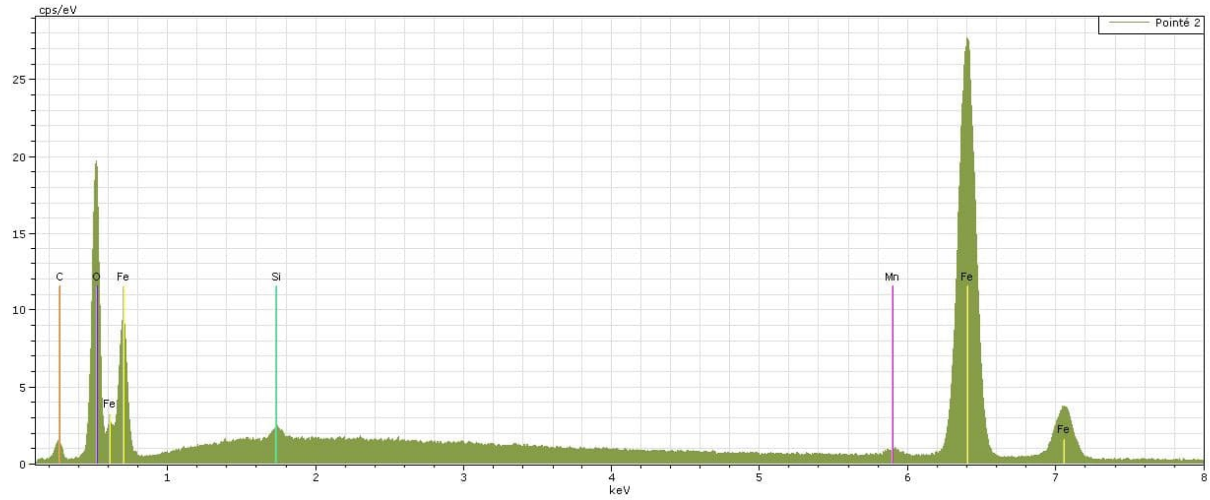


Photo MEB I1 Marked 2

1st hypothesis on the causes of formation of this defect:

According to the morphology and position of the defect, this could be from 3 cumulative causes:

- The phenomenon of CO gas emission occurring during pouring (peak of CO gas emission identified during the measurements carried out by AX Consulting in phase B3 of the project: see Life report 17/ENV/FI/173),
- Faster cooling rate in this area of the part (thin thickness),
- A pouring temperature too low in this case.

Under these conditions, the CO gas does not have time to escape from the cavity because of the faster cooling rate in this thin area of the casting.
The gas thus trapped, formed an internal cavity by making a pinhole appear at the surface of the casting.
2nd hypothesis on the causes of formation of this defect:

- Unsuitable mould degassing in relation to the ratio of sand mass to metal mass and the fall casting system that was used to cast the part,
- A faster cooling rate in this area of the casting (thin thickness),
- A too low pouring temperature in this case.

Under these conditions, a part of air and pouring gases are trapped in this area and form an internal cavity by making a pinhole appear at the surface of the part.
Remind: the surface oxygen content measured on the CTIF's sample I1 is above the critical hreshold for the occurrence of defects (see Table 2 : 174 ppm measured for a maximum of 150 ppm).

Pinhole and micro-shrinkage detected on sample I3 of the CTIF part cast with an inorganic sand:

Pinhole trapped in the part and located at the top of the mould (diameter ≈ 1 mm)

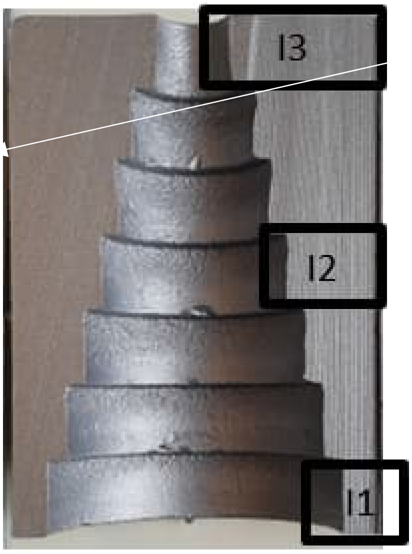


Photo I 3-6

Position of the defect in relation to the casting

Pinhole with the presence of aluminum, silicon and manganese oxides

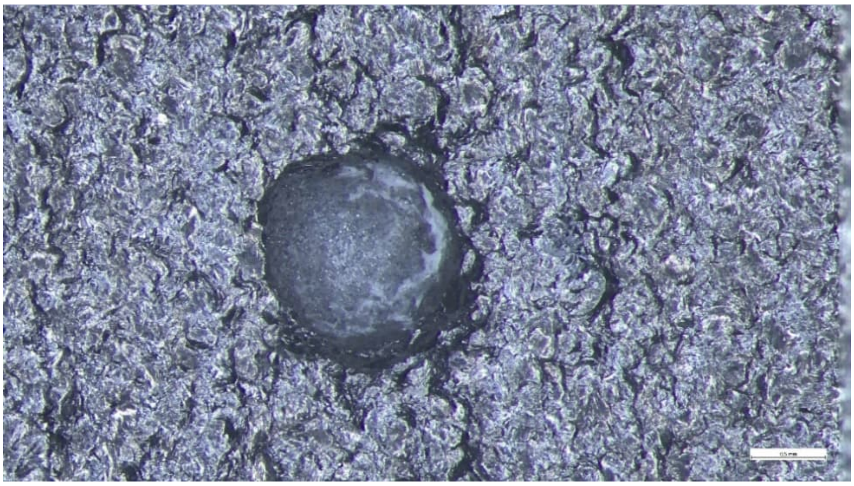


Photo I3 bino-6

Pinhole and micro shrinkage detected on sample I3 of the CTIF part cast with an inorganic sand: Cont'd

Identification of aluminum, silicon and manganese oxides in the pinhole

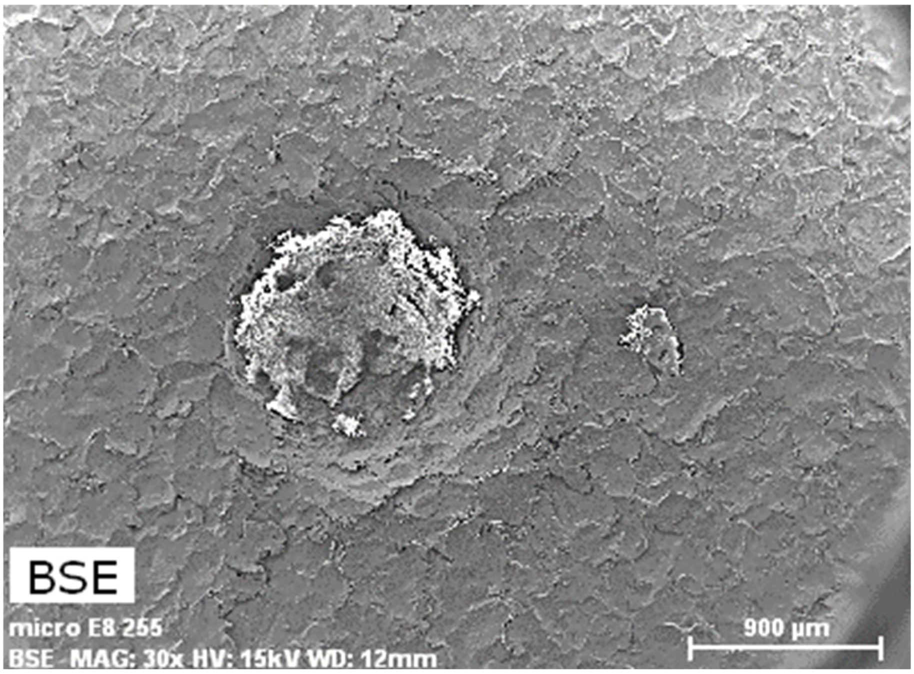


Photo MEB I3 BSE-BSE

Identification of the elements present in the pinhole: oxygen

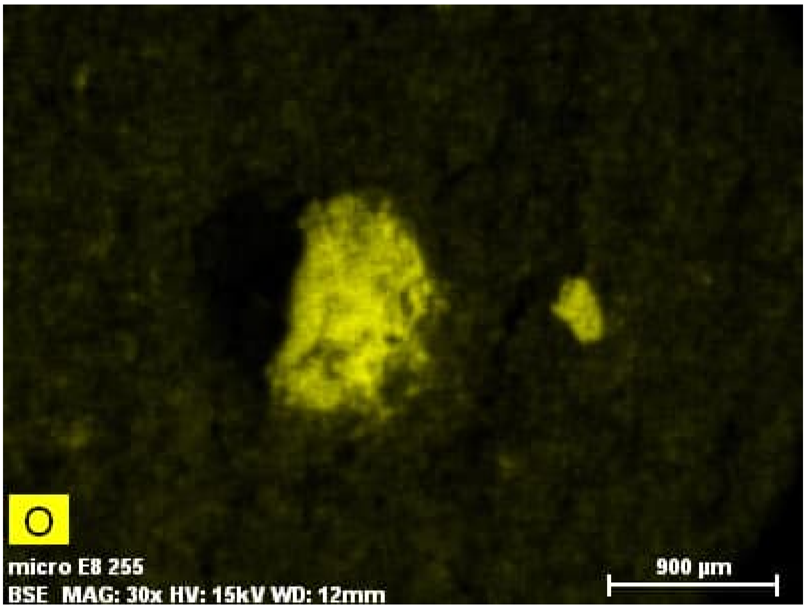


Photo MEB I3 BSE-O

Pinhole and micro-shrinkage detected on sample I3 of the CTIF part cast with an inorganic sand: cont'd

Identification of the elements present in the pinhole: aluminium

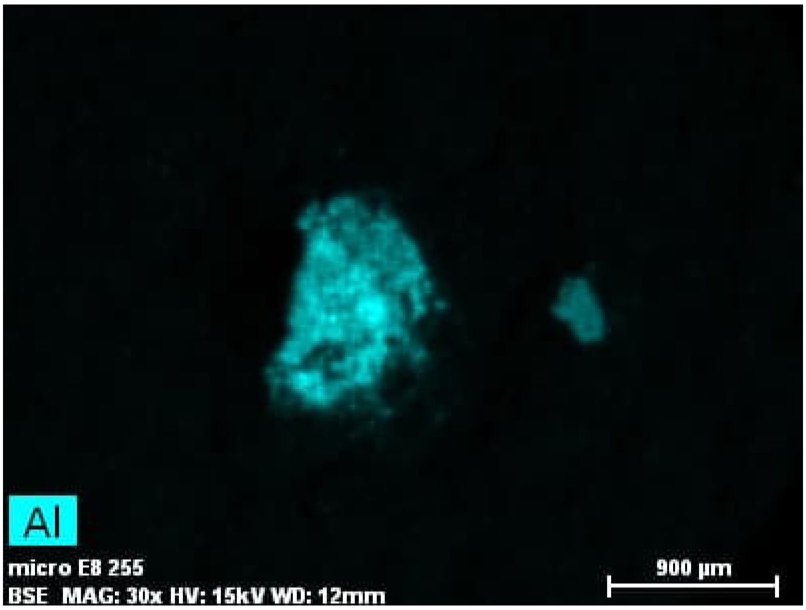


Photo MEB I3 BSE-Al

Identification of the elements present in the pinhole: silicon

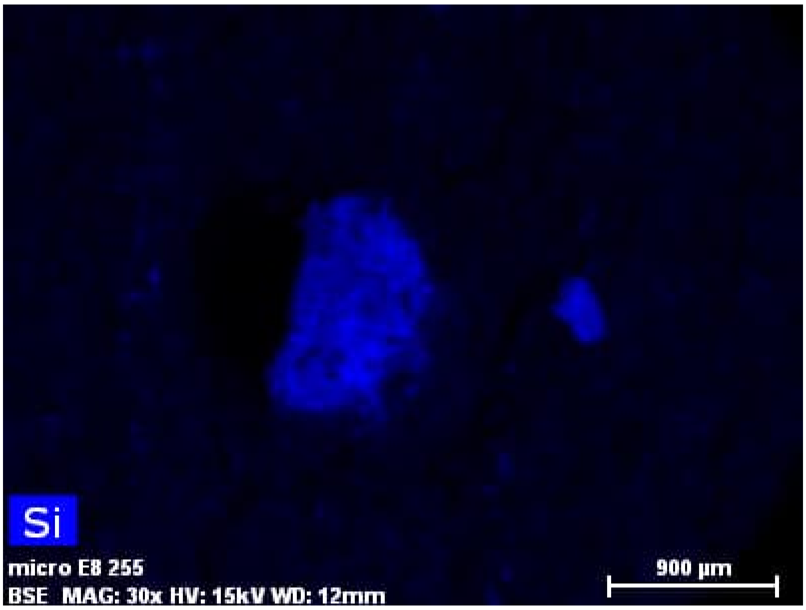


Photo MEB I3 BSE-Si

Pinhole and micro shrinkage detected on the I3 sample of the CTIF part cast with an inorganic sand: Cont'd

Identification of the elements present in the pinhole: manganese

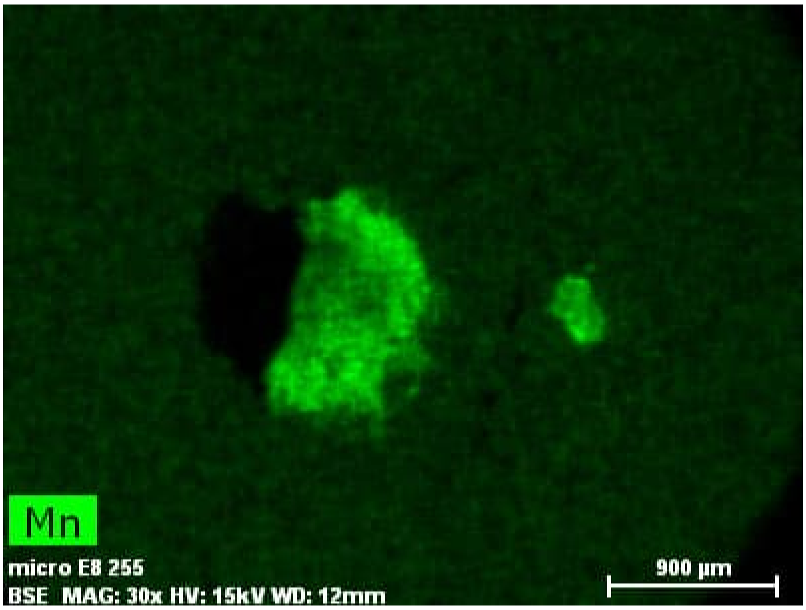


Photo MEB I3 BSE-Mn

Micro-shrinkage distributed in sample I3

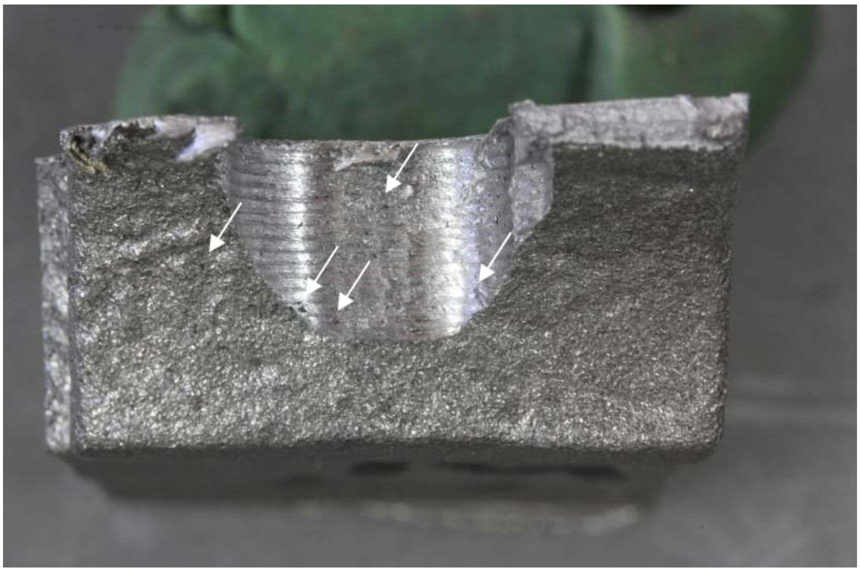


Photo I3-1

These defects are not attributable to the inorganic binder, they are mainly due to oxide inclusion due to dross settling and turbulent cavity filling (fall casting system).

The micro-shrinkage is related to a feeding failure at the feeder necks (as for sample O3).

Cavity detected on sample W37-20/2 of the GEOPOL part cast with an inorganic sand:

Identified cavity, length 6 mm and diameter ≈ 3 mm, with a surface deposit

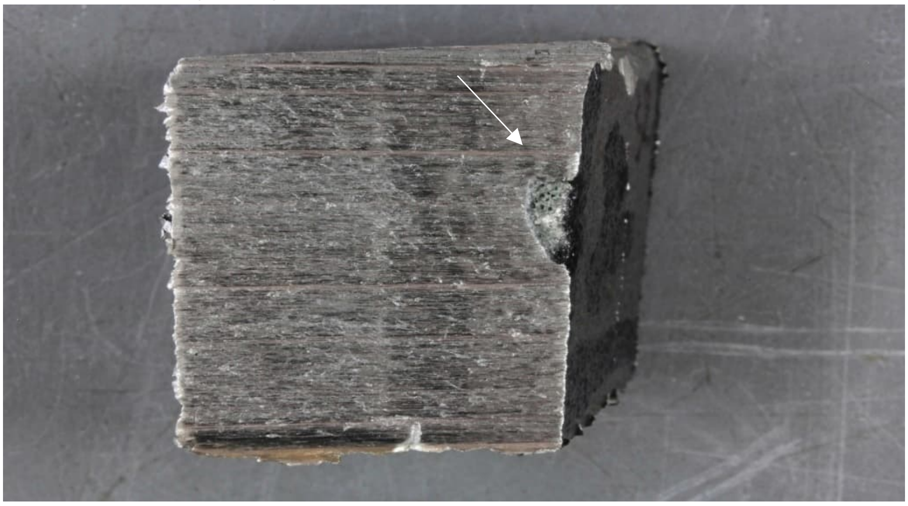


Photo « geopol W372-3 »

Identification of silicon and zirconium oxide deposits in the cavity

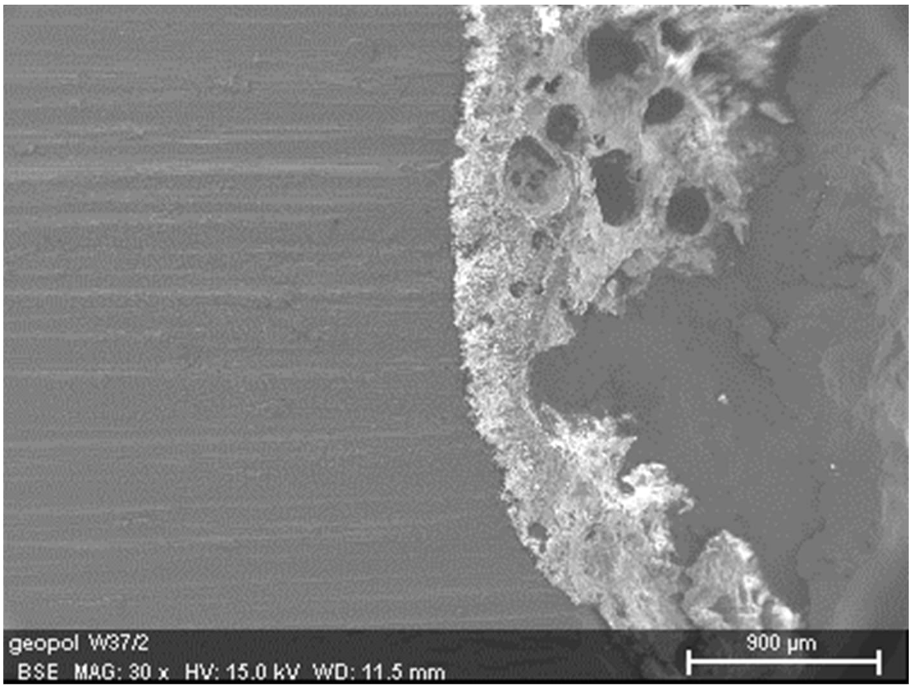


Photo MEB « geopol W37-2 »

This defect is probably not due to the inorganic binder, it could be due to an inclusion related to a coating containing zirconium, or to a dross related to the elaboration of the metal (in this case, Zr could come from the deoxidizing product).

Cavity detected on sample Inotec 3 of the ASK part cast with an inorganic sand:

Cavity identified at the surface (diameter ≈ 1 mm)

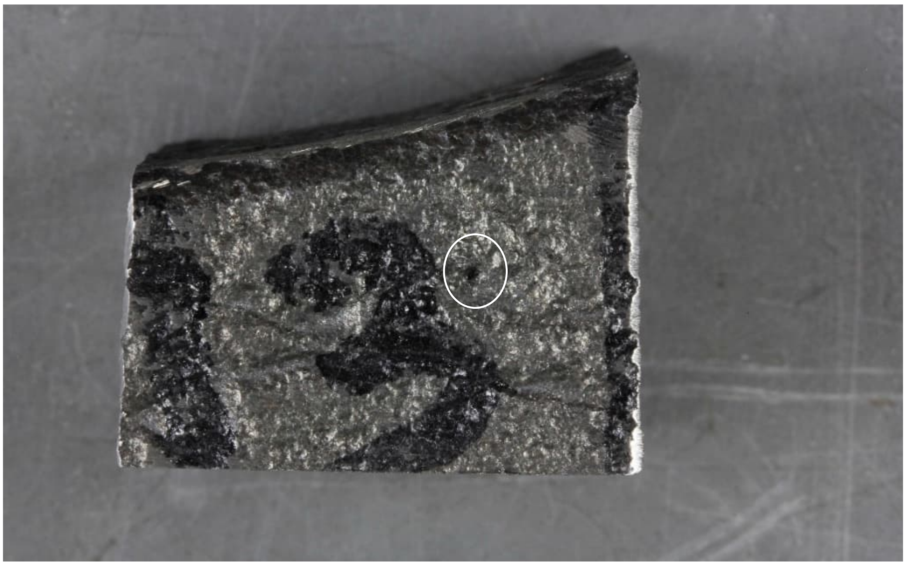


Photo Inotec 3-1

Analysis of the elements present in the cavity

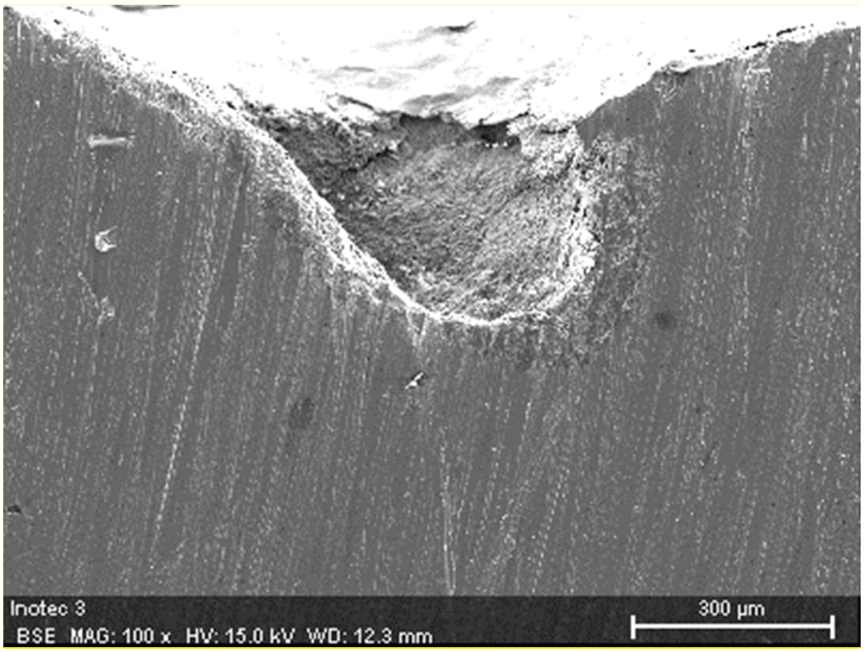
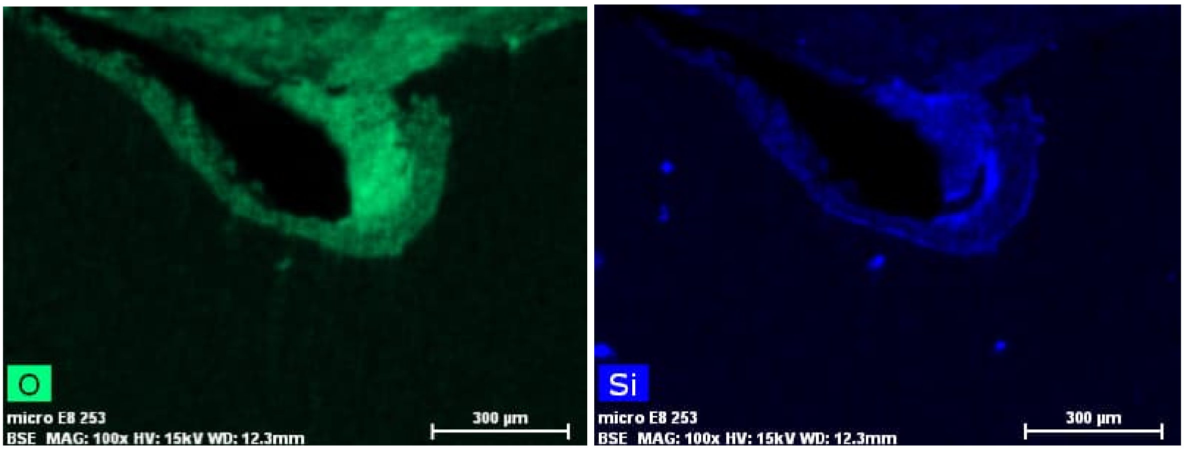


Photo MEB Inotec 3

Cavity detected on Inotec 3 sample of the ASK part cast with an inorganic sand: Cont'd

Identification of silicon oxide in the cavity



Photos MEB Inotec 3 BSE-O and BSE-Si

This defect is probably not attributable to the inorganic binder, it is a sand inclusion: a metal penetration defect is visible at the surface of the inotec part, close to the above inclusion defect (see page 14 for the position of the sample "Inotec 3" in relation to the metal penetration defect).

Note that the sulphur content is higher than 150 ppm and this may favour the metal penetration defect by lowering the surface tension of the liquid metal (see Table 2).