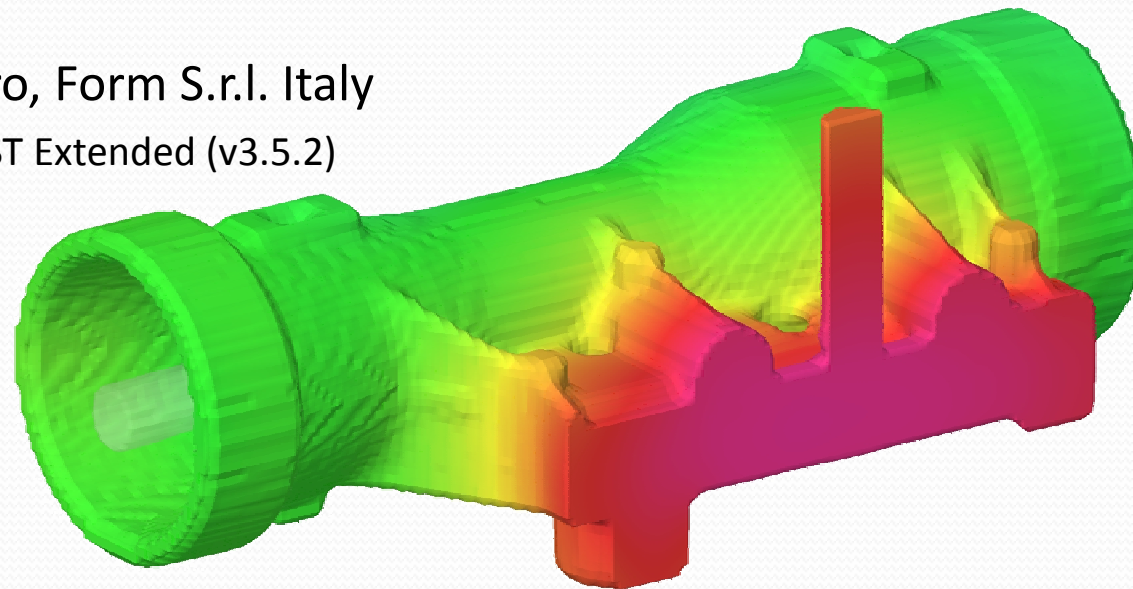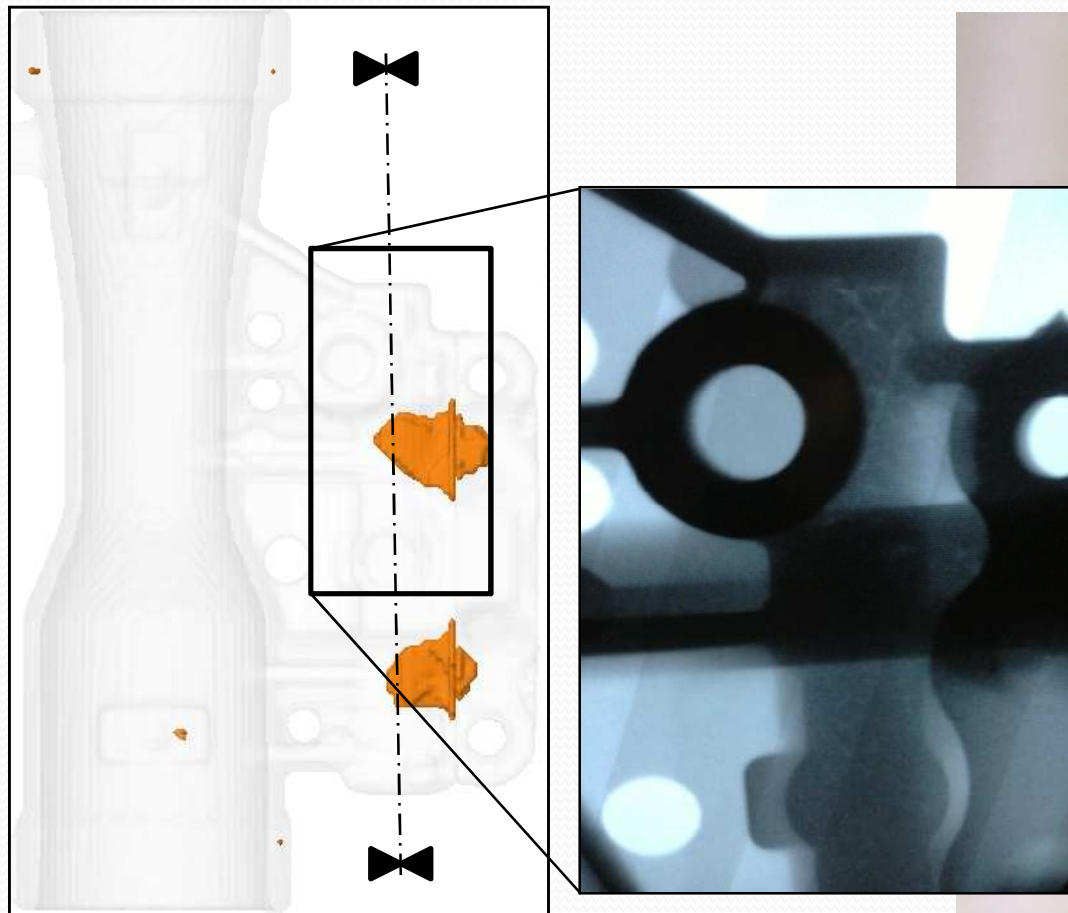**HPDC MOULD**

IMPROVEMENTS TO THE MACRO-SHRINKAGE MODEL FOR HPDC AND APPLICATION WITH SQUEEZE PIN

Daniele Grassivaro, Form S.r.l. Italy

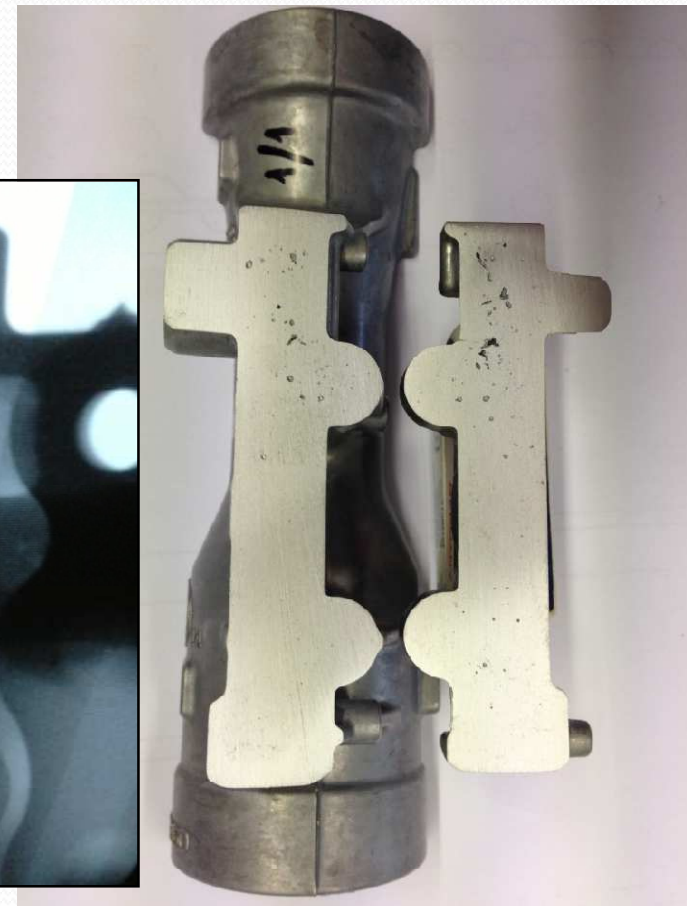User of FLOW-3D CAST Extended (v3.5.2)

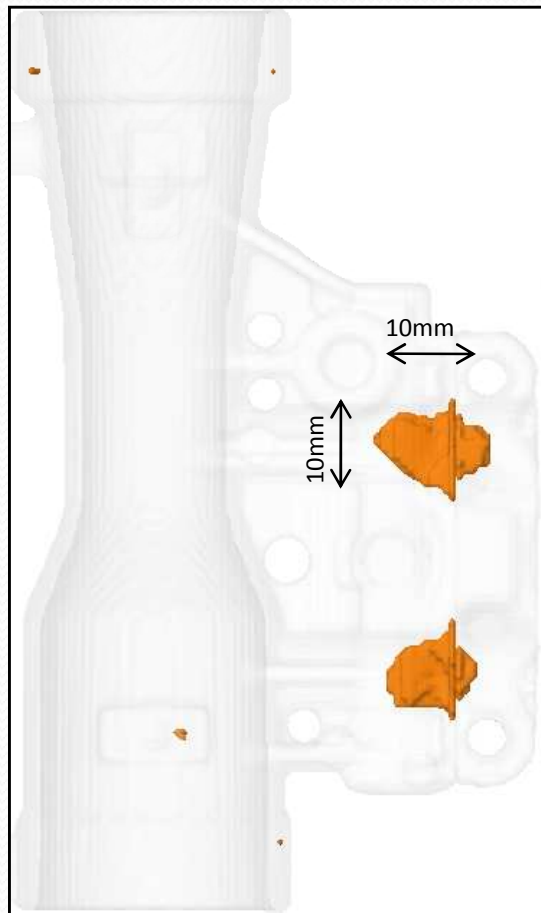# Why this difference in terms of shrinkage macroporosity?

INITIAL SIMULATION   CAST

INITIAL SIMULATION

There are 2 big pores

Pores are spheroidal and coalescent

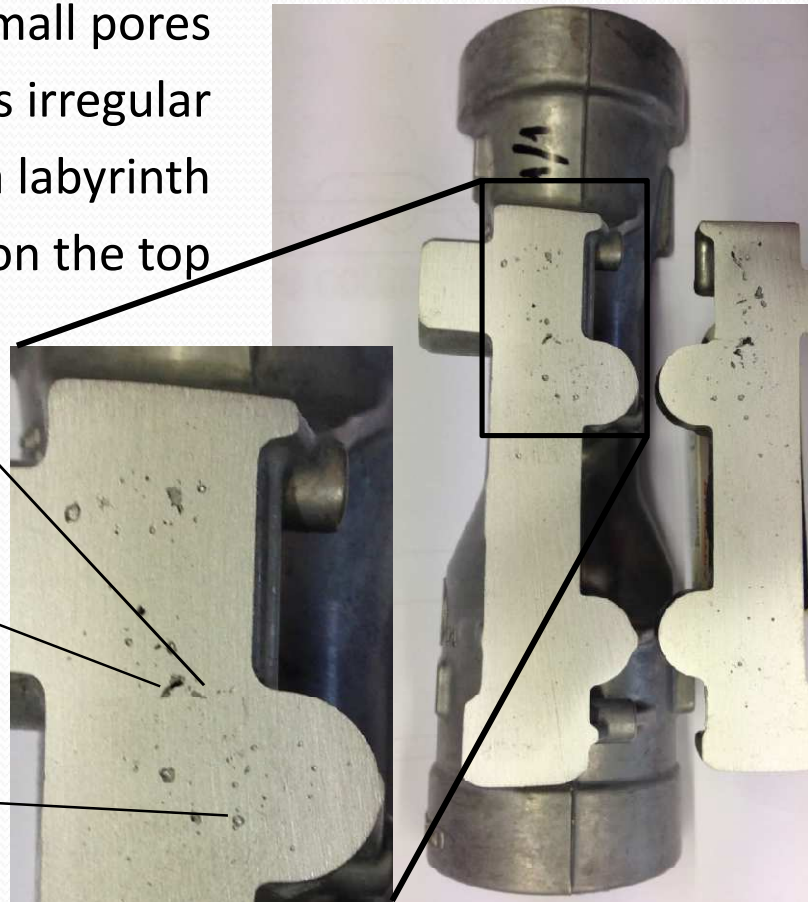They've nearby same dimension

CAST

There are more small pores

Pores shape is irregular

They are connected in a labyrinth

They are localizated on the top

micro-shrinkage pores

macro-shrinkage pore

Entrapped air pore

Model for prediction of shrinkage porosity

- Two models are available in *FLOW-3D* to predict porosity:

    - macroposity (Shrinkage without flow or Shrinkage with flow)

    - microporosity

- Both models assume a linear dependency of metal density ρ on solid fraction fs:

$$\rho = fs \cdot \rho_s + (1 - fs) \cdot \rho_l$$

where ρ_s and ρ_l are the user-defined constant *solid* and *liquid* phase densities, respectively.

- For HPDC we use the rapid shrinkage model that assumes <u>no</u> fluid flow and interdendritic feeding only enabled

- The feeding occurs by interdendritic flow in the direction of the temperature gradient – from hot to cold zones – with creation of shrinkage macropores

- No feeding occurs when the solid fraction exceeds the critical value (FSCR). Above this point we have only creation of shrinkage micropores

NO FEEDING = MICROPOROSITY

CRITICAL SOLID FRACTION

INTERDENDRITIC FEEDING = MACROPOROSITY

FEEDING FROM HOT TO COLD ZONES
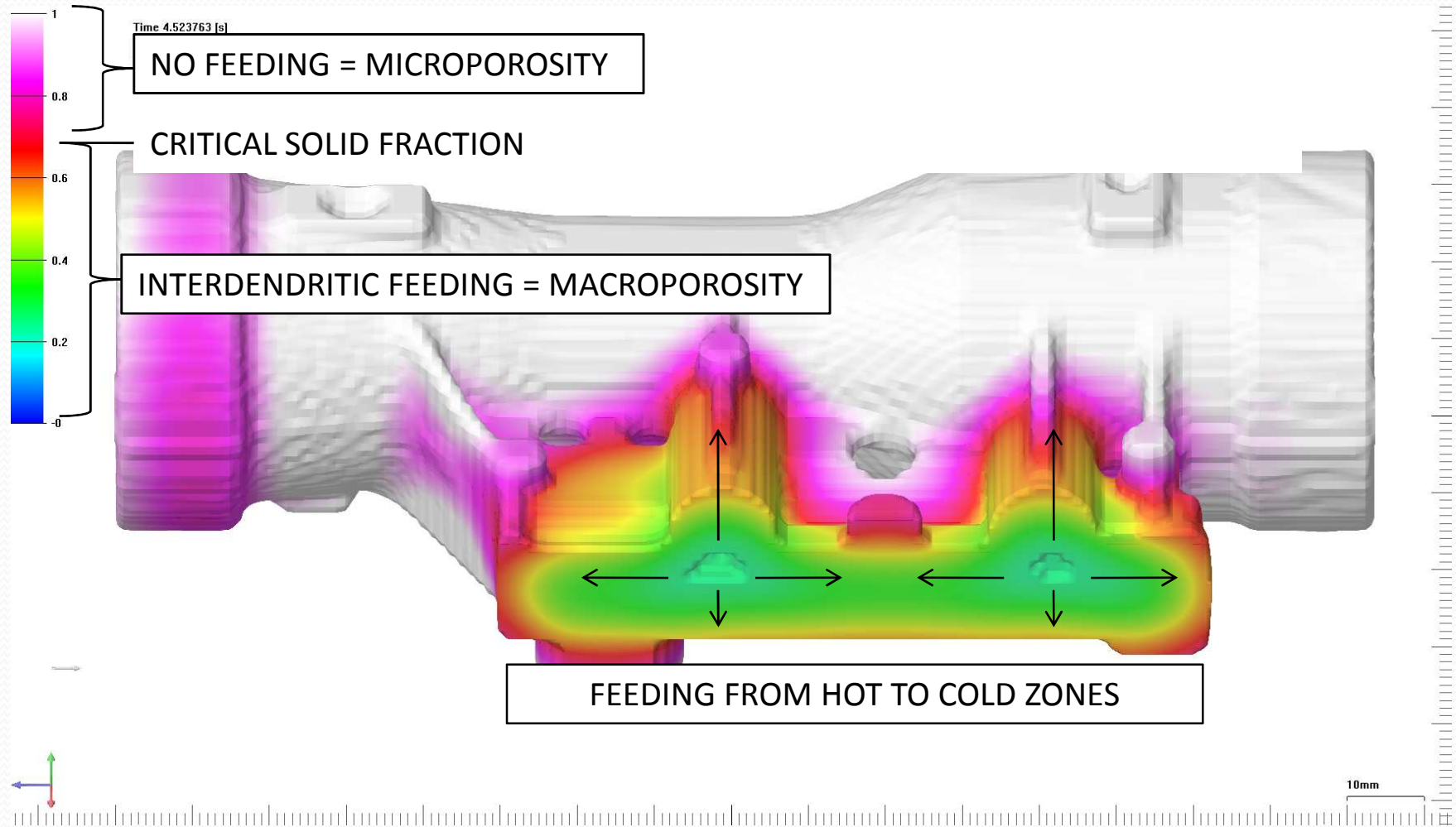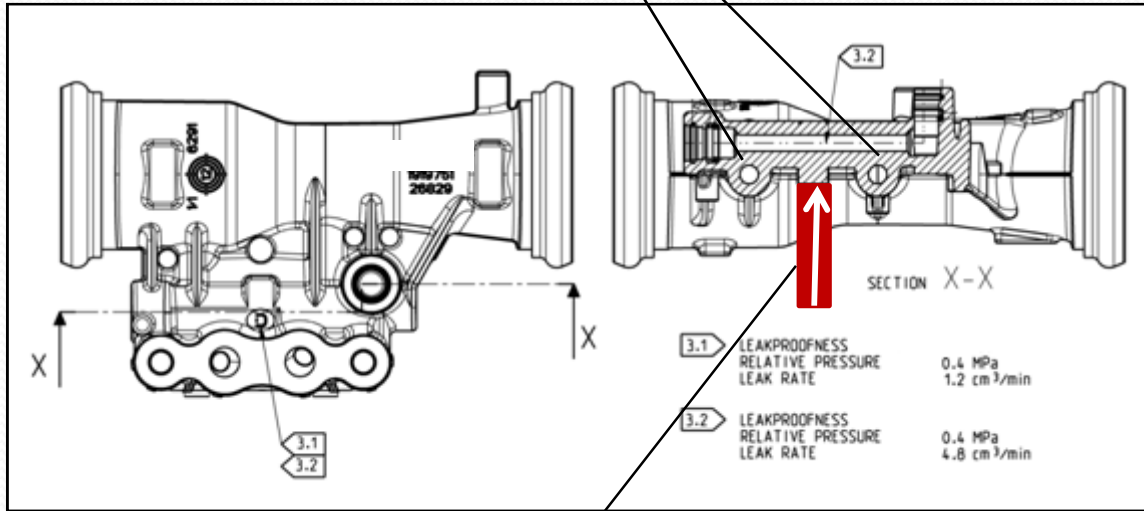
The object of this study: part "Exhaust pipe"

MATERIAL: ALLOY EN AB 46000 - AlSi9Cu3
SOLID DENSITY=2.675 kg/dm^3 (BY DEFAULT DATABASE)
LIQUID DENSITY=2.529 kg/dm^3 (BY DEFAULT DATABASE)
CRITICAL SOLID FRACTION = 0.7 (BY DEFAULT DATABASE)
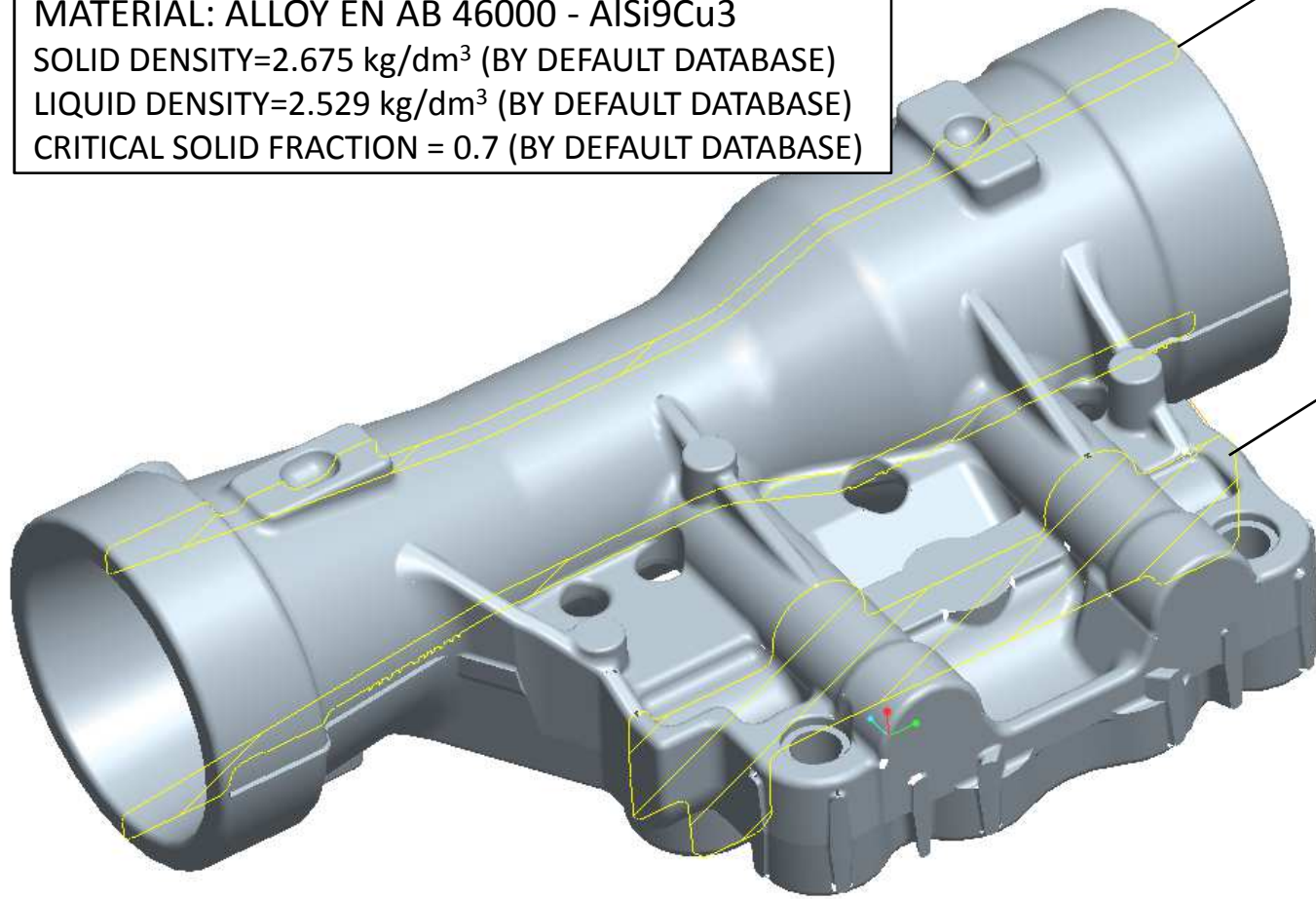
HOLLOW PIPE
3mm THICK

CONNECTION
BLOCK
17.5mm THICK

PRESENCE OF PORES!!

SQUEEZE PIN RECOMMENDED!!

SECTION X-X

| 3.1 | LEAKPROOFNESS RELATIVE PRESSURE LEAK RATE | 0.4 MPa 1.2 cm³/min |
| 3.2 | LEAKPROOFNESS RELATIVE PRESSURE LEAK RATE | 0.4 MPa 4.8 cm³/min |

Ø6±0.2 (2x)

SECTION P-P

SECTION Y-Y

Ø6±0.2
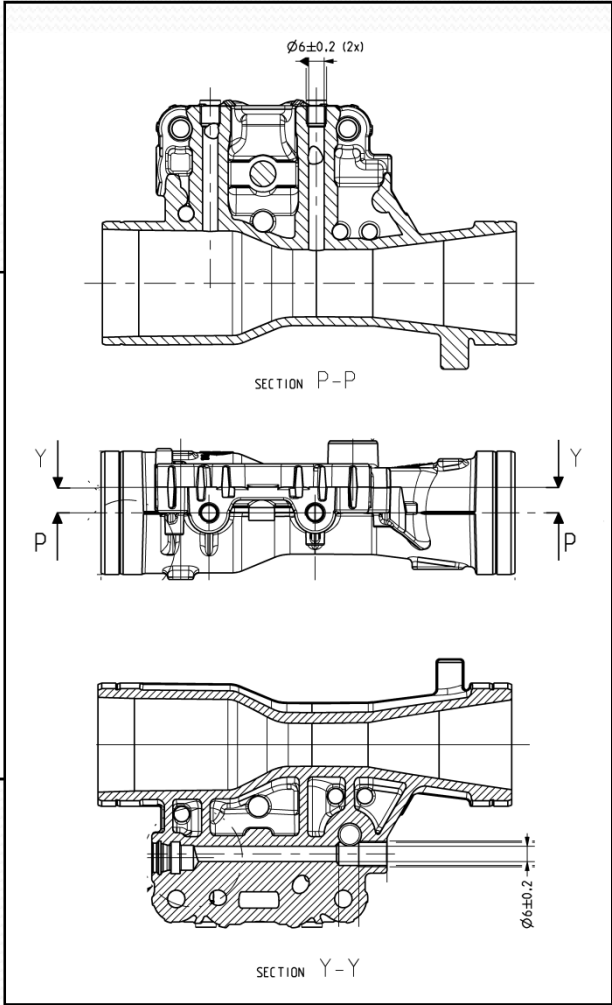
How can we adjust our solidification simulation to fit the dimension of macropores??

To reduce pores dimension:

- Reduce the FSCR to move shrinkage from macro to microporosity

- Consider the compressibility of the molten metal: during last stage of feeding, the 3° phase, the pressure raises up to 600 bar, and thus the liquid could not be considered incompressible. The density at T liquidus should be increased by about 4% (value comparable to other liquids)

- Add boundary condition "Outflow" at biscuit that allow liquid feeding across it, have no influence on temperature gradient and don't need to define the temperature of incoming metal.

- Slowing down the solidification introducing heat resistance between die and solidified metal, to increase feeding from outflow boundaries

To adjust pores position:

- Adjust die temperature map considering tempering channels + thermal die cycling

New simulation
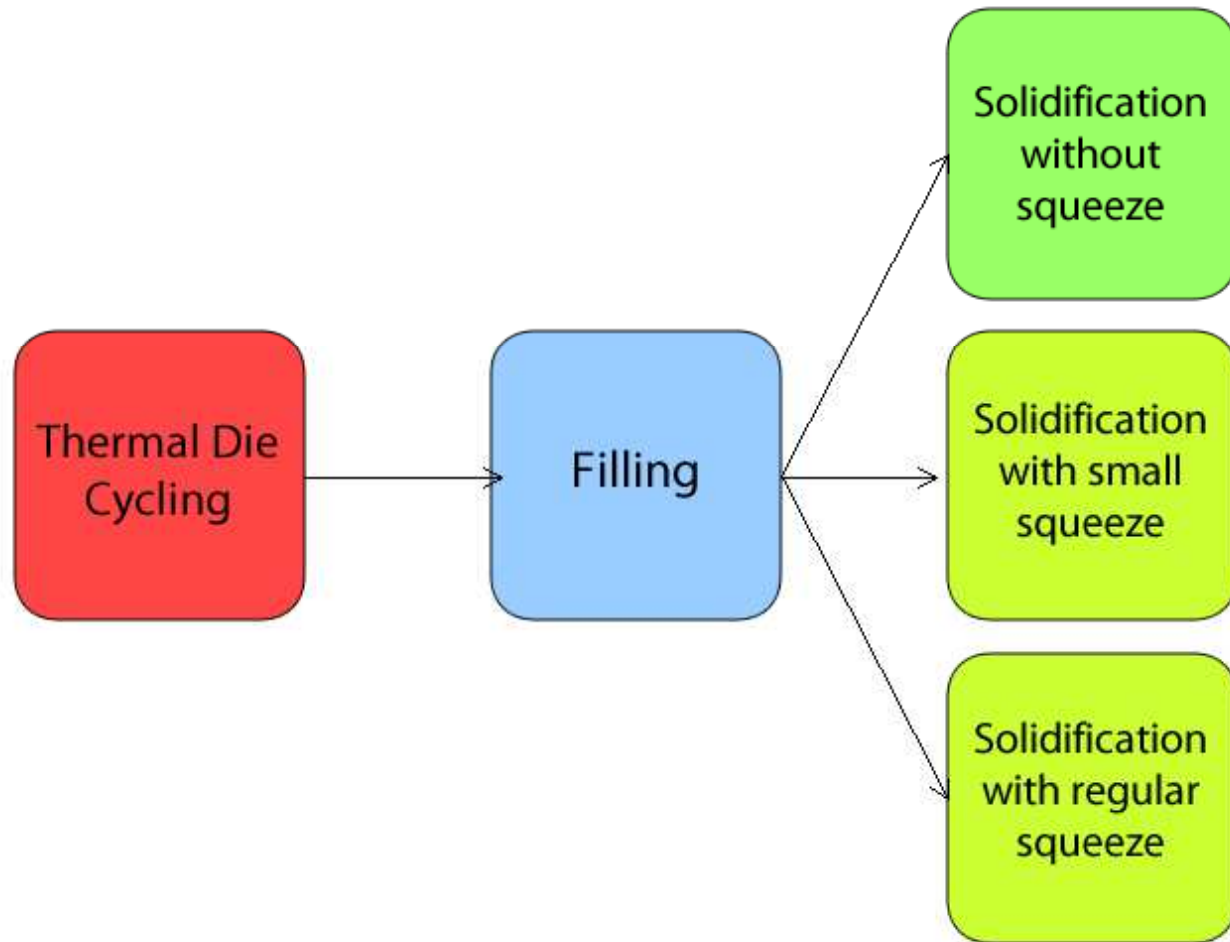
Thermal Die Cycling
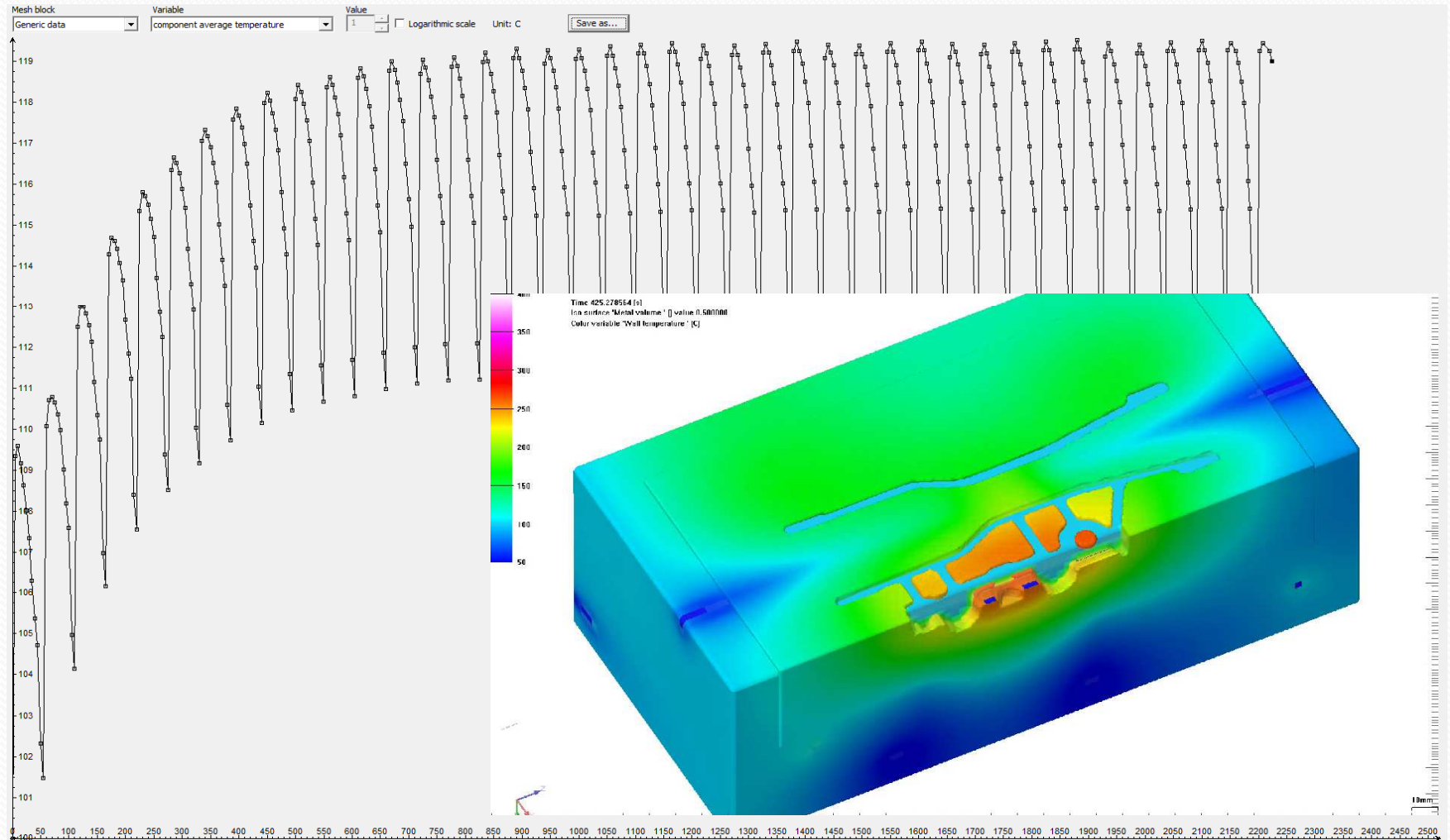
Set-up:

- Symmetry Boundary conditions
- N°40 cycles:

Name of the phase	Time [s]	Temperature [°C]	HTC
Filling and solidification	30	650	22000
Die open-cast ejection	15	125	140
Spraying	5	25	1500
Blowing-Die close	5	25	150
Total	55		

Solver parameter:

- HT explicit

Thermal Die Cycling

Thermal Die Cycling

Comments:

- The final temperature map of the die seems about 50°C lower than the usual die temperature. A further adjustment to the simulation set-up should be done according to the temperature measured during production.

Filling

Set-up:

- Added metal into sleeve and plunger as moving object
- Limited heat transfer calculation to depth 15 mm
- Added HTC at interface metal-mould 2500 W/m^2 K
- End when 100% filled

Solver parameter:

- Adiabatic gas region
- Air entrainment model activated
- Solidification without shrinkage model activated
- HT explicit

Filling

Time 2.170350 [s]
Iso surface 'Metal volume ' [] value 0.500000
Color variable 'vol. fraction of entrained air' [N/A]

NEST 1 / 1

NEST 1 / 2
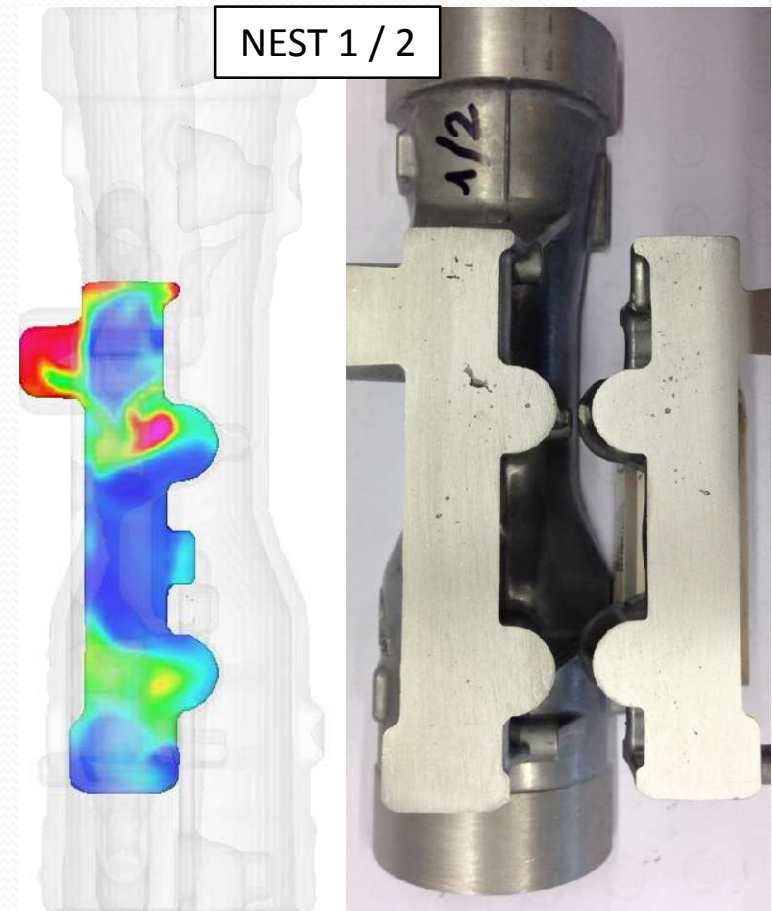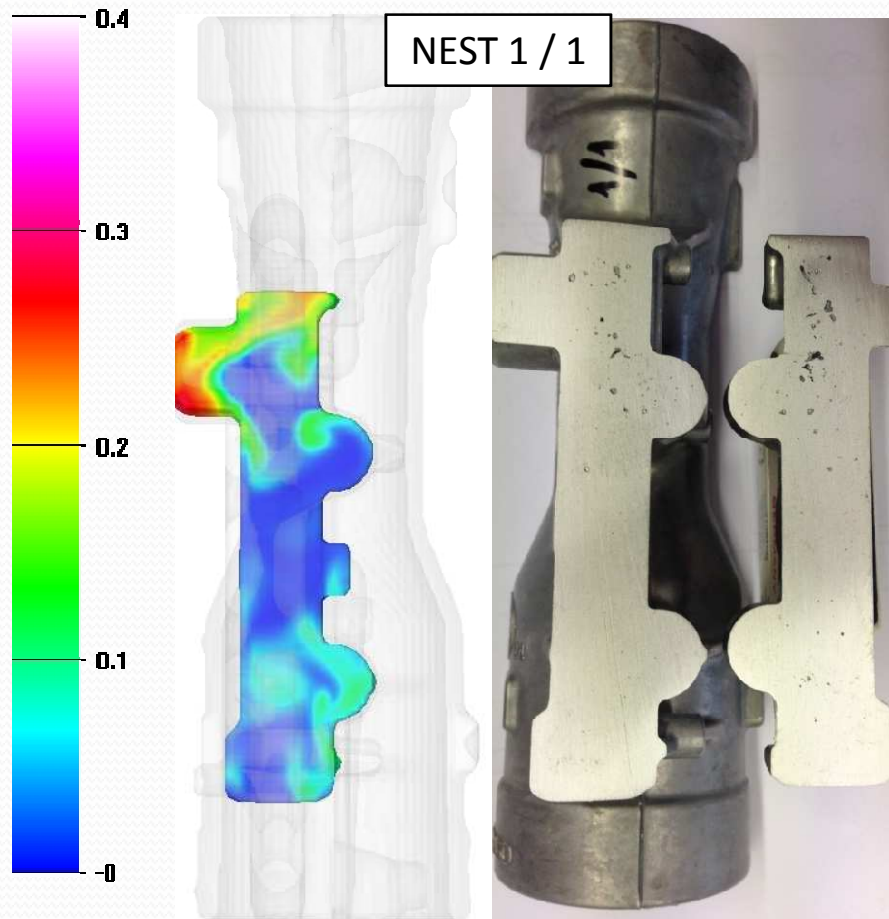
Filling

Comments:

- The shrinkage seems to be dependent to air bubbles. Where we have air bubbles after filling, during solidification they are starting points for opening of shrinkage pores.
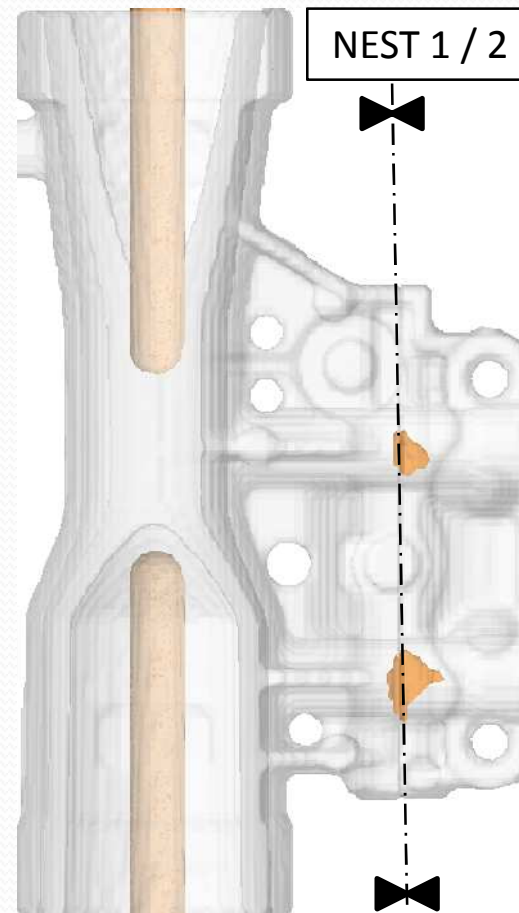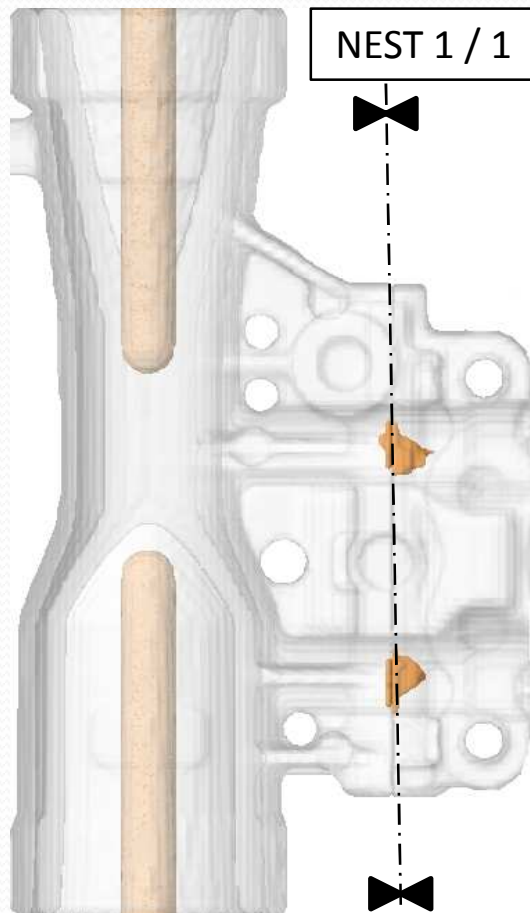
Solidification without Squeeze

Set-up:

- Limited heat transfer calculation to depth 25mm
- End when 100% solidified
- Forced manually liquid density at T liquidus = 2.630 kg/dm^3
- Set FSCR=0.8
- Changed boundary condition at biscuit as "Outflow"
- Added HTC at interface solidified metal-mould 500 W/m^2 K

Solver parameter:

- Adiabatic gas region
- Air entrainment model activated
- Solidification with shrinkage (no flow, interdendritic feeding only) enabled
- HT implicit
- Microporosity evaluation activated

Solidification without squeeze

Time 30.158947 [s]
Iso surface 'Void volume ' [] value 0.500000

NEST 1 / 1

NEST 1 / 2

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Solidification without Squeeze

Comments:

- The pores are now smaller than the initial simulation. Their dimension is now comparable to the pores present in the cast but still bigger.

- There are still only 2 major pores, and their dimensions are almost equal, in spite of the cast where the pores are concentrated on the upper zone. This demonstrate that, in this case, the pores distribution is not influenced by the thermal die cycling and confirm that it depend by air entrapment.

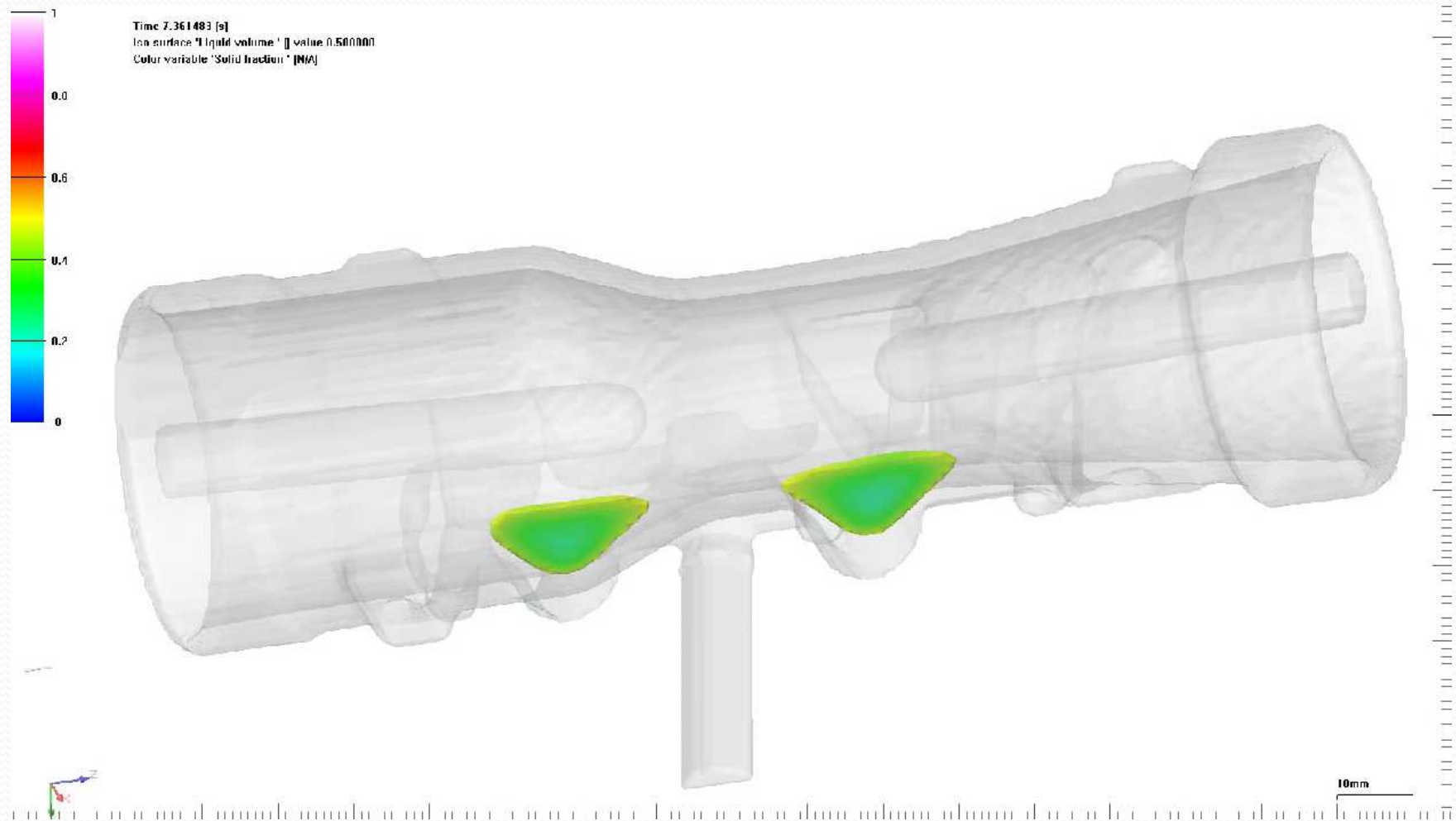# Solidification with small Squeeze (preliminary Squeeze pin design)

Set-up:

- Same as solidification without Squeeze

- Added cylinder of squeeze pin diameter 10mm and defined it as metal at 631°C

- The Squeeze pin was considered cutting the cylinder and setting a boundary condition type "Outflow". If the pin section is enough big, it will feed metal across the boundary. This simplified model can work with solidification without flow, much lighter in terms of calculation than considering the movement of the pin and its pressure with the model of solidification with flow.
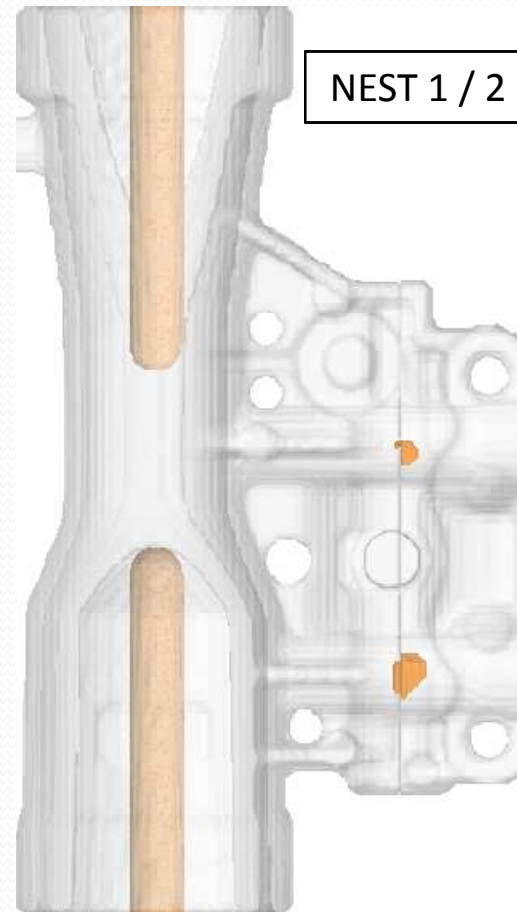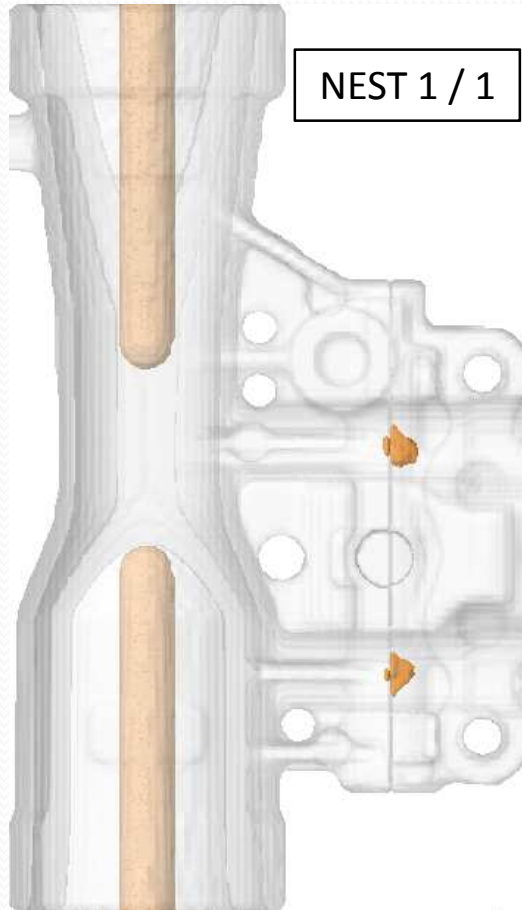
Solver parameter:

- Same as solidification without Squeeze

Solidification with small Squeeze

Solidification with small Squeeze

Time 30.166414 [s]
Iso surface 'Void volume ' [] value 0.500000

NEST 1 / 1

NEST 1 / 2

Solidification with small Squeeze

Comments:

- In comparison with solidification without Squeeze, it was aspected a great improvement in terms of shrinkage pores dimension but results show that there aren't big bifferences.

- This is caused by the dimension of the Squeeze metal reservoir, that is too thin compared to the thickness of the zone to feed, so it solidify earlier.

- Next simulation will consider a larger metal reservoir.

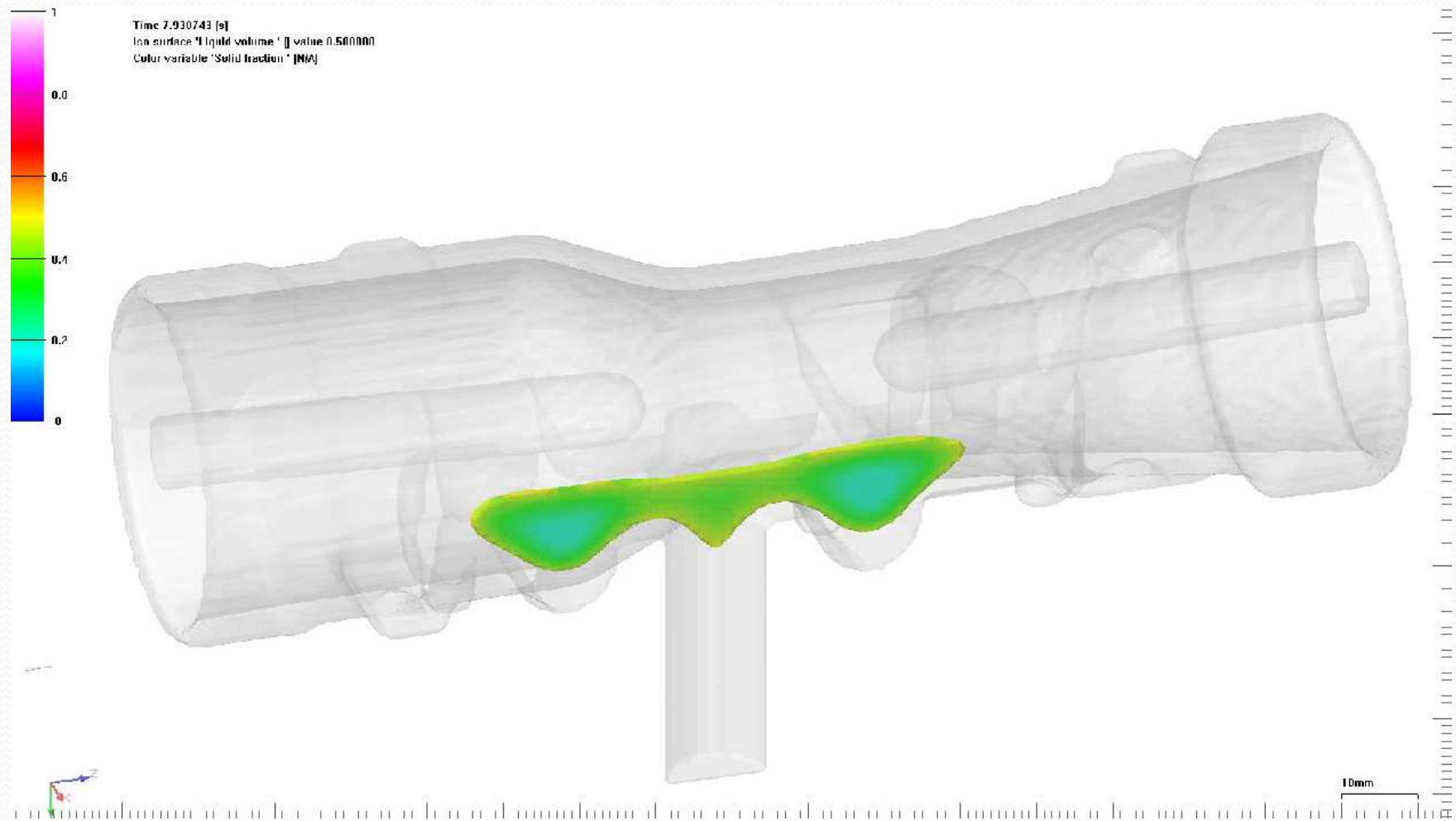## Solidification with large Squeeze (definitive Squeeze pin design)

Set-up:

- Same as solidification with small Squeeze
- Modified the cylinder of squeeze pin to diameter 14mm

Solver parameter:

- Same as solidification with small Squeeze

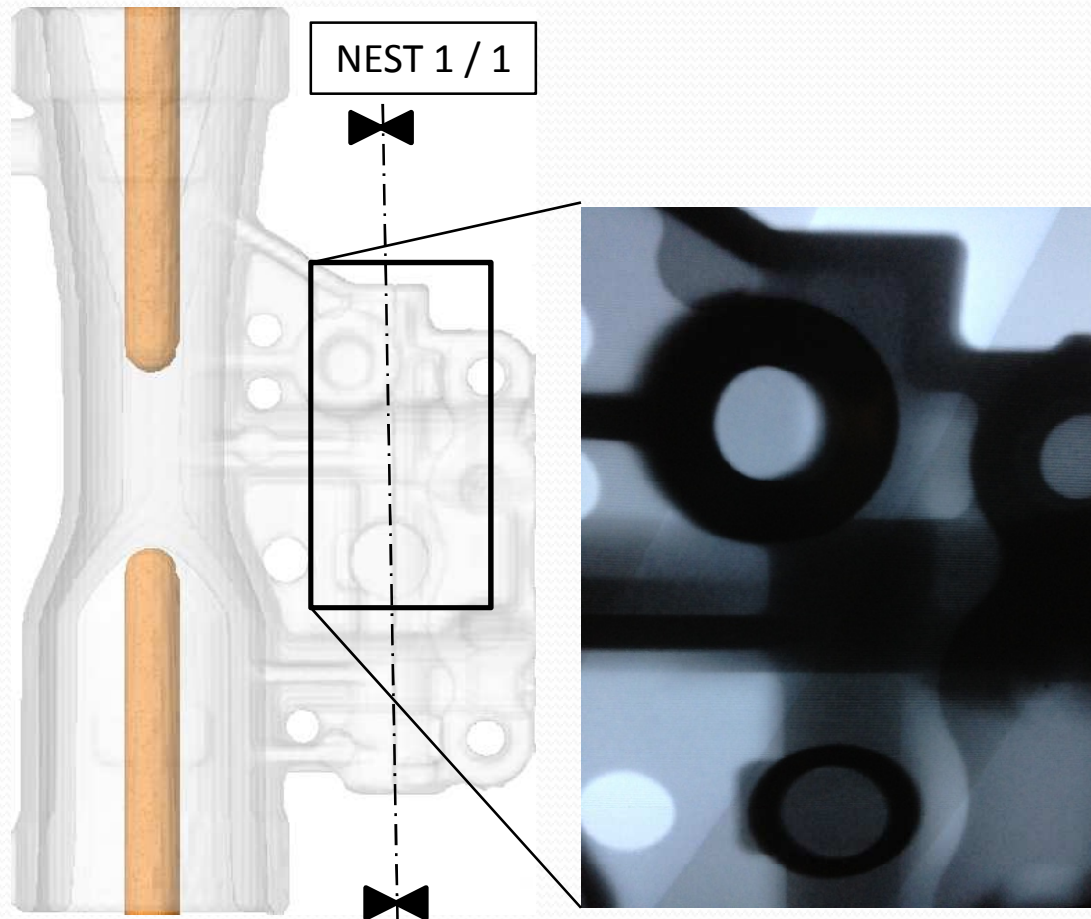# Solidification with large Squeeze

Time 7.930743 [s]
Iso surface "Liquid volume " [] value 0.500000
Color variable "Solid fraction " [N/A]

Solidification with large Squeeze

Time 11.018090 [s]
Iso surface 'Void volume ' [] value 0.500000

NEST 1 / 1

Solidification with large Squeeze

Comments:

- Both in results and in the cast we don't have any pore!
- Actually this configuration with large Squeeze pin is used successfully for production , with a scrap rate of 2% after the leakproofness test.

Conclusions

Shrinkage porosity model:

- We've seen a synergy between air entrapment and shrinkage porosity. Also in the cast is difficult to distingue one to the other. We purpose to add a scalar result "total porosity" that put together air entrapment and shrinkage (macro+micro).

- Another useful improvement could be to consider the influence of pressure on liquid density and thus on prediction of macro-shrinkage porosity using the solidification without flow model (such in a way it's now considered into the microporosity model).

Squeeze pin model:

- The model used is simply and fast. The effect of Squeeze depends by it's diameter and it's position, so it's useful for die design. But the limit of this model is that it doesn't consider the pressure and the time of intervent, two crucial aspects of squeeze pin set-up before production

Thanks to:

Brabant Alucast The Netherlands, Site Heijen