Using numerical simulations to optimize quality and costs in HPDC foundries

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EASTERN EUROPE Forum 2016

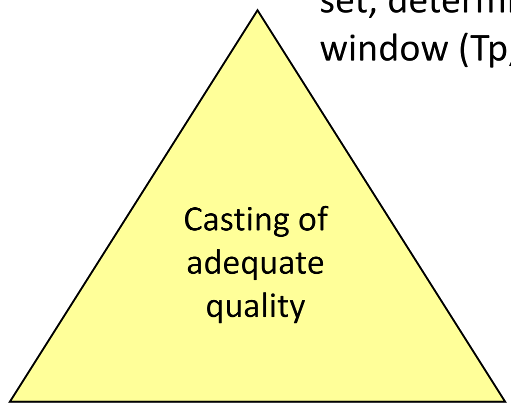
Prague, 15. November 2016

Casting technologies - basics

Casting, technology

- Permanent mold (GDC, GDTC, HPDC; LPDC)
- Sand or ceramic mold (GSC, INV)
  - Gravity (G, T)
  - **Pressure (HPDC**, LPDC)
  - Centrifugal (H, V)
  - Vacuum
  - Continues,…

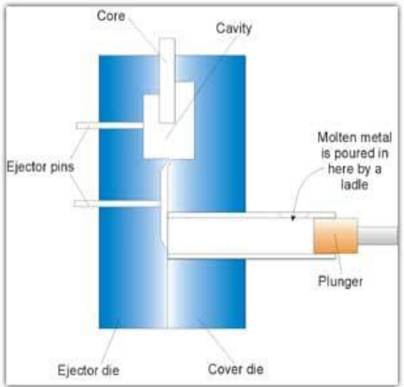
Casting technology
(selection of technology, calculation of gating system, selection of cold chamber set, determining the technological process window (Tp, ...))



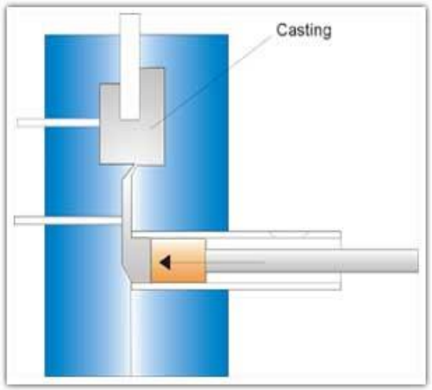
Alloy
(raw material, degree of recycling, melt treatment, way of pouring, Chemical composition, NP)

Type of the mould
(selection of different hot working toll steel, W-alloy, heat treatment, properties)

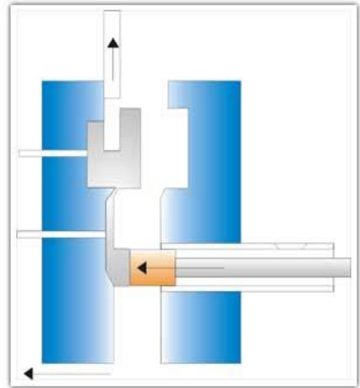
HPDC – basics



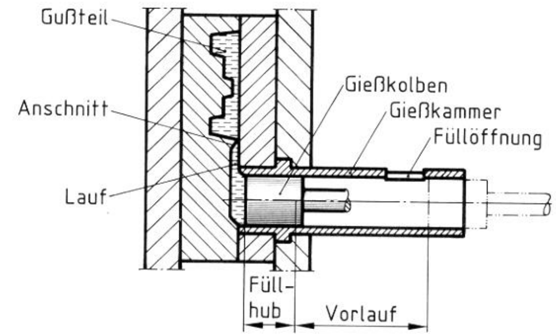
1 st phase
piston motion

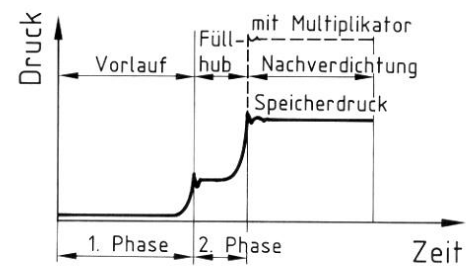


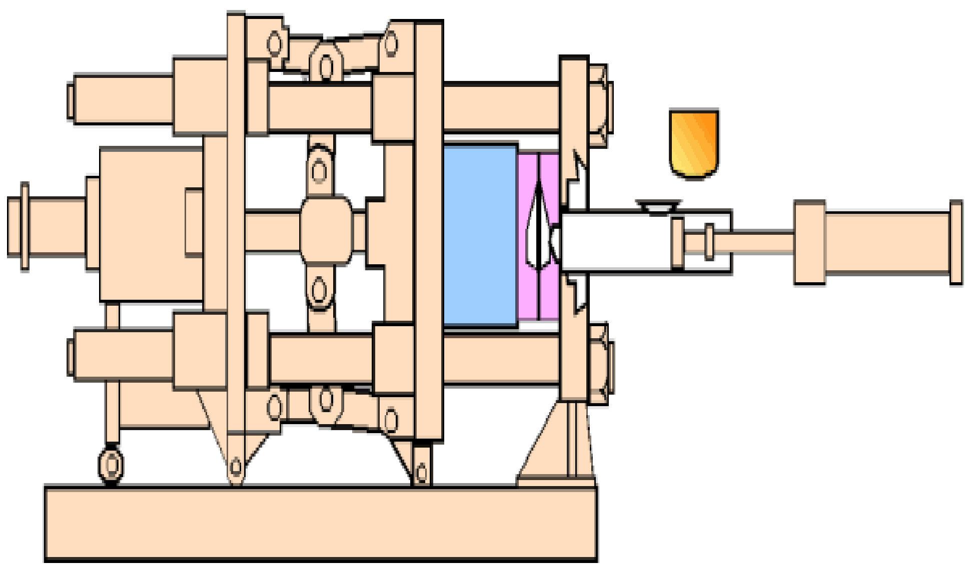
2 nd phase
die cavity filling - shot



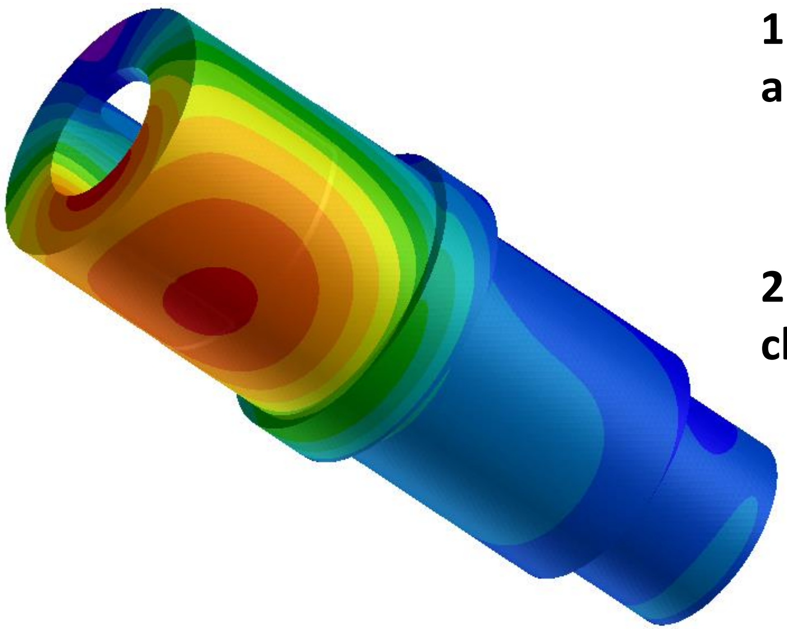
3 rd phase
high pressure







HPDC- Cold chamber

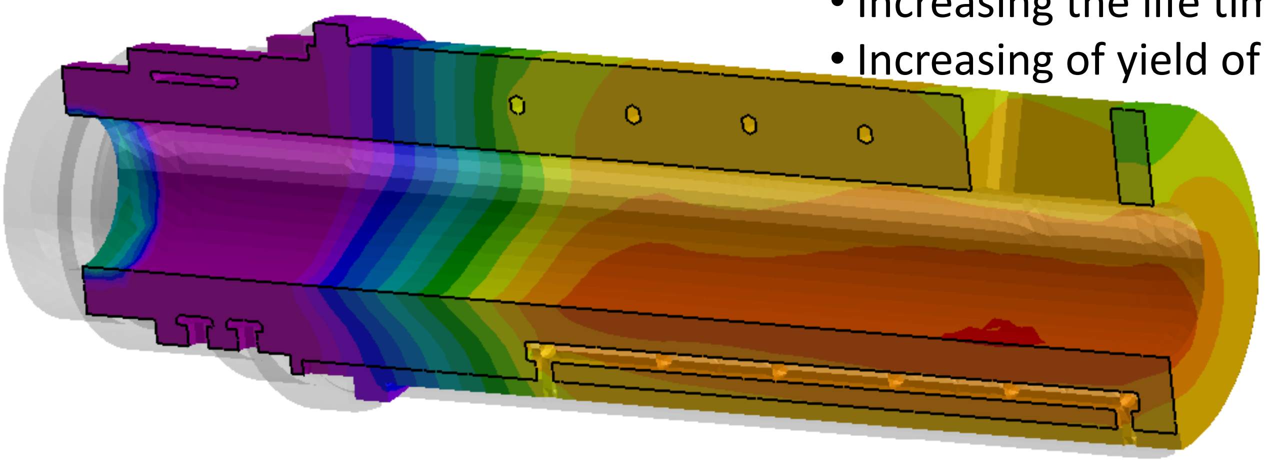


1. What is the main problem to pour the molten Al alloy?

- Solubility of iron in Al alloys
- Cycle time

2. How to increase the efficiency of working the cold chamber?

- Decreasing the solidification of molten alloy in chamber (time for phase I and II has to be short, Temperature of chamber high) This cause the new situation which is connect with time for shot (II phase)
- Increasing the life time of sleeve and piston
- Increasing of yield of molten metal

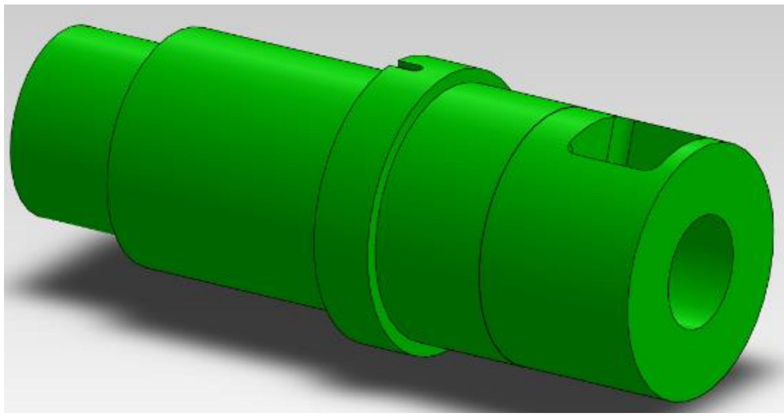


HPDC- Cold chamber

What is the main problem to prepare the accurate calculation of casting process for HPDC?

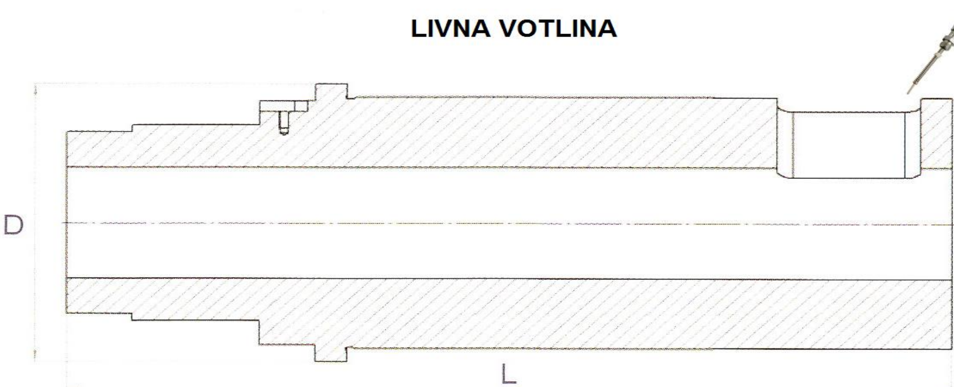
- It is necessary to choose and/or calculate or measure the real material properties:
  T_l, T_s, f_s-f(T), ρ-f(T), ŋ_f(T), E, ..
- The calculation must start in the phase 0
- The description of phase I to III is required for accuracy
- The boundary conditions has to be set properly (T, HTC, t)
- The geometry should be describe with fine mash
- Technological process window should reflect the real (experimental) data input

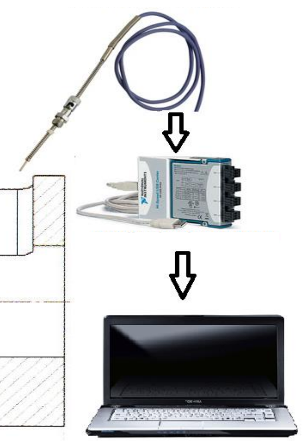
HPDC- Cold chamber

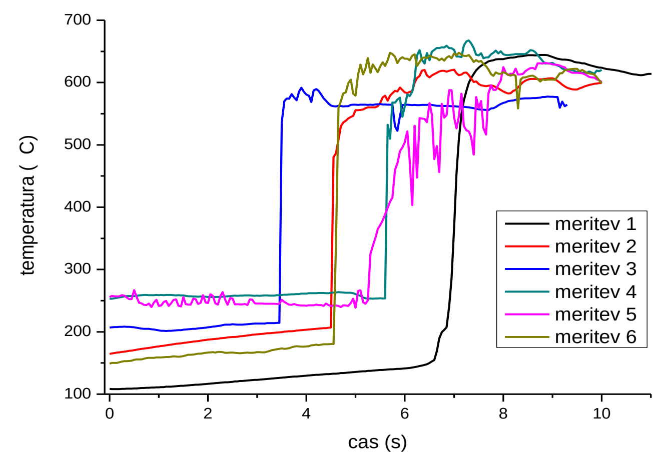


Calculation of melt flow and melt temperature drop from furnace to casting chamber

Measurements of melt temperature in the casting chamber before the first stage starts



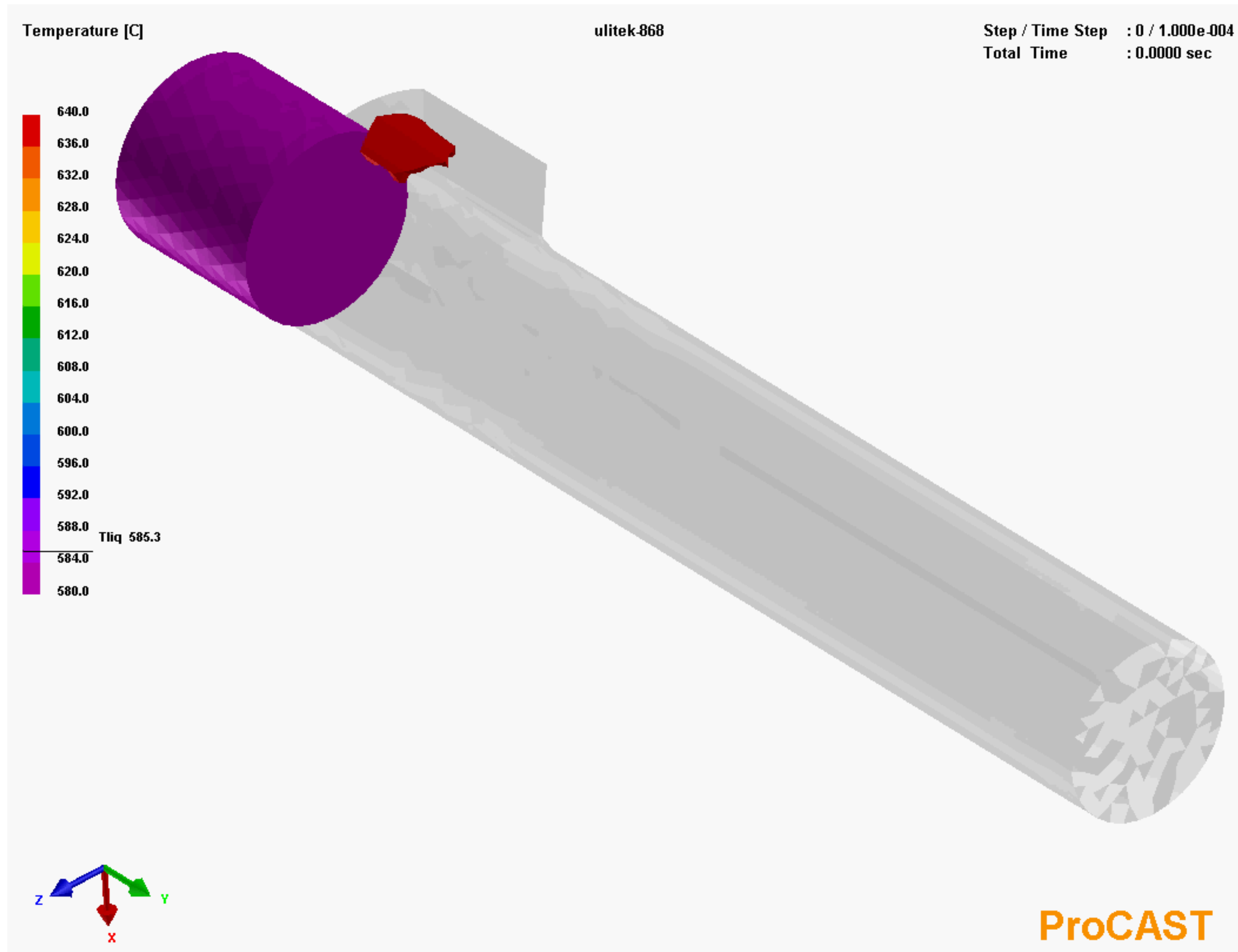




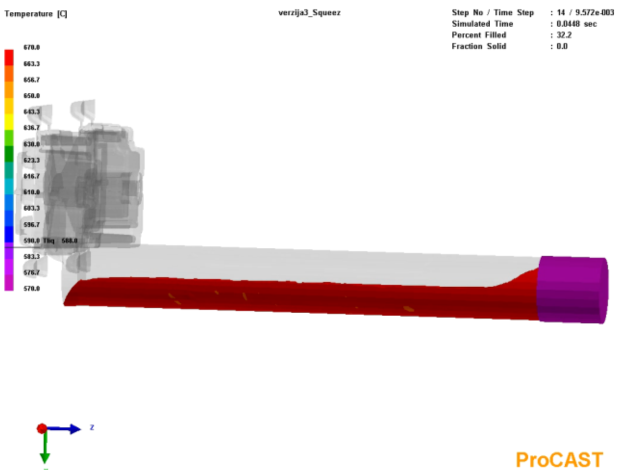
Simulation of melt flow and melt temperature drop from furnace to casting chamber

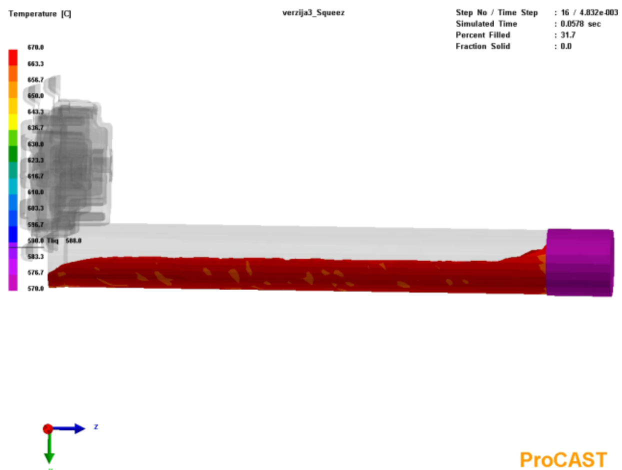
- Filing of casting chamber calculation compered with experimentaly determined temperatures.

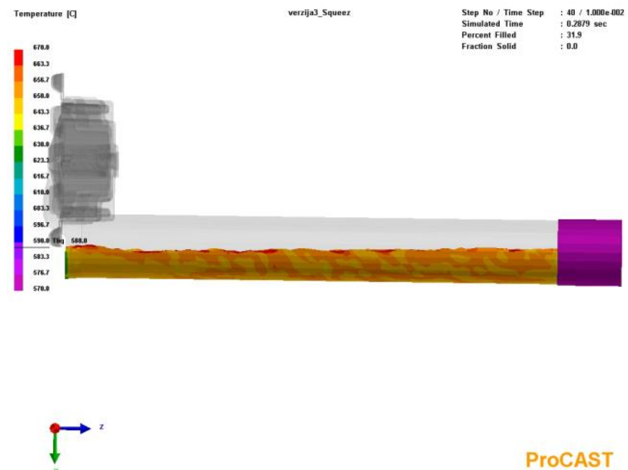
- Temperature in the chamber before the shot at 650 °C, temperature of the melt in the casting furnace 677 °C ⇒ temperature drop 20 - 30°C.



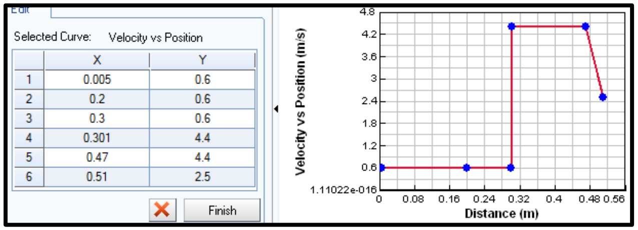
Example: Optimization of phase I and II





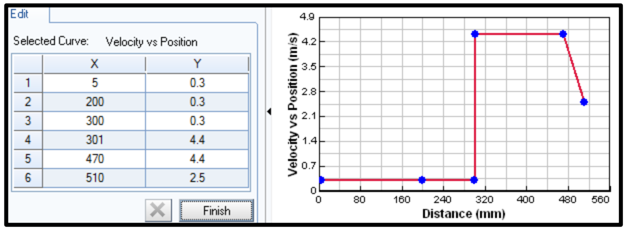


V1= 0,6 m/s



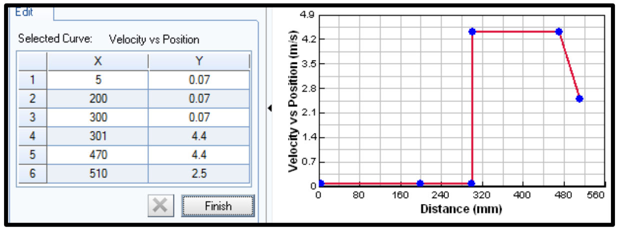
	X	Y
1	0.005	0.6
2	0.2	0.6
3	0.3	0.6
4	0.301	4.4
5	0.47	4.4
6	0.51	2.5

V1= 0,3 m/s



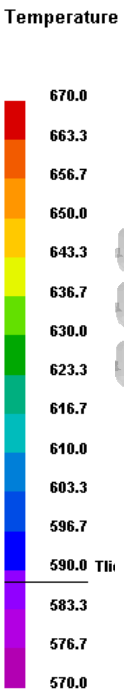
	X	Y
1	5	0.3
2	200	0.3
3	300	0.3
4	301	4.4
5	470	4.4
6	510	2.5

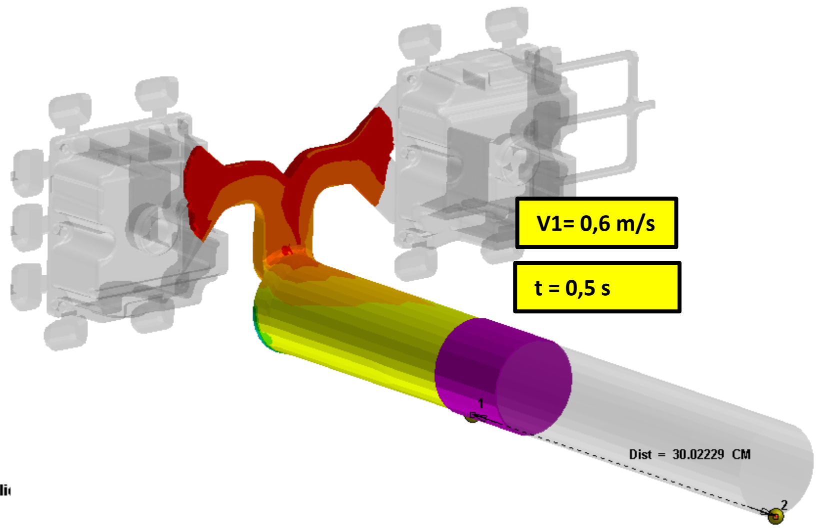
V1= 0,07 m/s



	X	Y
1	5	0.07
2	200	0.07
3	300	0.07
4	301	4.4
5	470	4.4
6	510	2.5

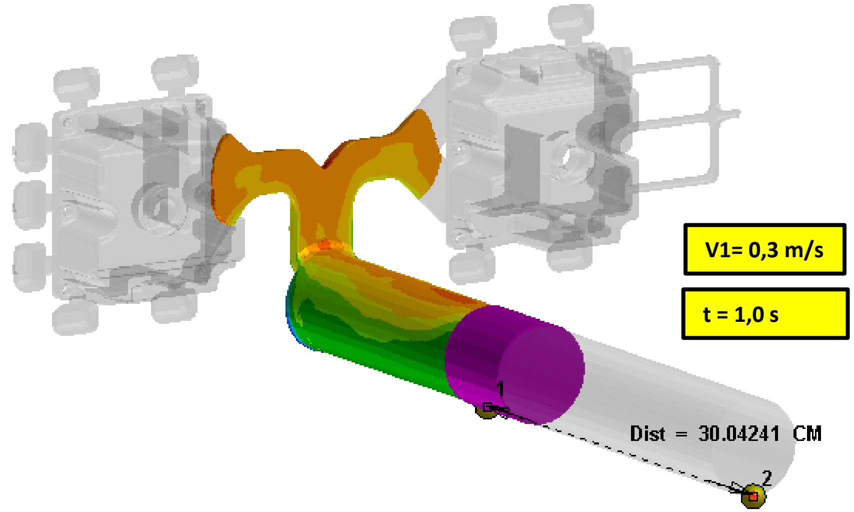
Example: Cooling of molten metal in the cold chamber in the first phase

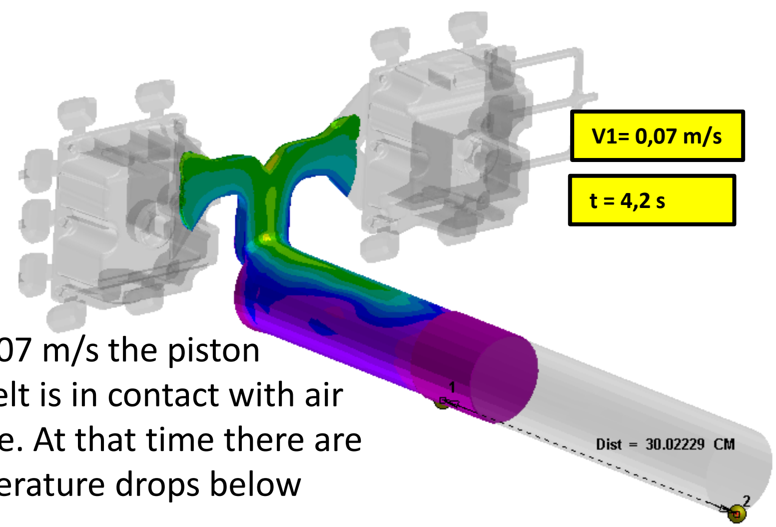




When the speed of the first phase is 0,6 m/s we avoid hold-wave. The time from start of the piston movement to switching to the second phase is 0,5 s. In this time the cooling of the melt in the casting chamber is minimal.

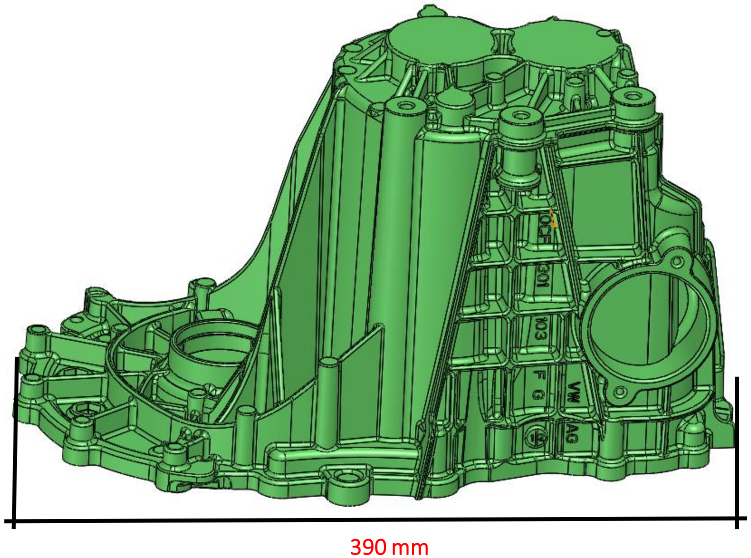
When the speed of the first phase is 0,3 m/s hold-wave accures.





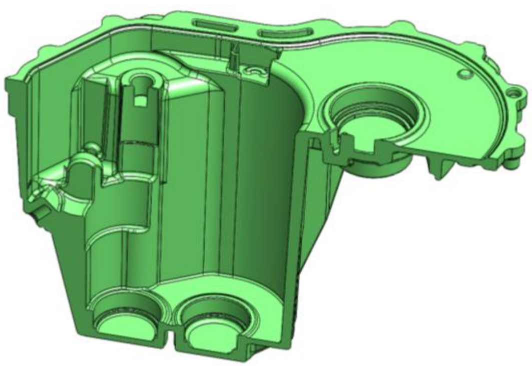
When the speed of the first stage is 0,07 m/s the piston travels 4,2 s during all this time the melt is in contact with air and causing large oxides on the surface. At that time there are areas in the chamber where the temperature drops below liquidous temperature.

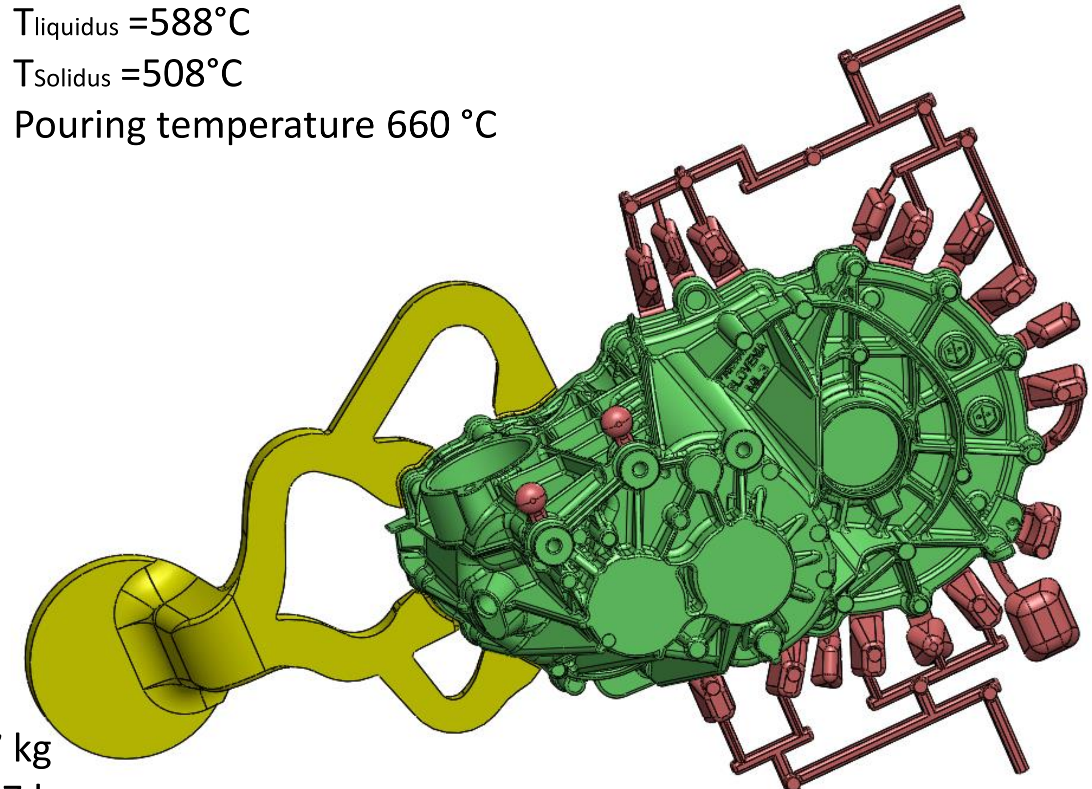
Example: gearbox casting – tool cooling system



Investigated geometry of gearbox casting and their gating system

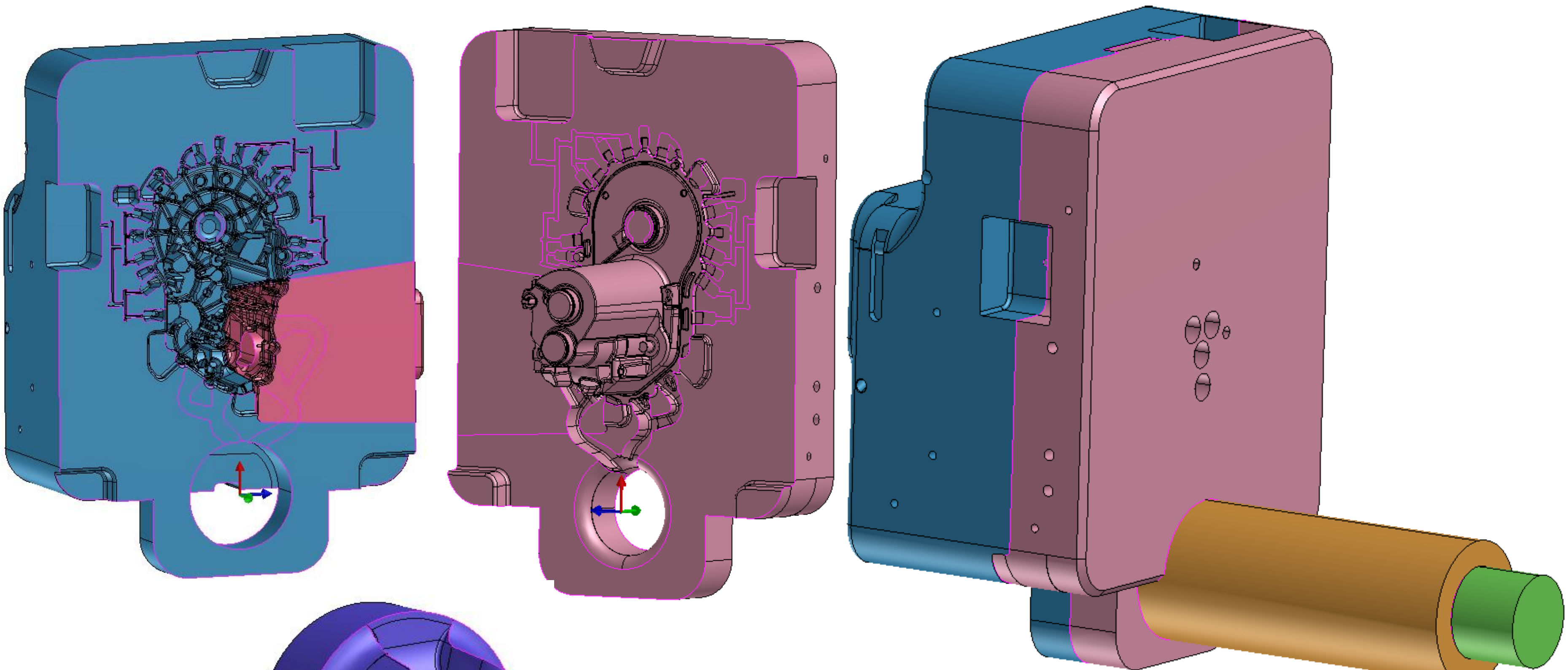
Alloy: AlSi9Cu3
$T_{liquidus}$ =588°C
$T_{Solidus}$ =508°C
Pouring temperature 660 °C

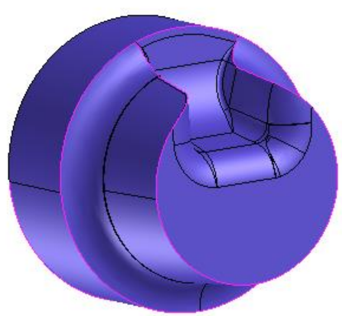




Bruto weight of casting: 7 kg
Neto weight of casting: 4,7 kg

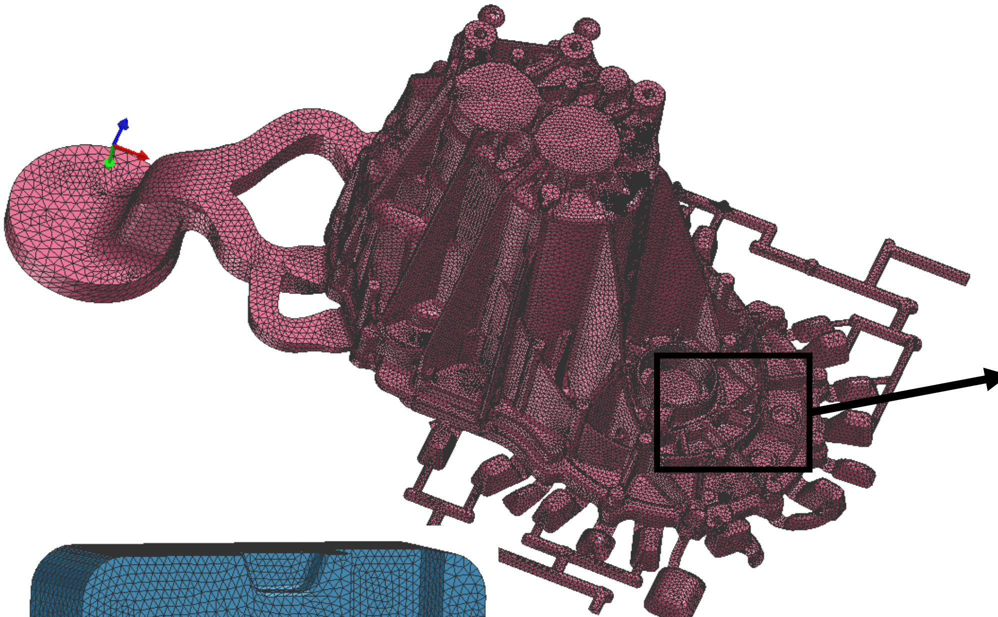
Geometry of tool assembled with cold chamber set

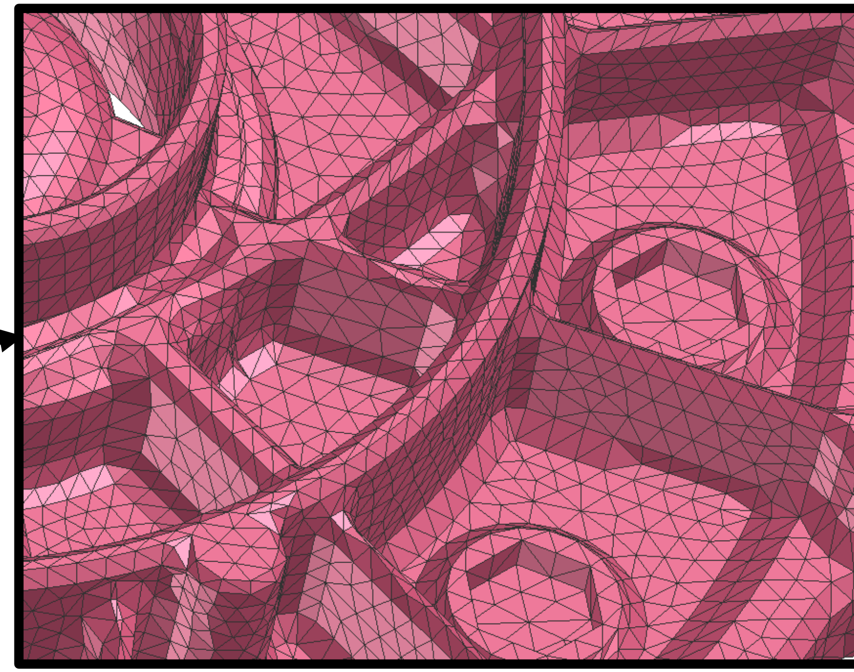


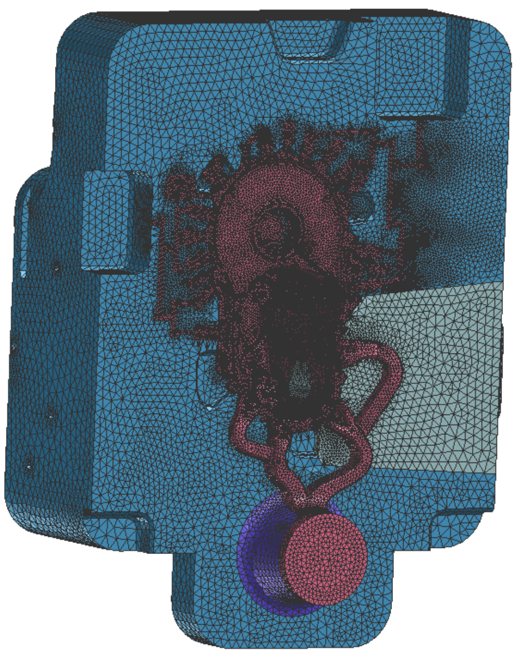


Casting distributor

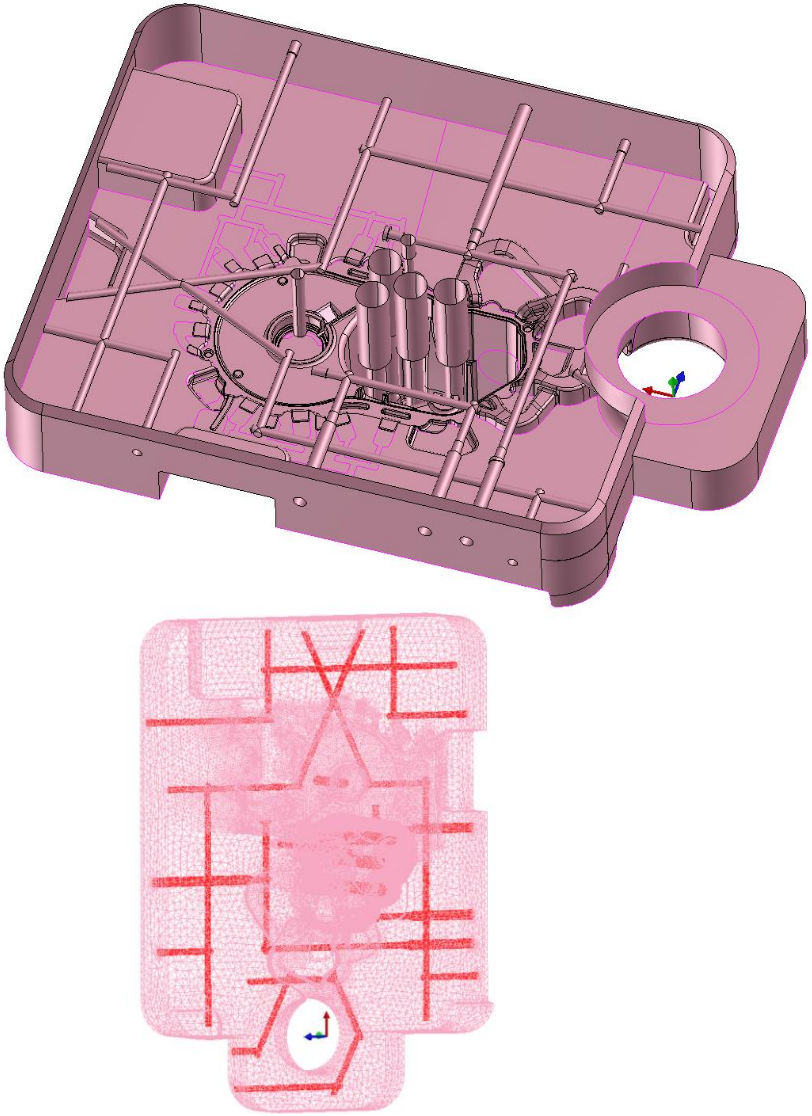
Surface mash for FEM analyses



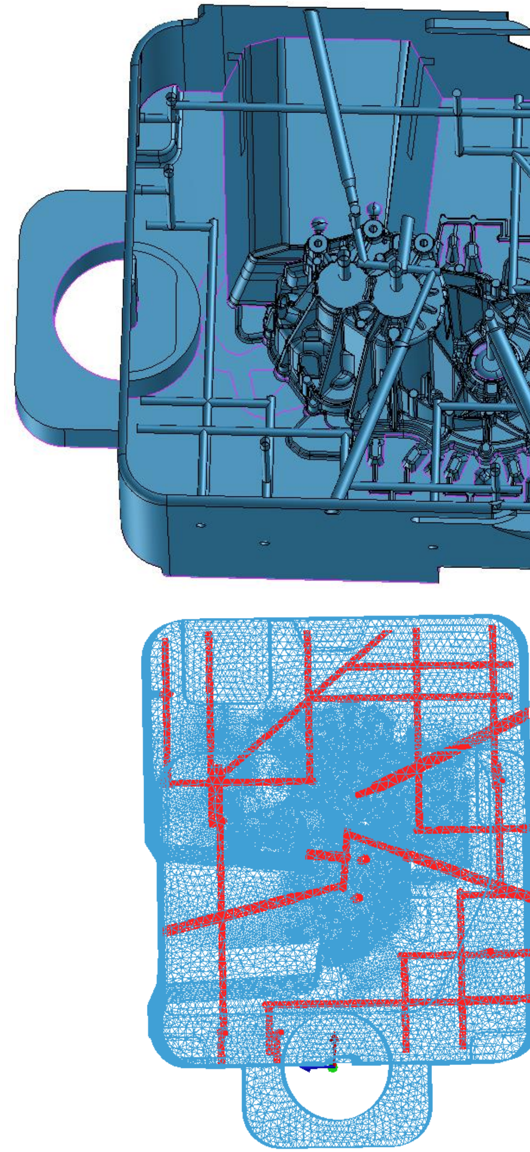




The layout of cooling and heating channels

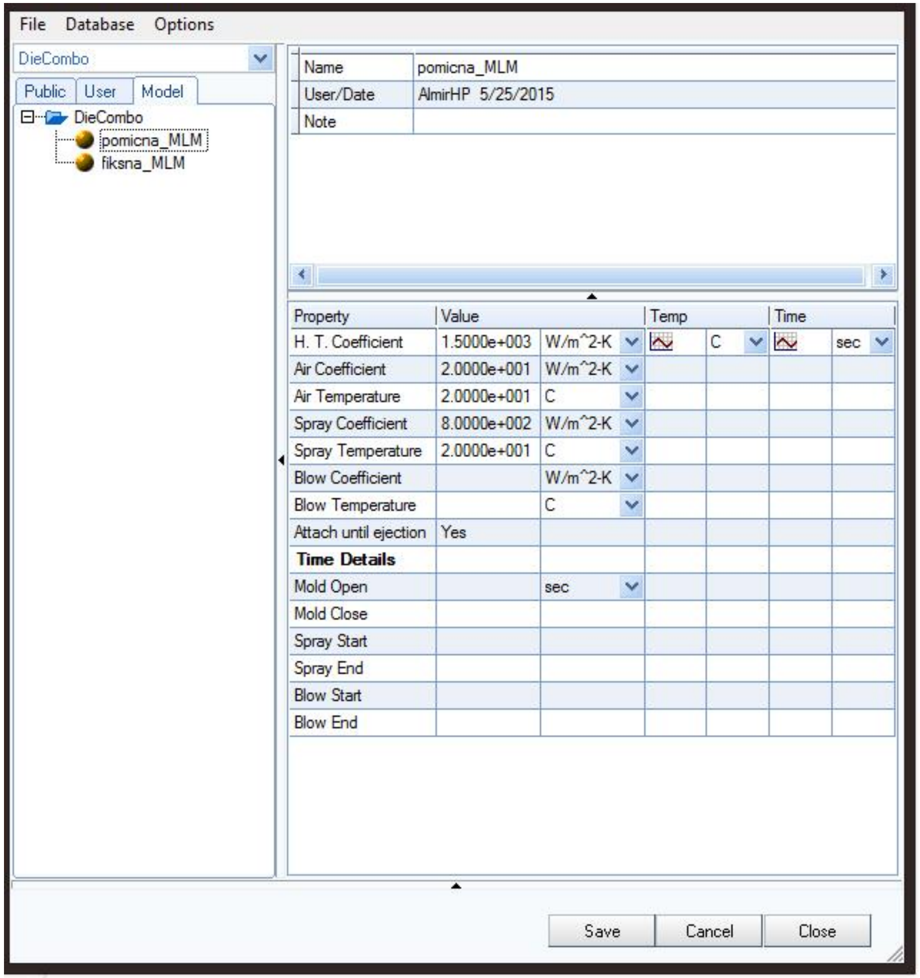


Fixed side of die



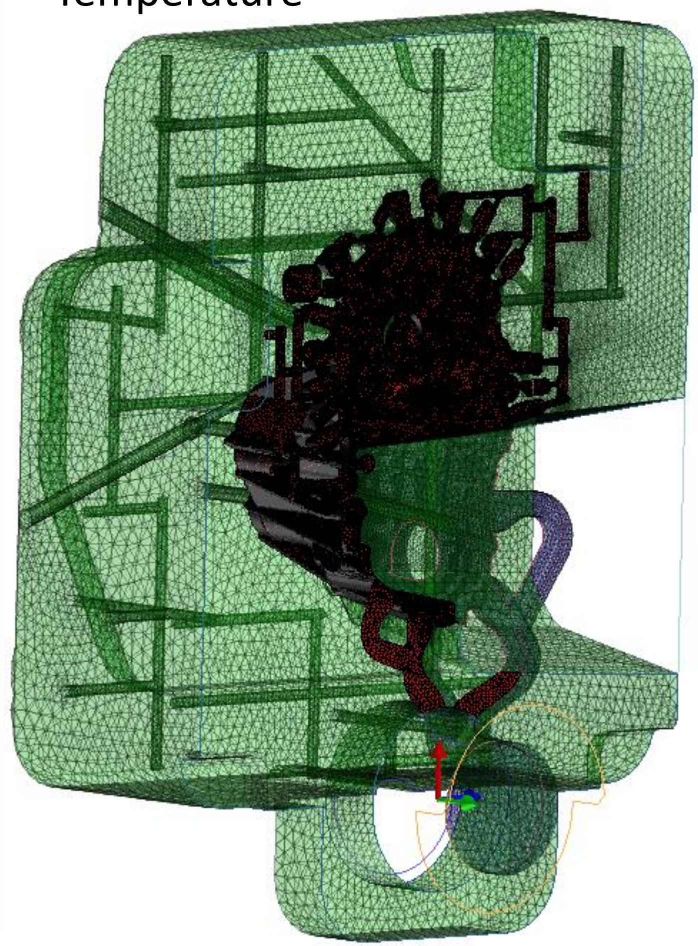
Moveable side of die

Boundary conditions

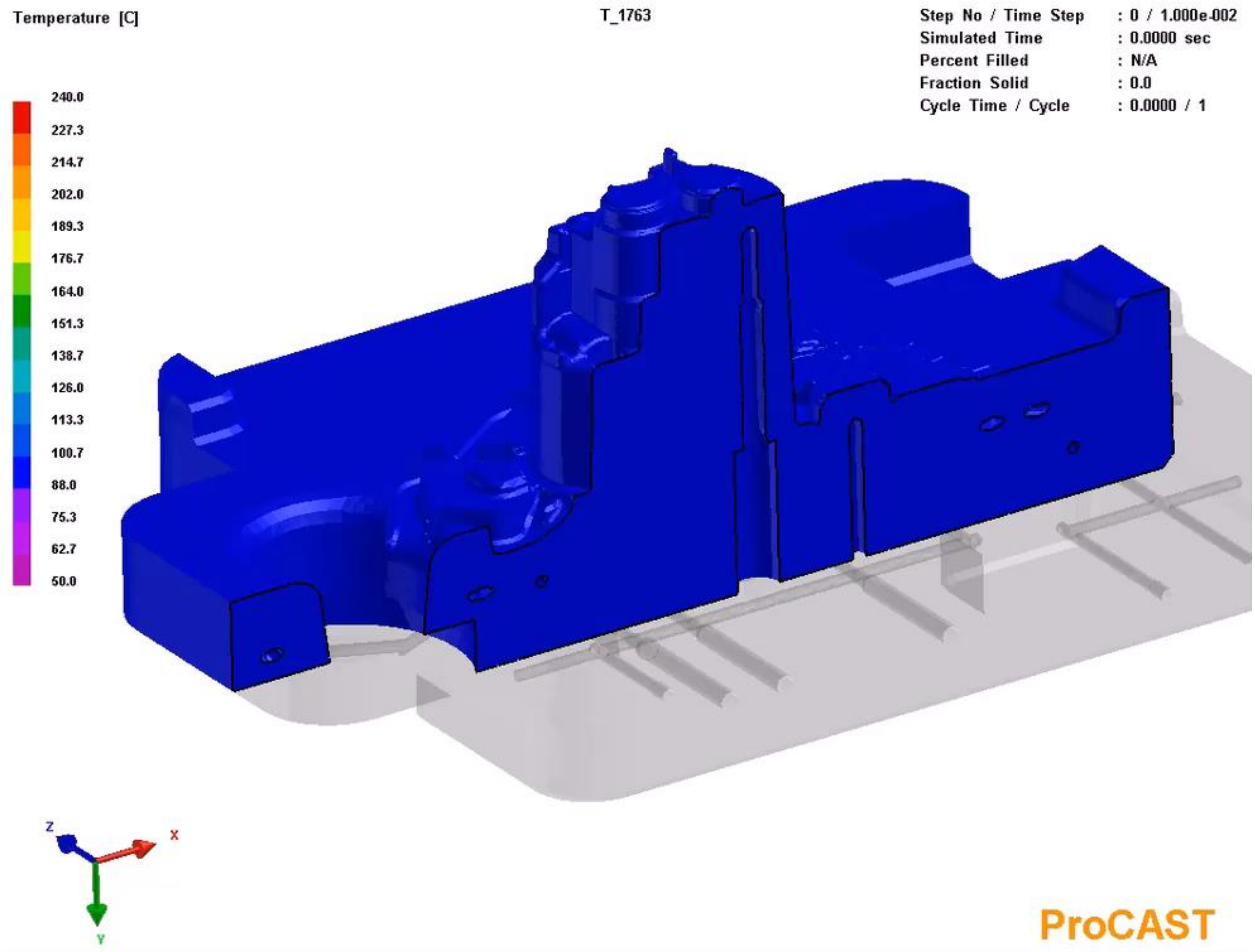


Heat transfer condition

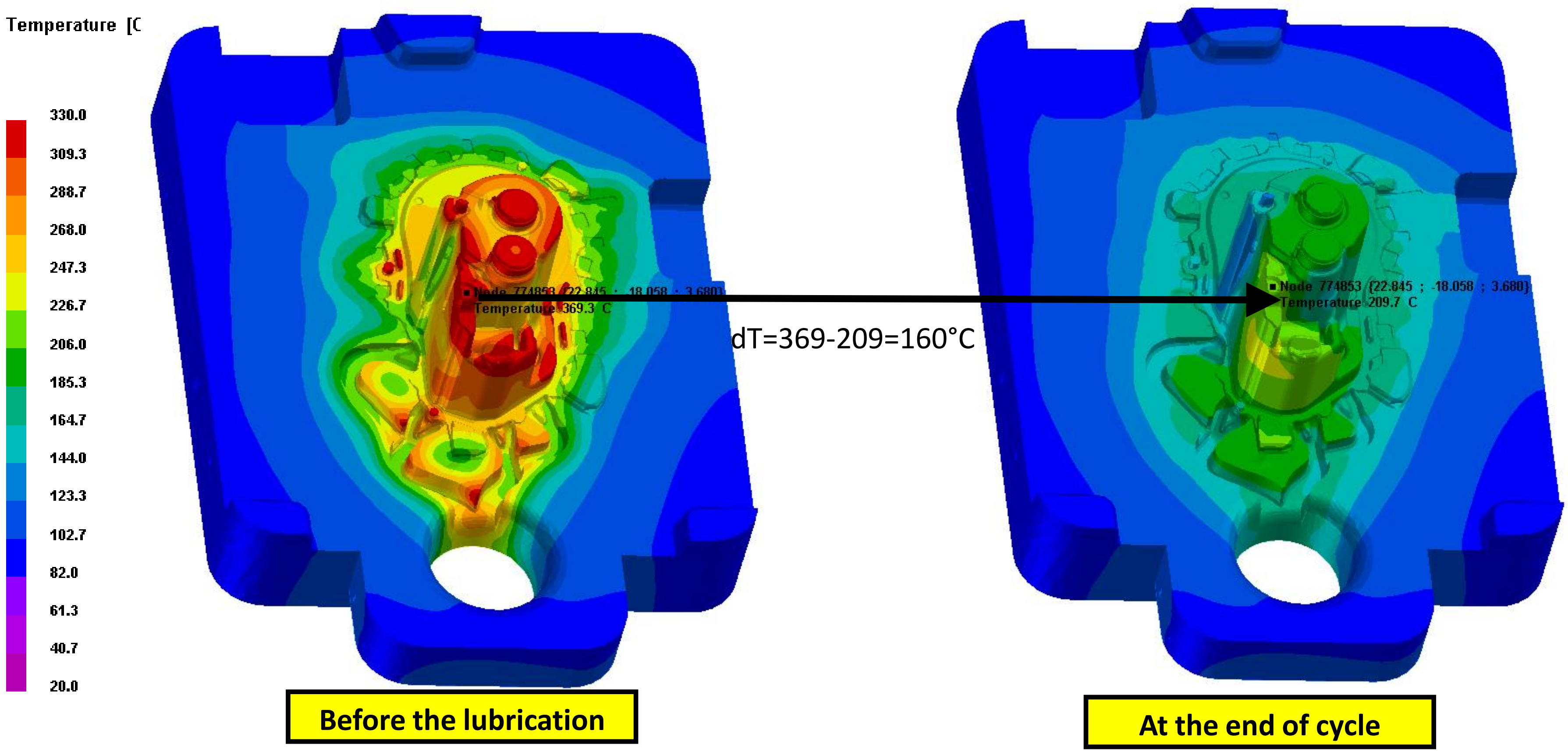
Temperature



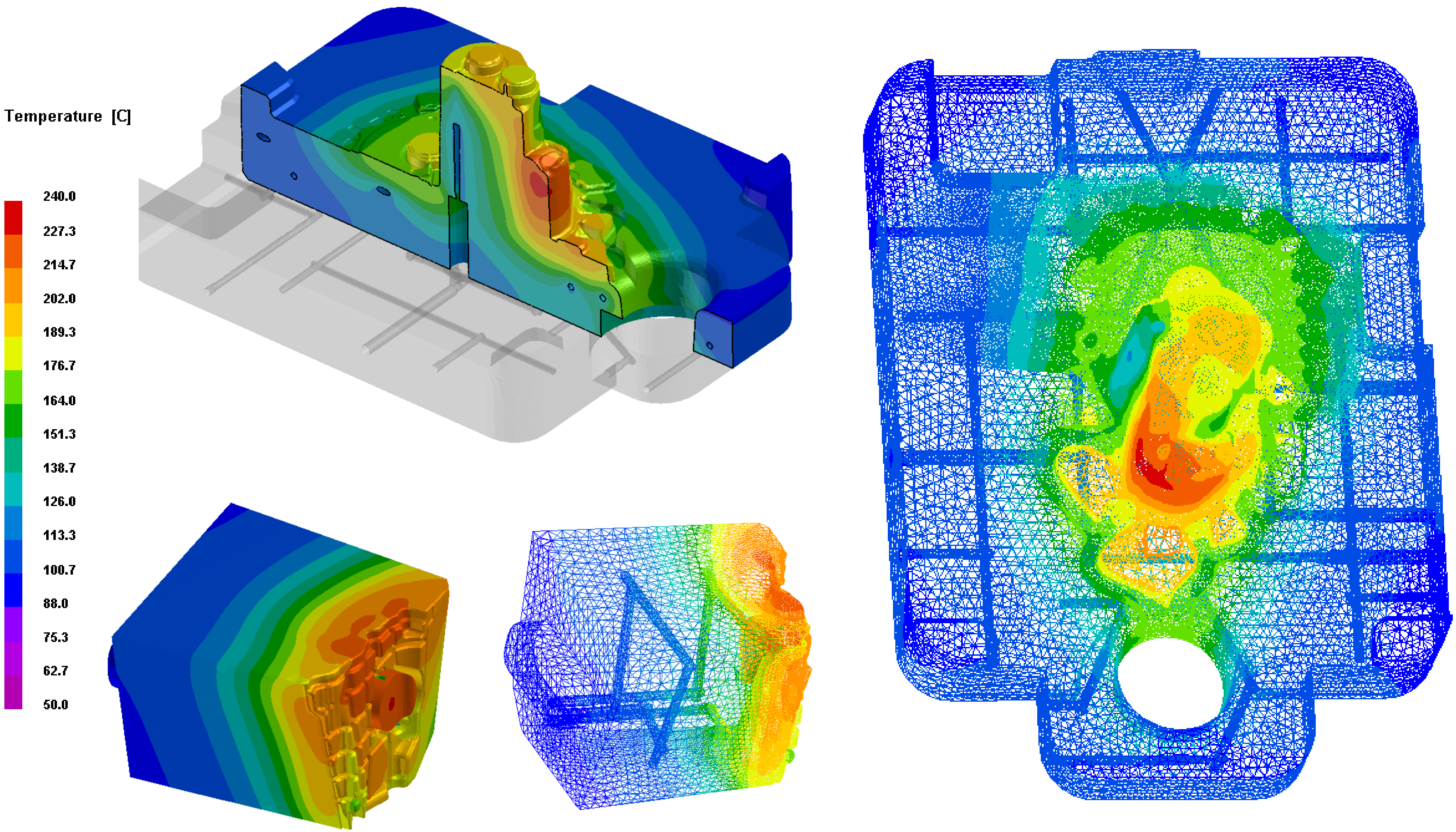
Cycling calculation, fixed side of the toll



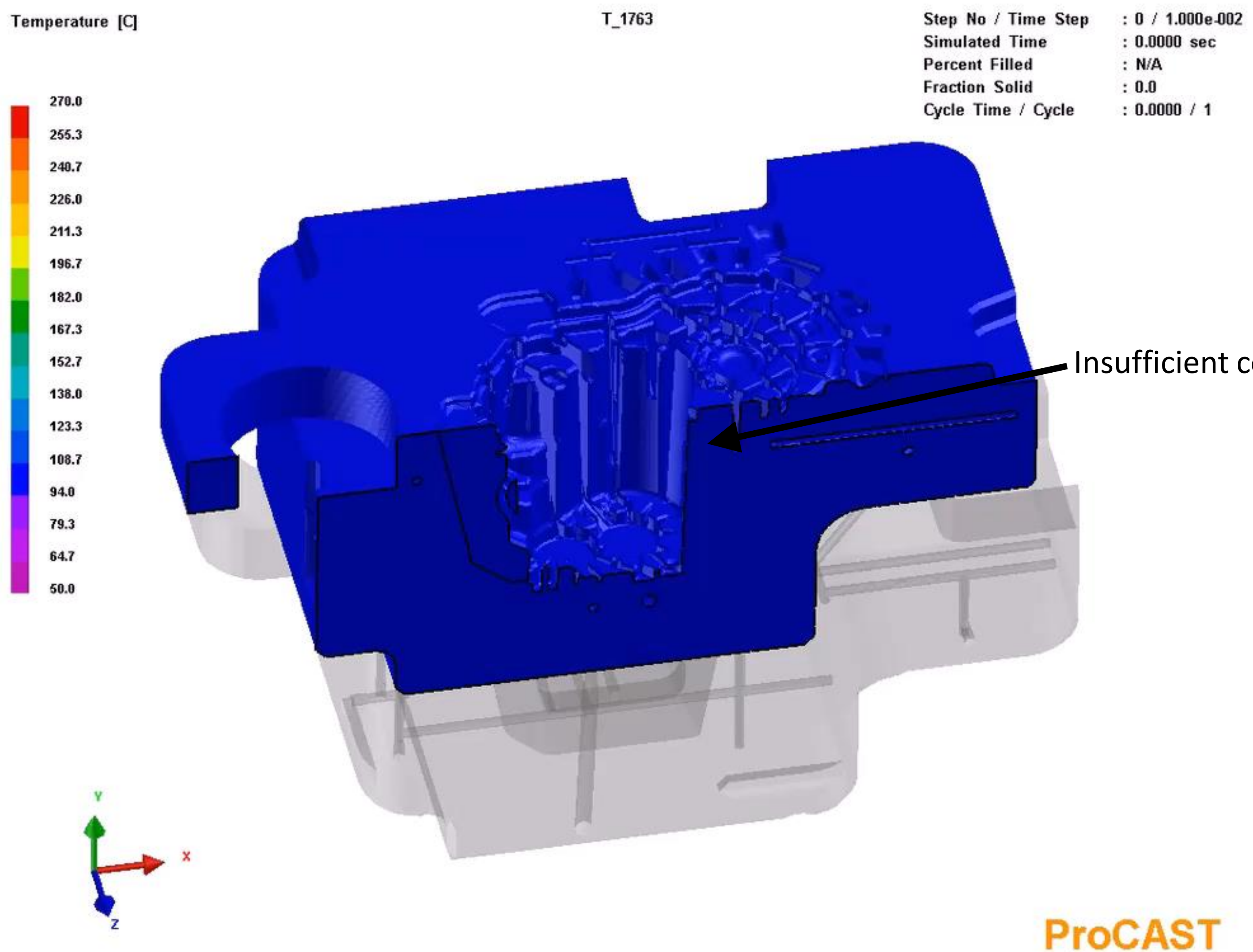
Cycling calculation on fixed side of die after 10 cycle



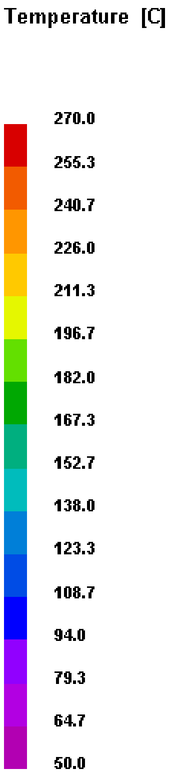
Cycling calculation on fixed side of die after 10 cycle – steady state temperature field

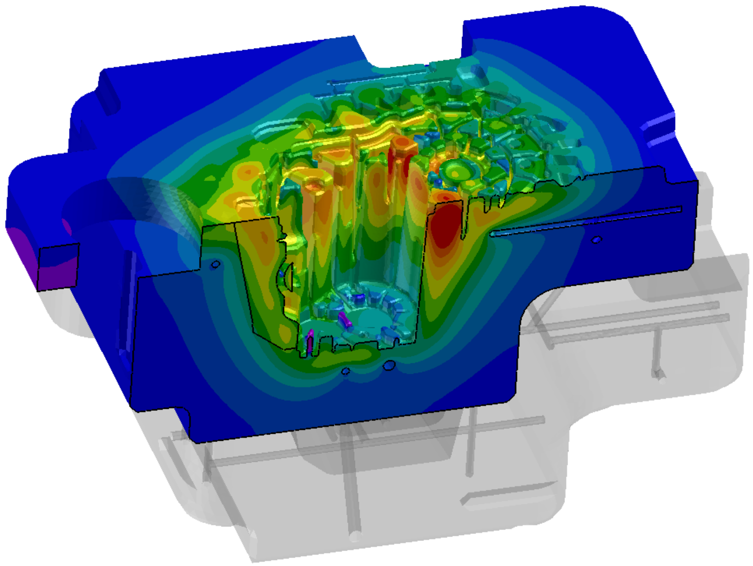


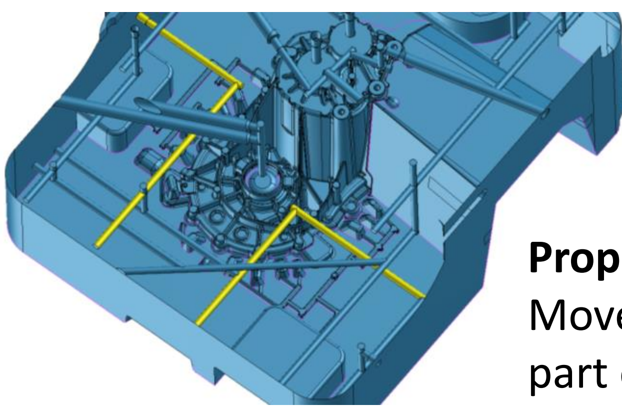
Cycling calculation on moveable side of die for 10 cycles



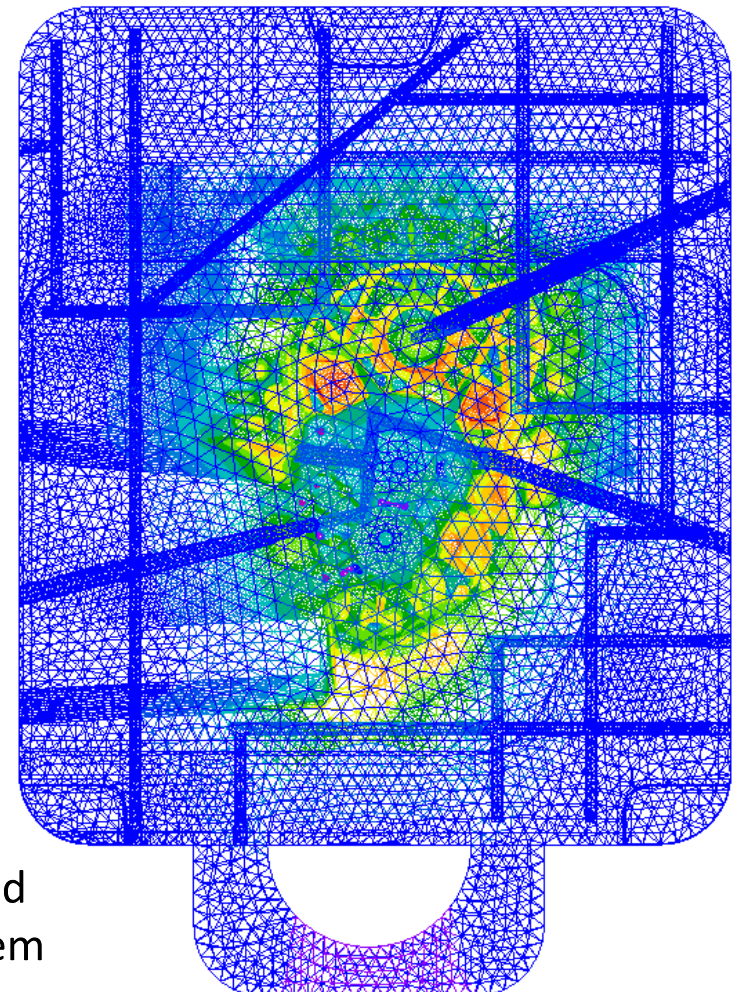
Cycling calculation on moveable side of die for 10 cycles - steady state temperature field



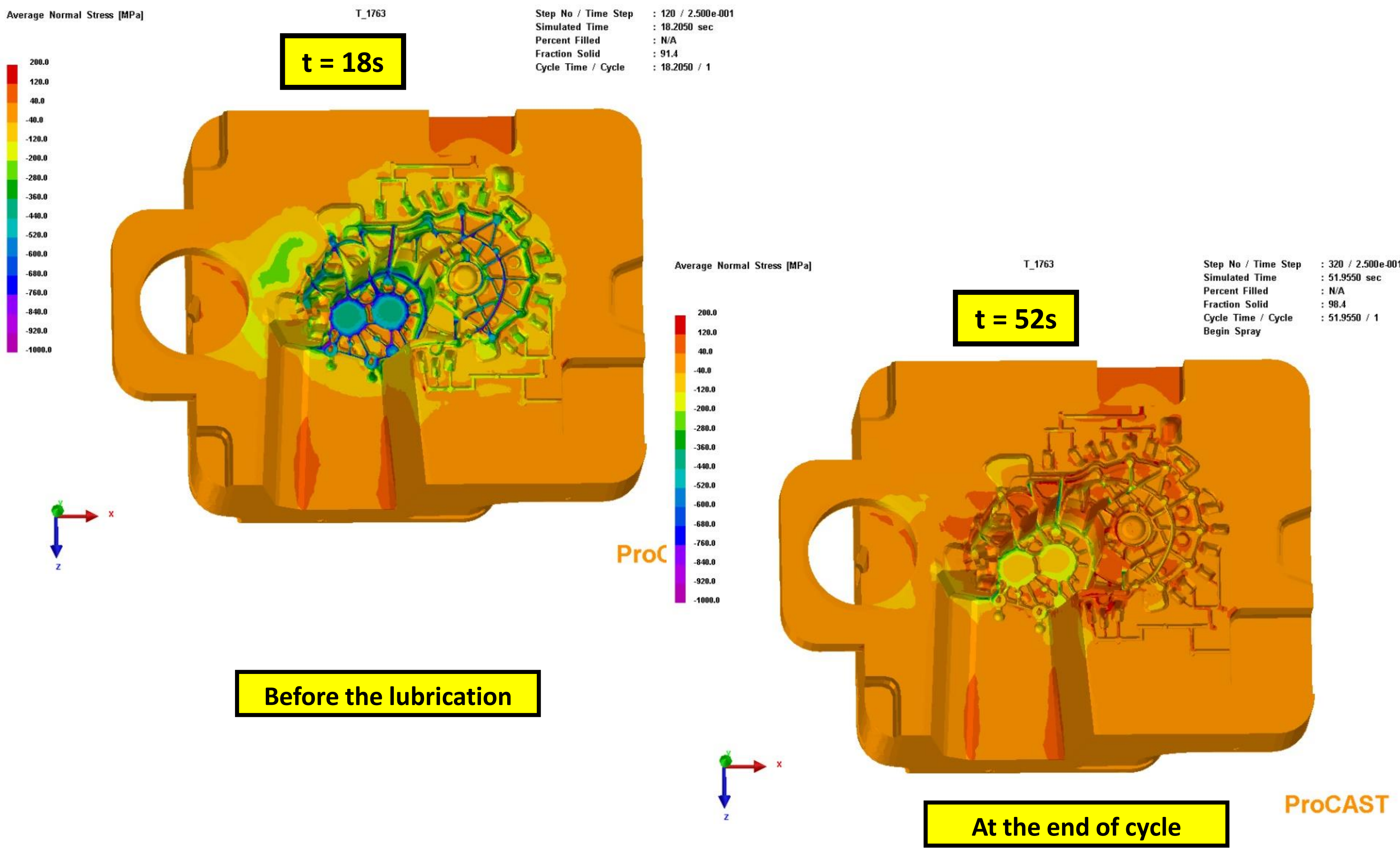




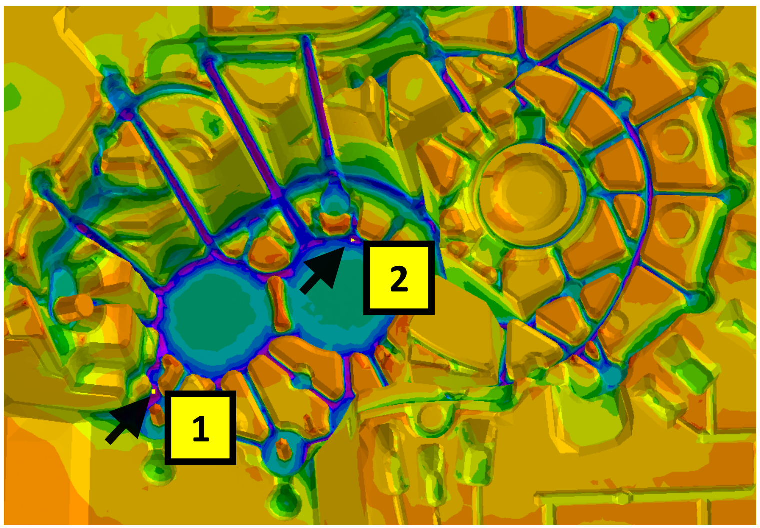
Proposed solution
Move closer selected part of cooling system to the overheated area of toll

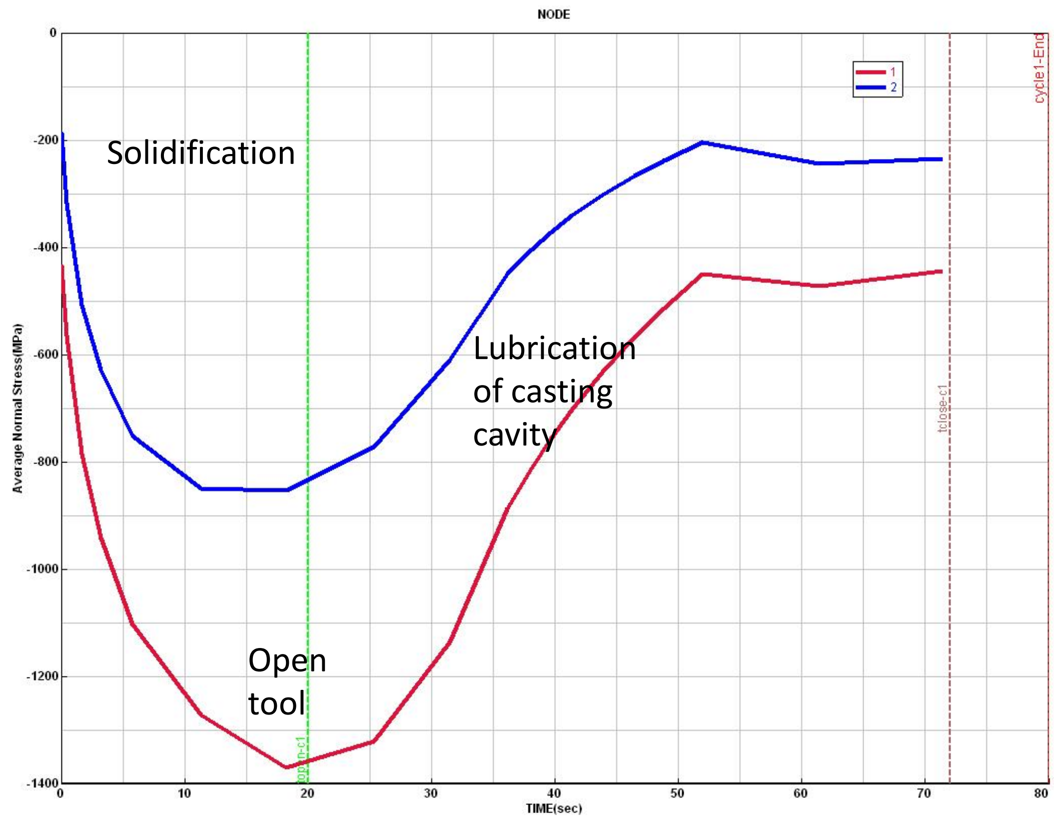


The calculation of normal stresses in the tool

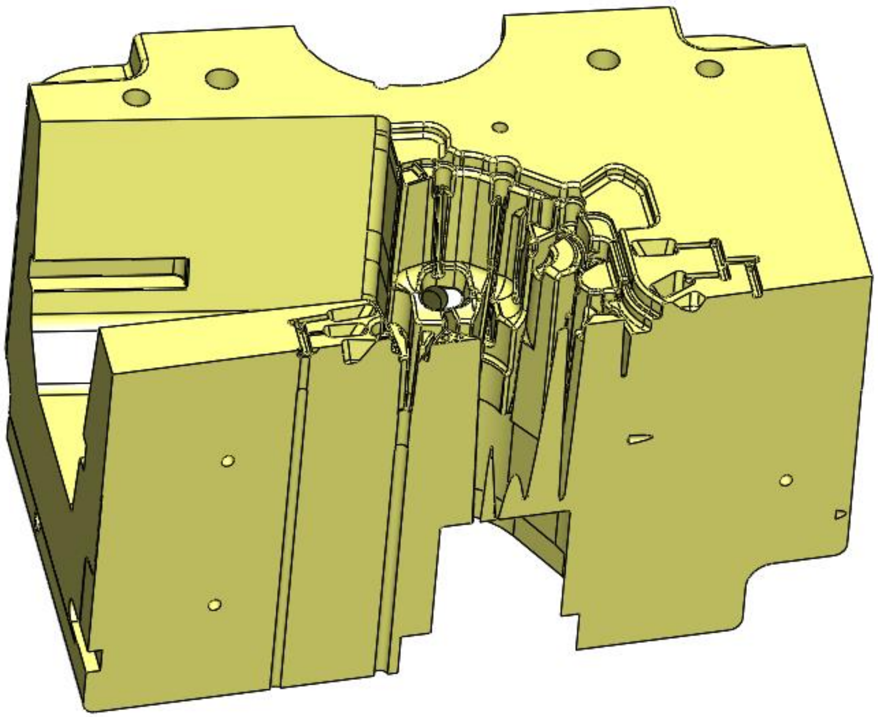


The calculation of normal stresses in the tool – stable side of the tool

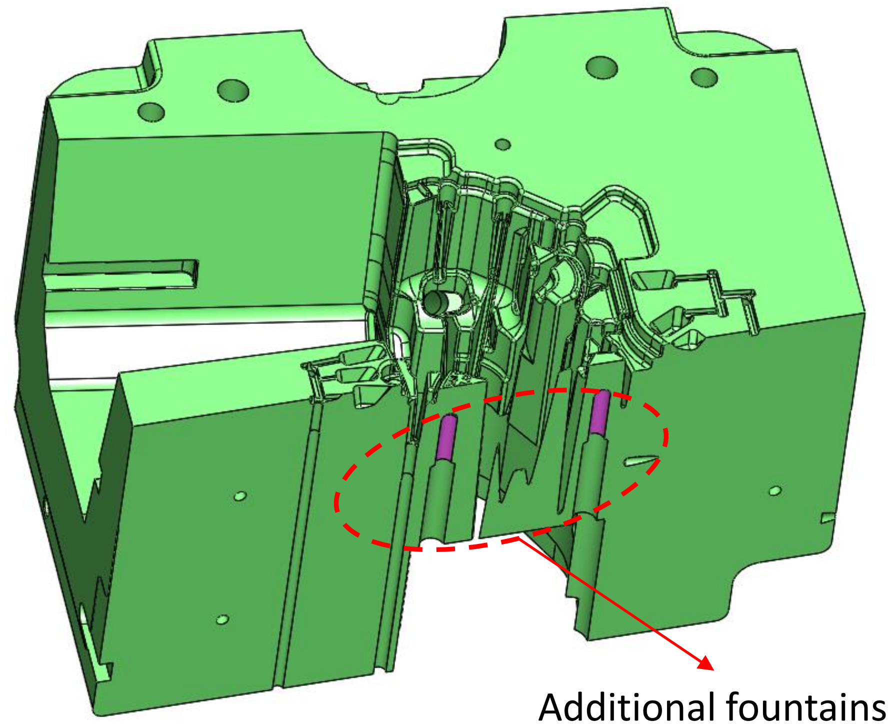




Optimization of the movble side of the tool

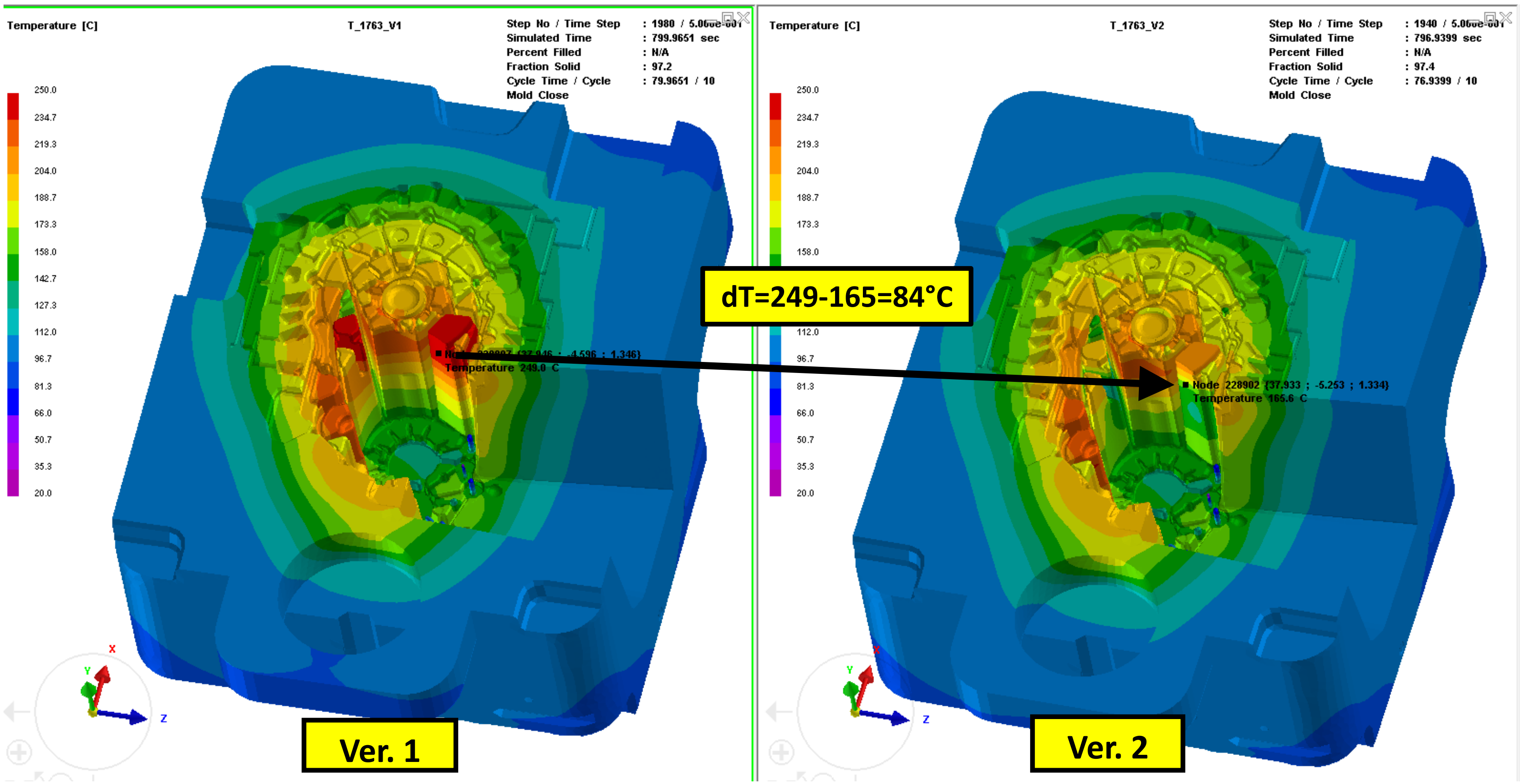


Ver. 1



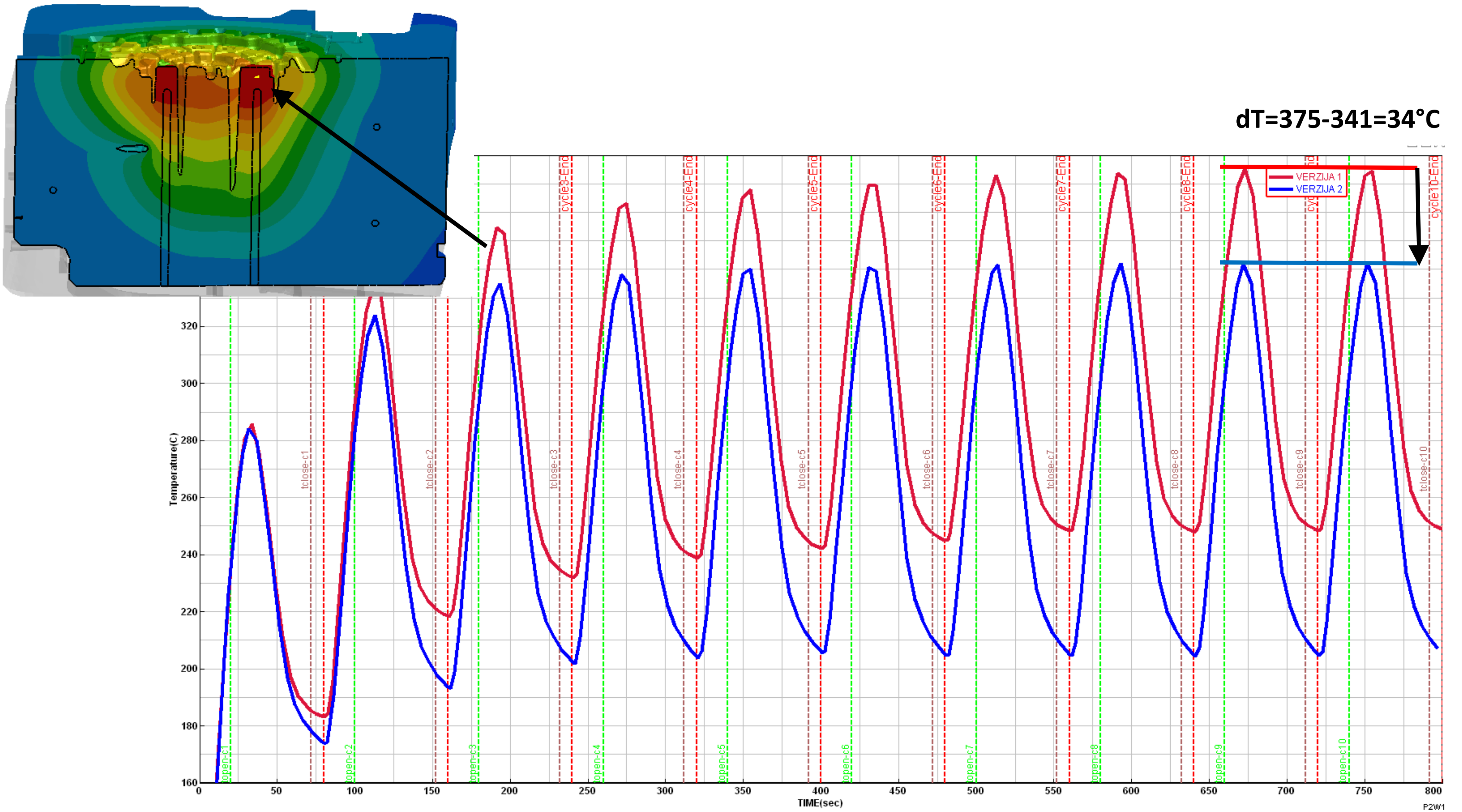
Ver. 2

The calculation of the temperature field after 10th cycle

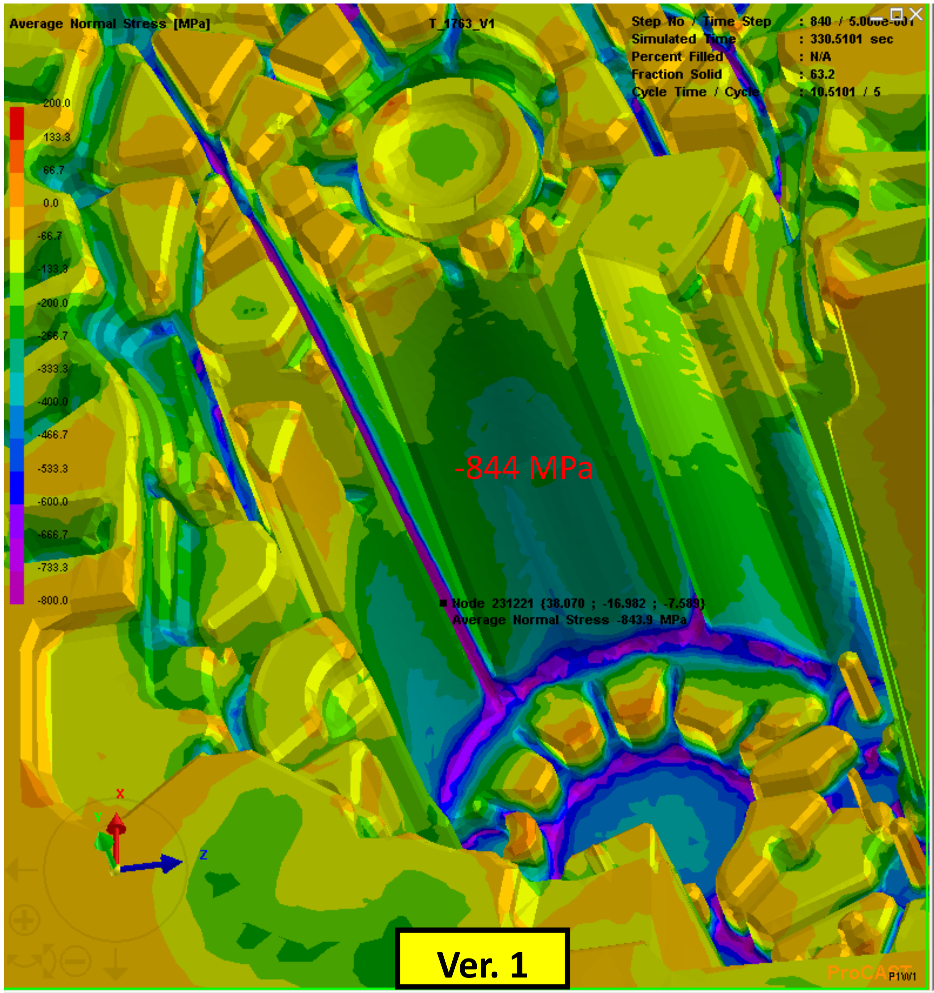


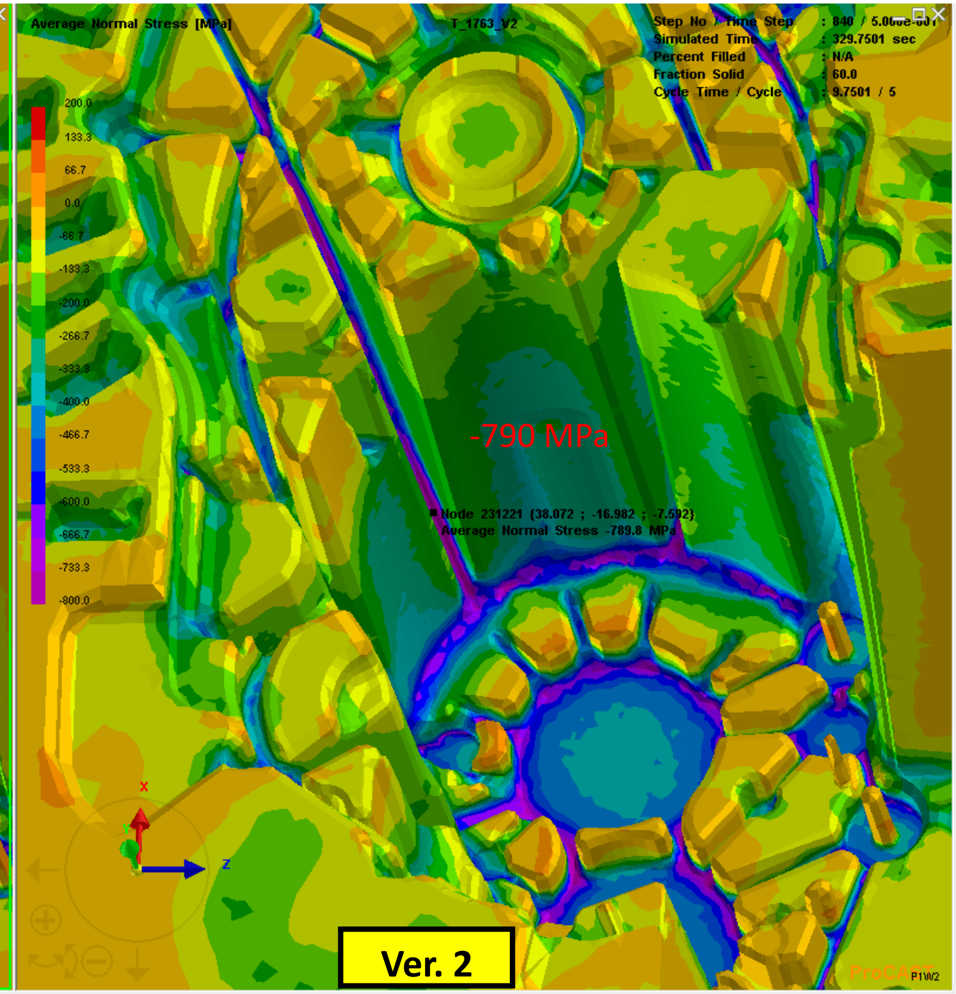
Calculation of temperature for variant 1 and 2

dT=375-341=34°C

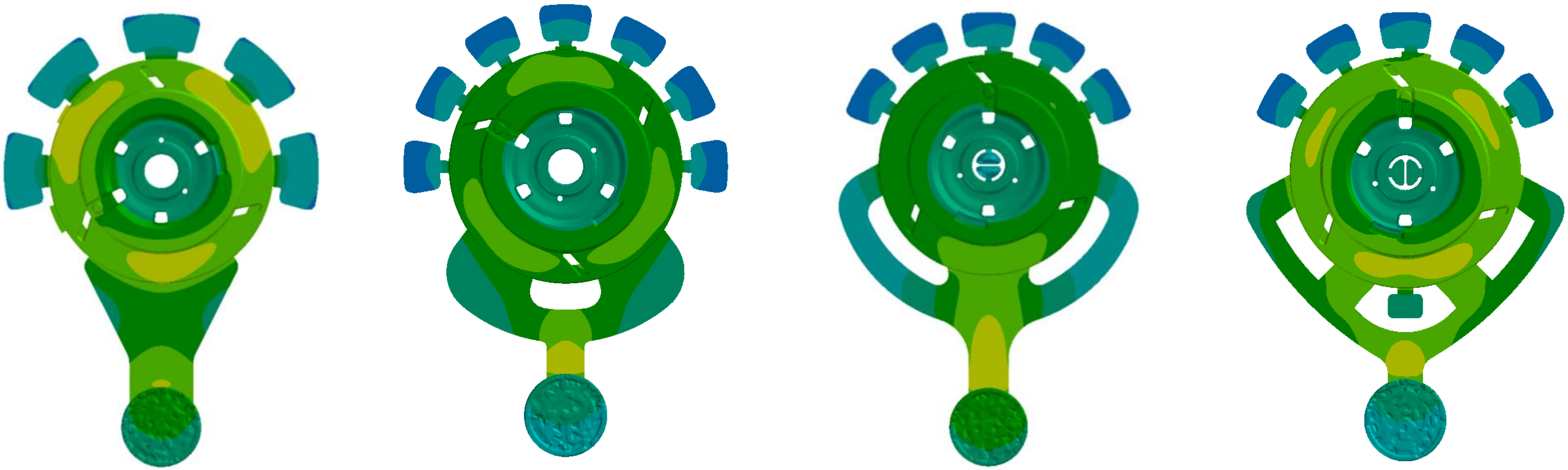


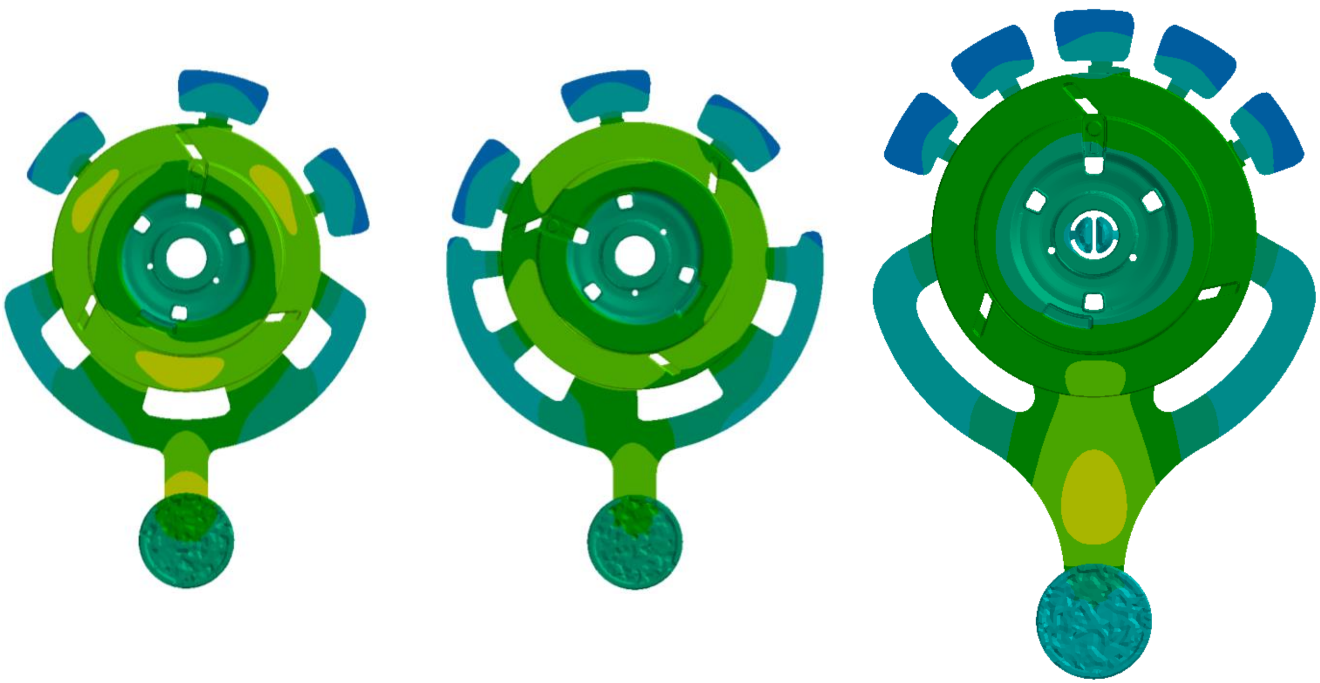
The calculation of normal stresses in the tool

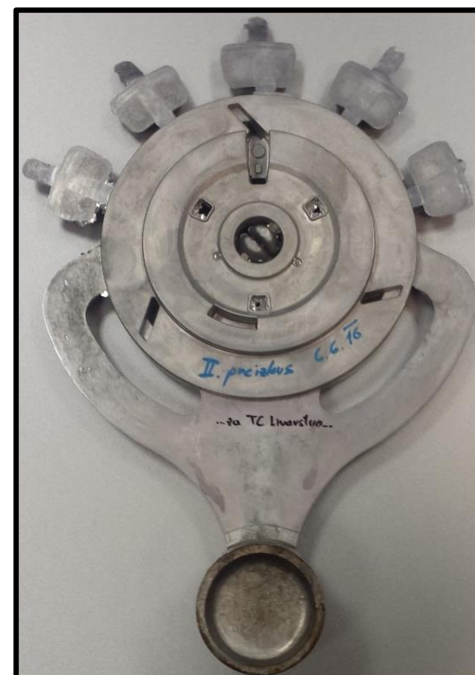




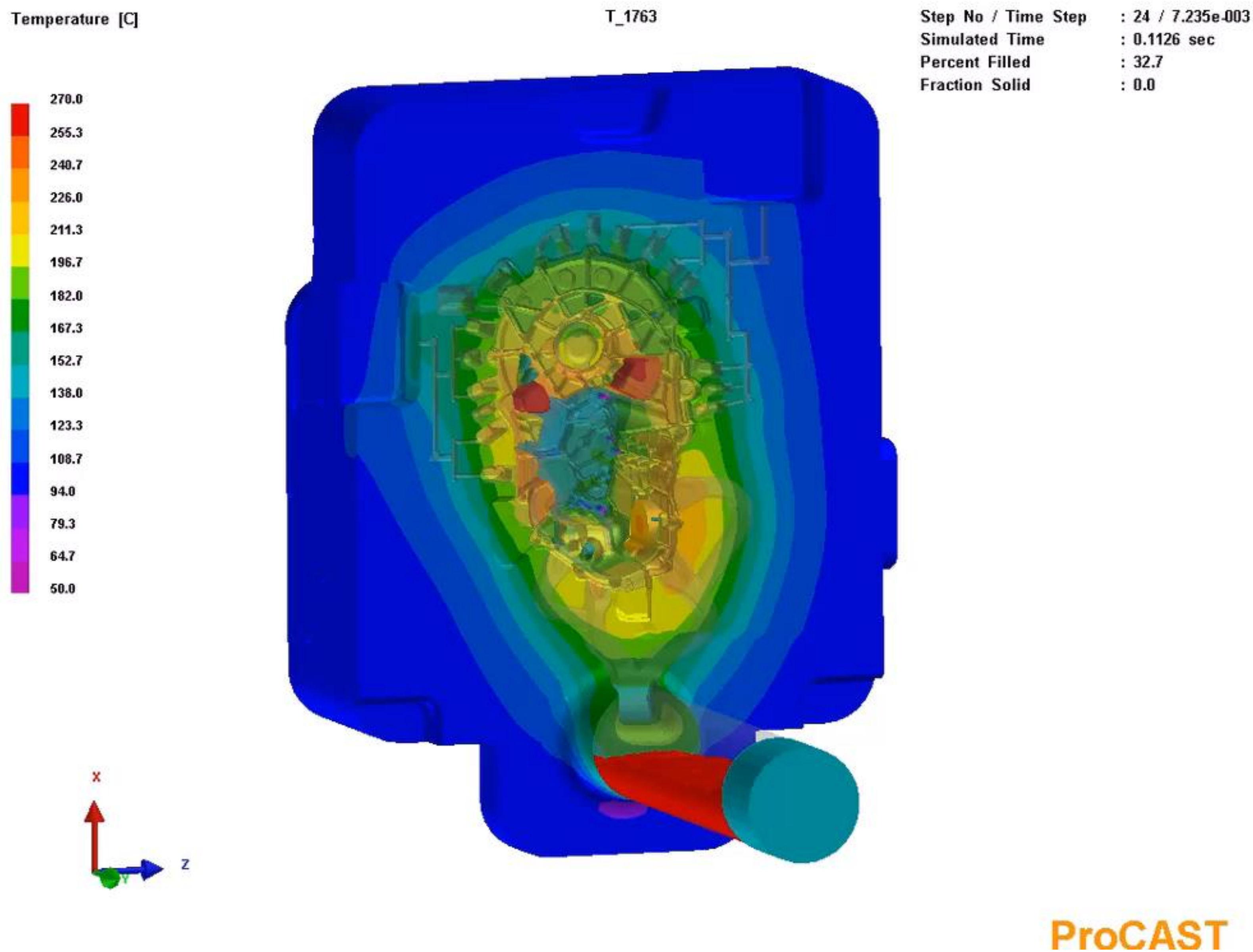
Calculation of pouring – different gating system



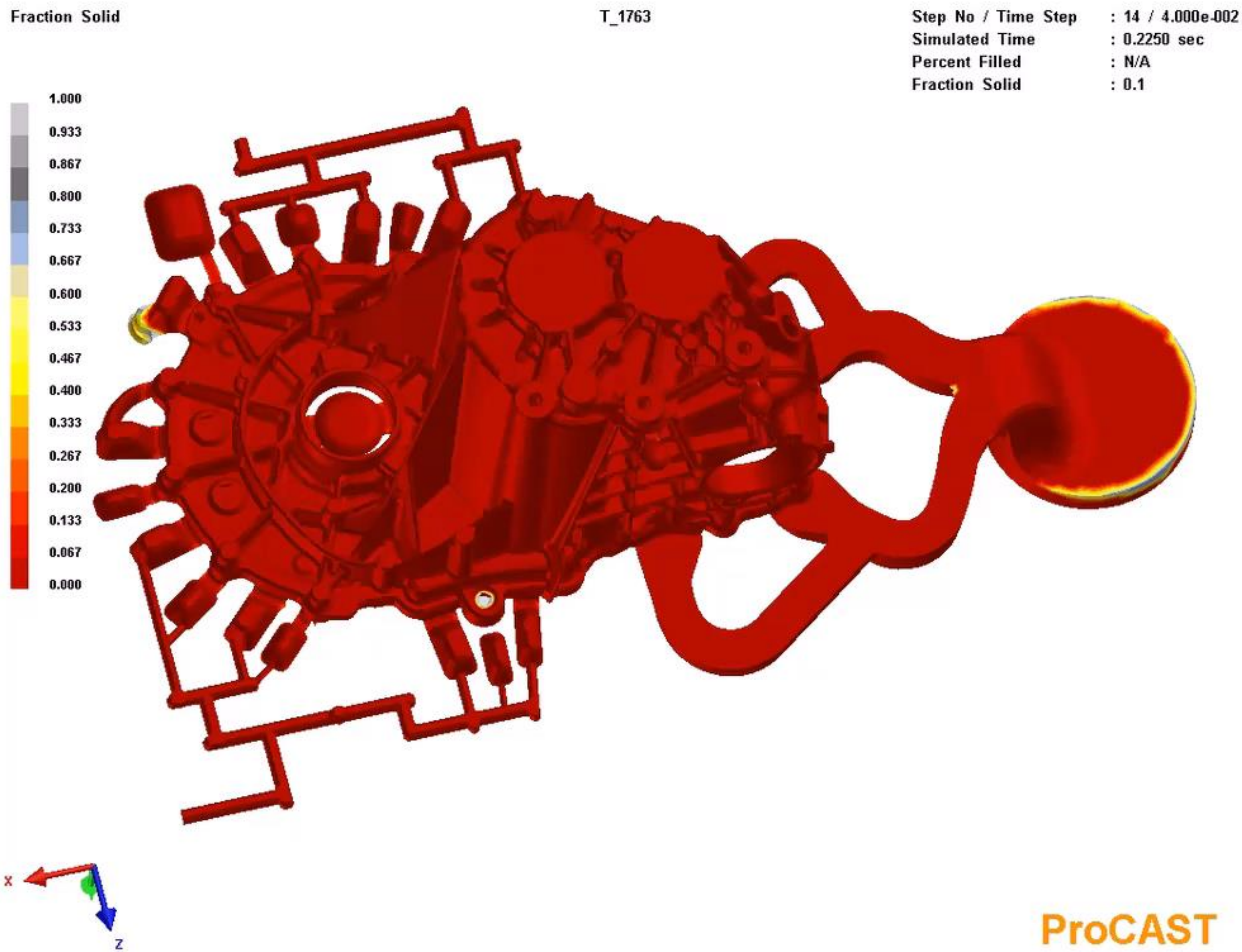




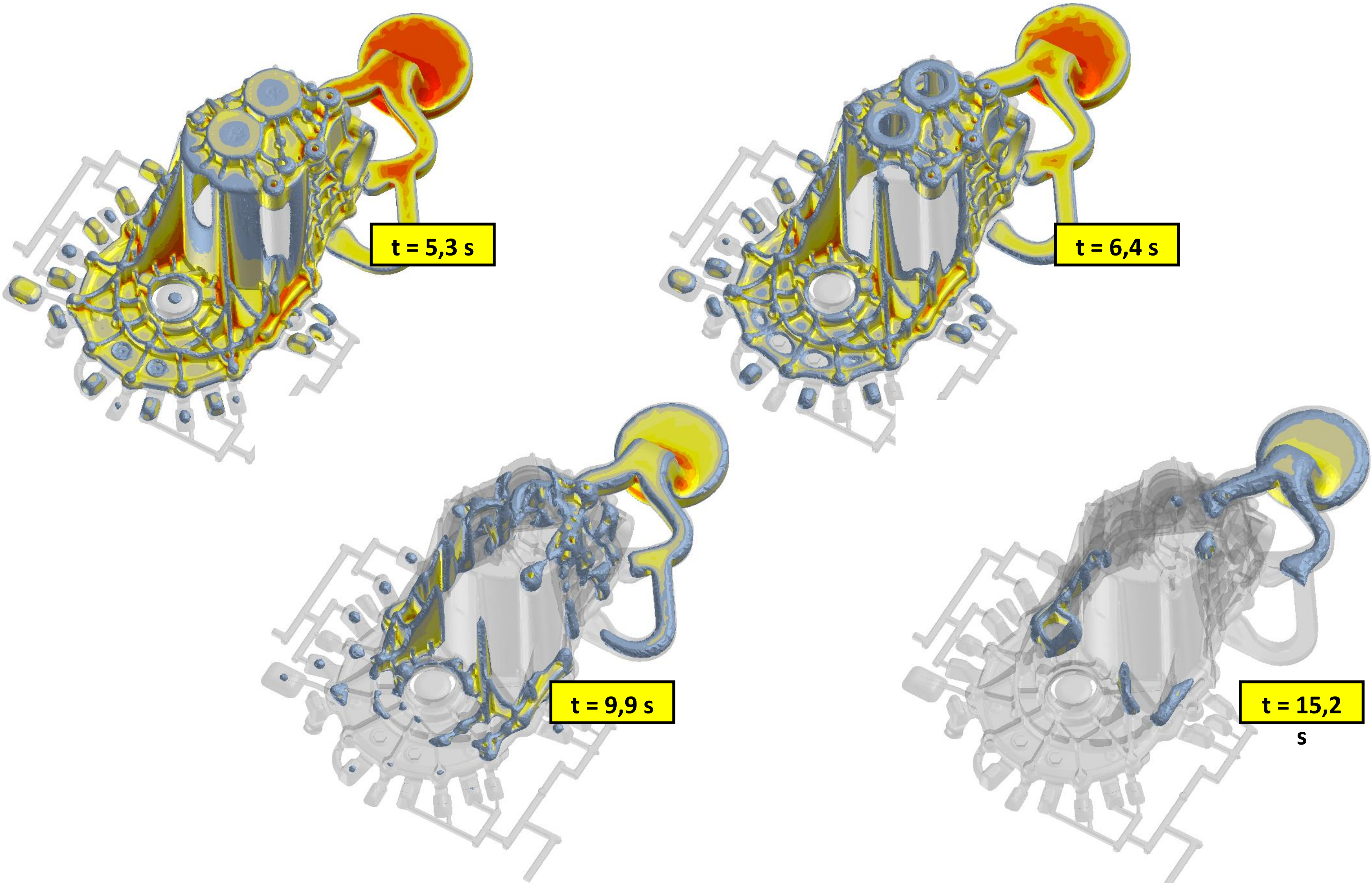
Calculation of pouring



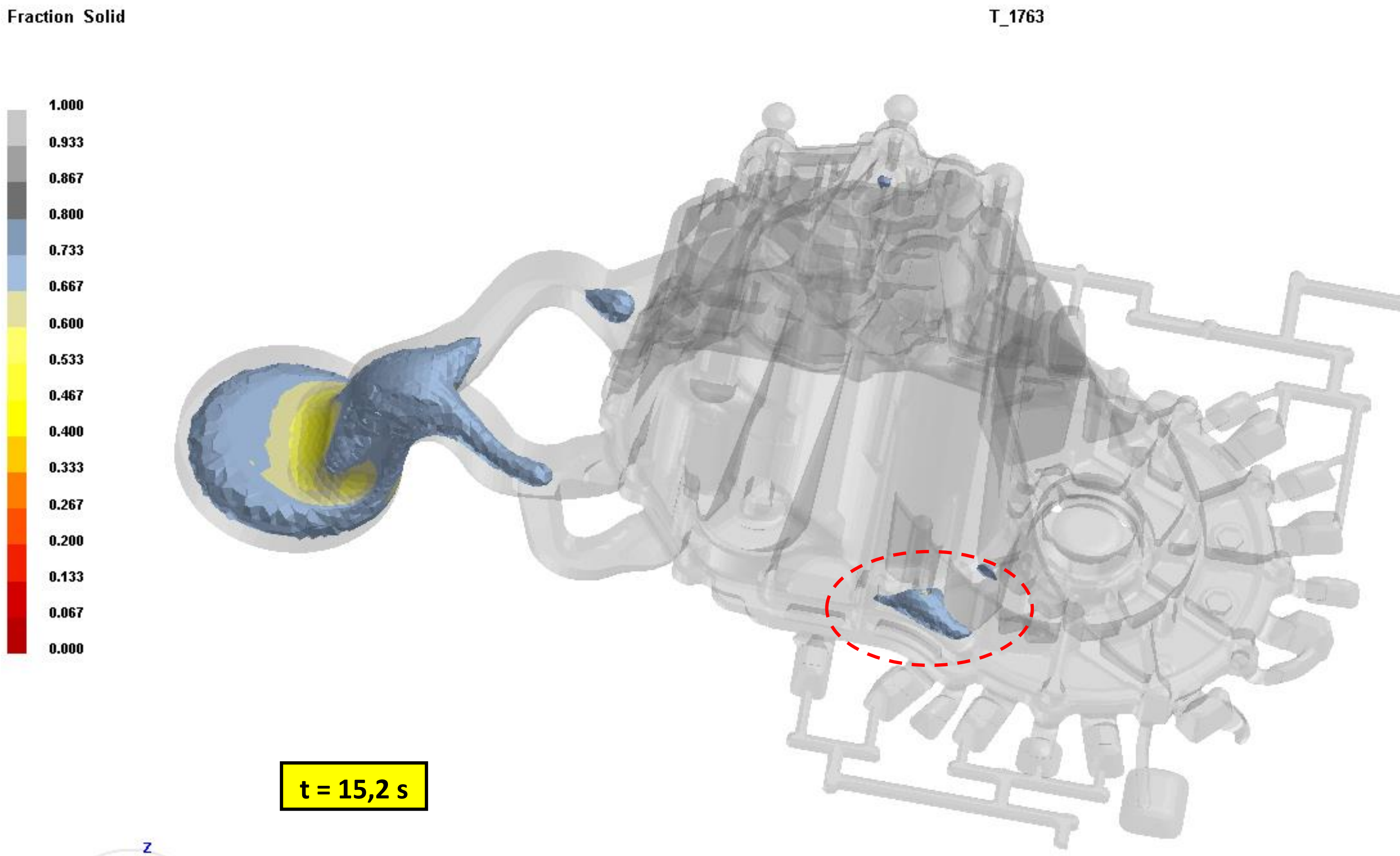
Calculation of solidification sequence



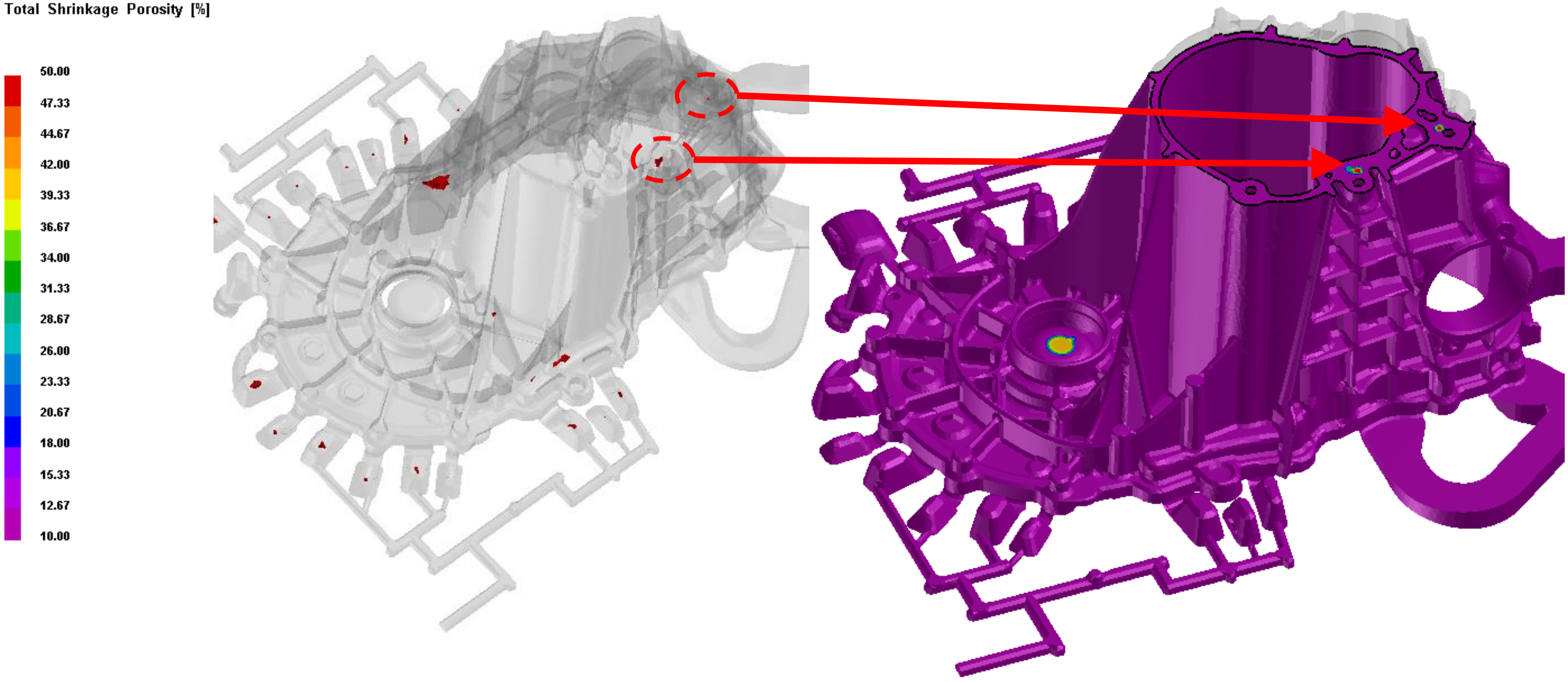
Calculation of solidification sequence versus time



Last solidified areas in the casting

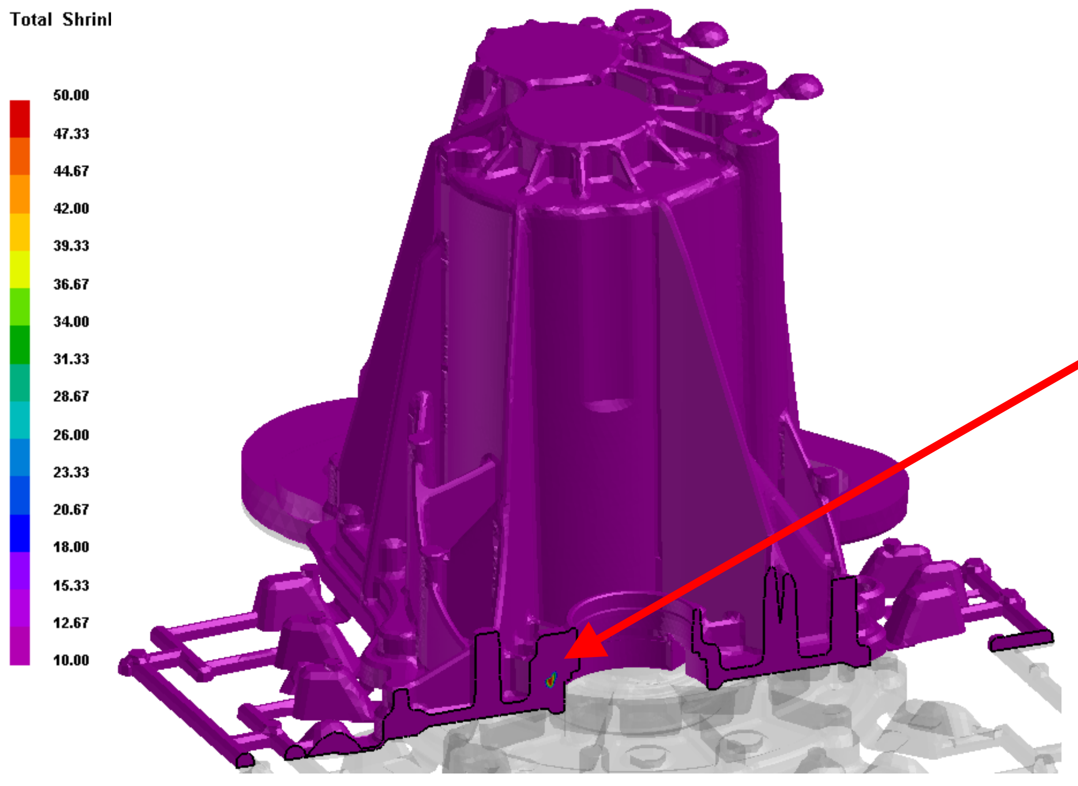


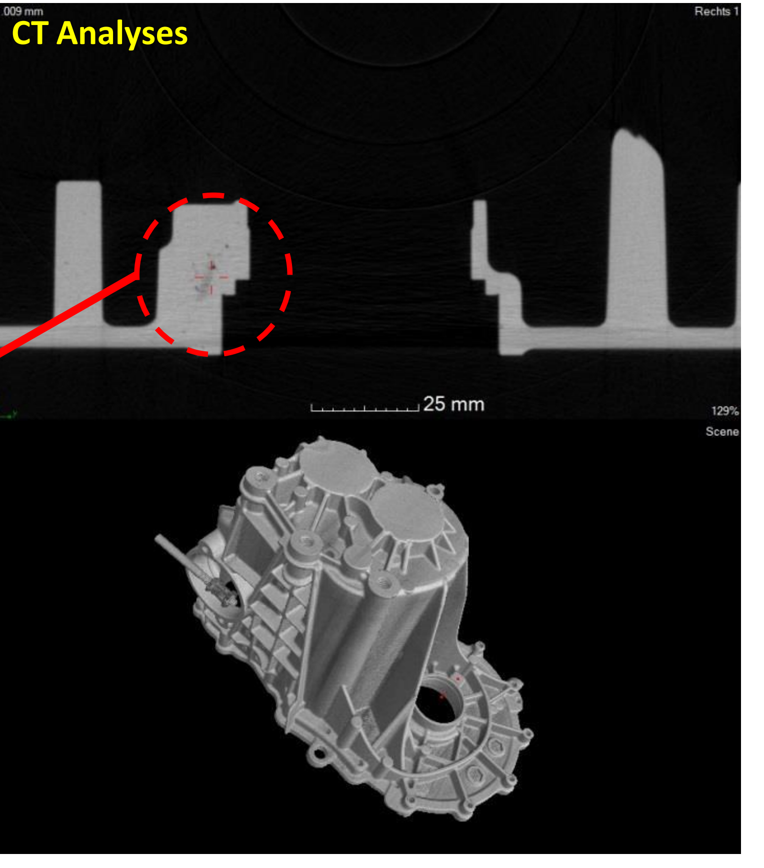
Calculation of porosity



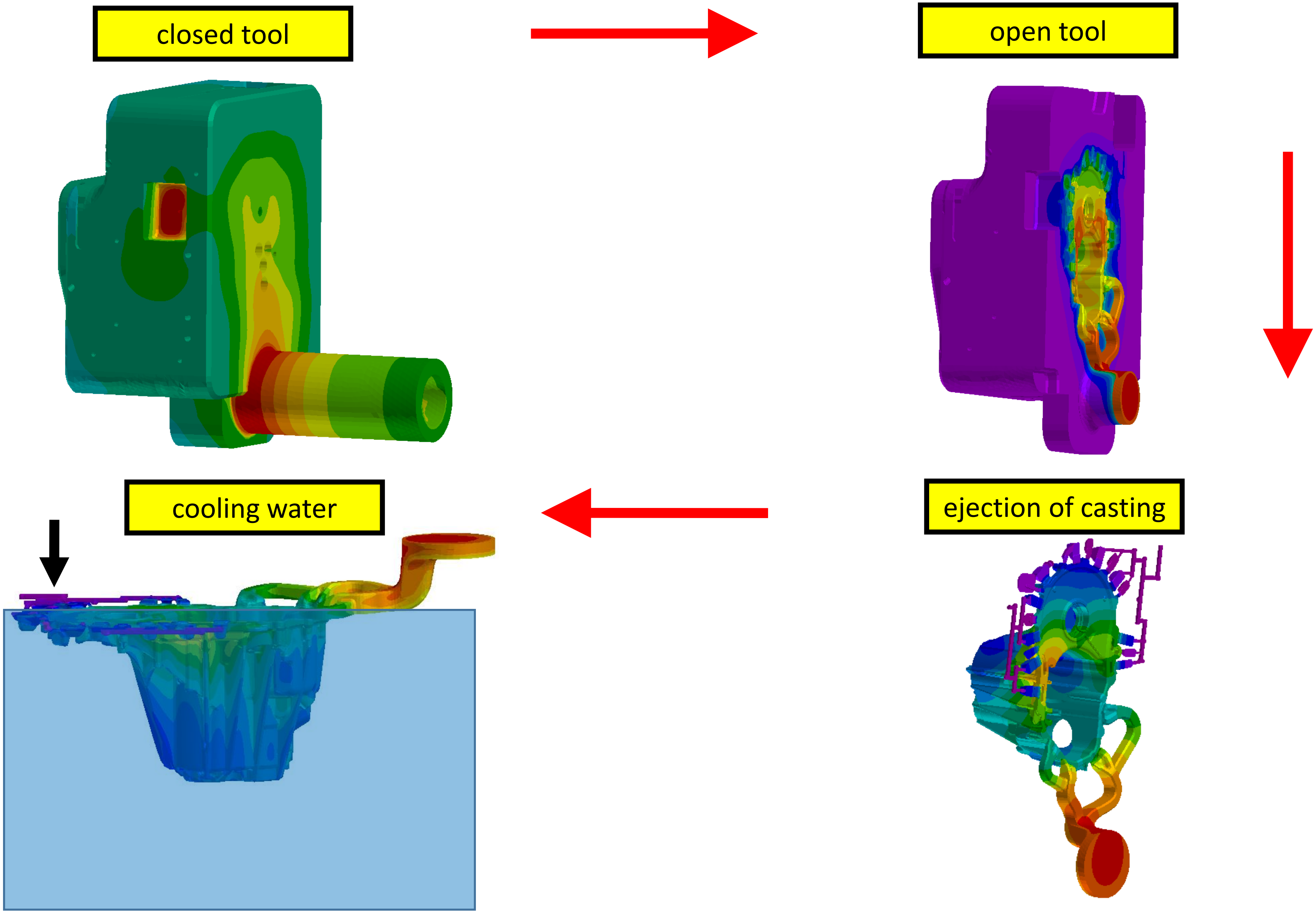
Presented shrinkage porosity areas are not allowed, with local squeezing technique can be eliminated.

Comparison of calculated and experimental shrinkage porosity

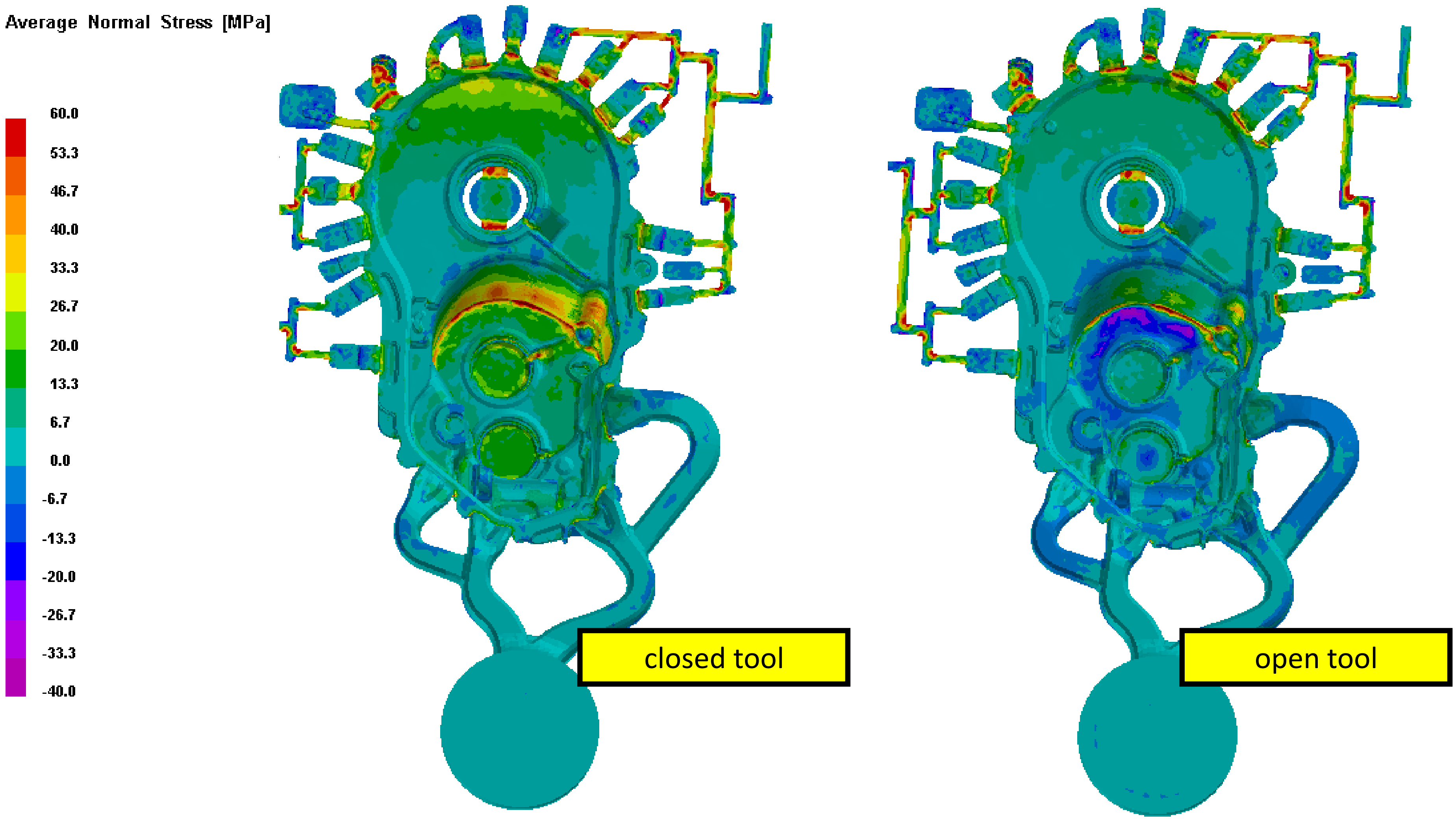




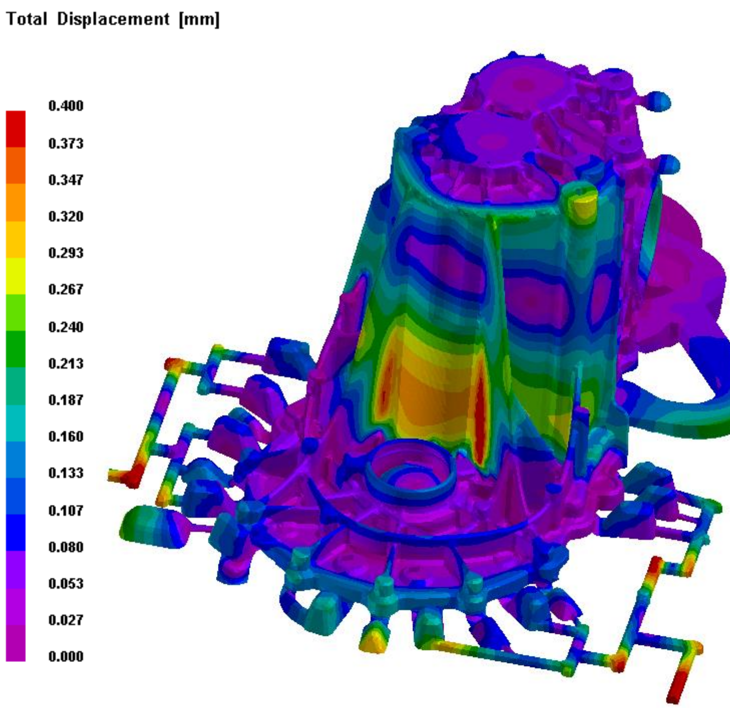
Calculation of the stress and deformation for each sequences after the solidification



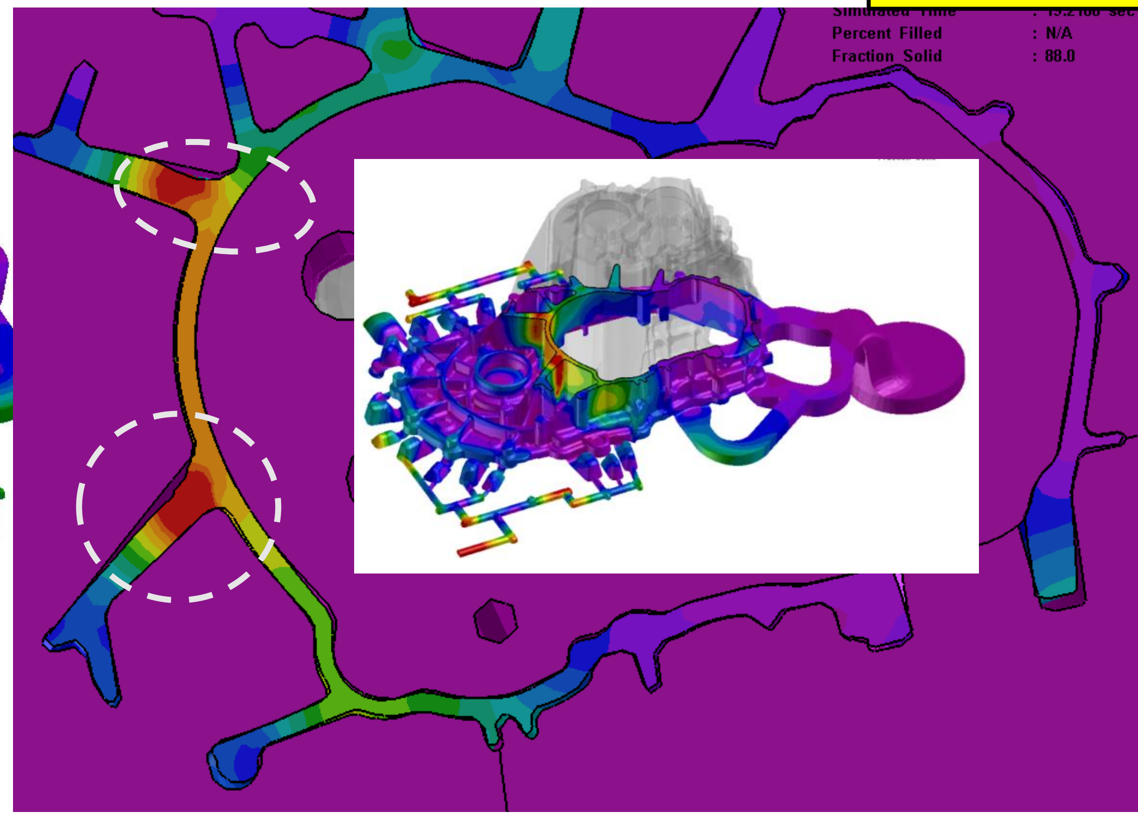
Relaxation of normal stresses in the casting after the die opening



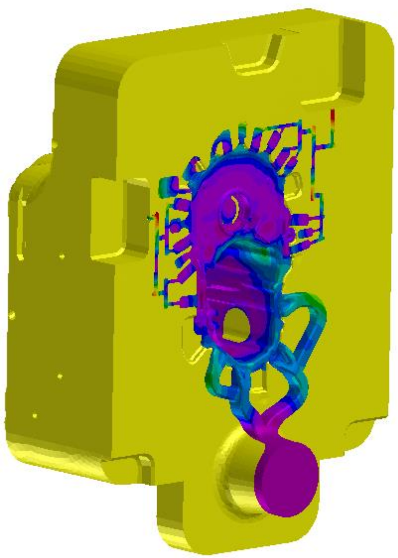
Calculation of the shrinkage of the casting and the formation of an air gap between the solidification



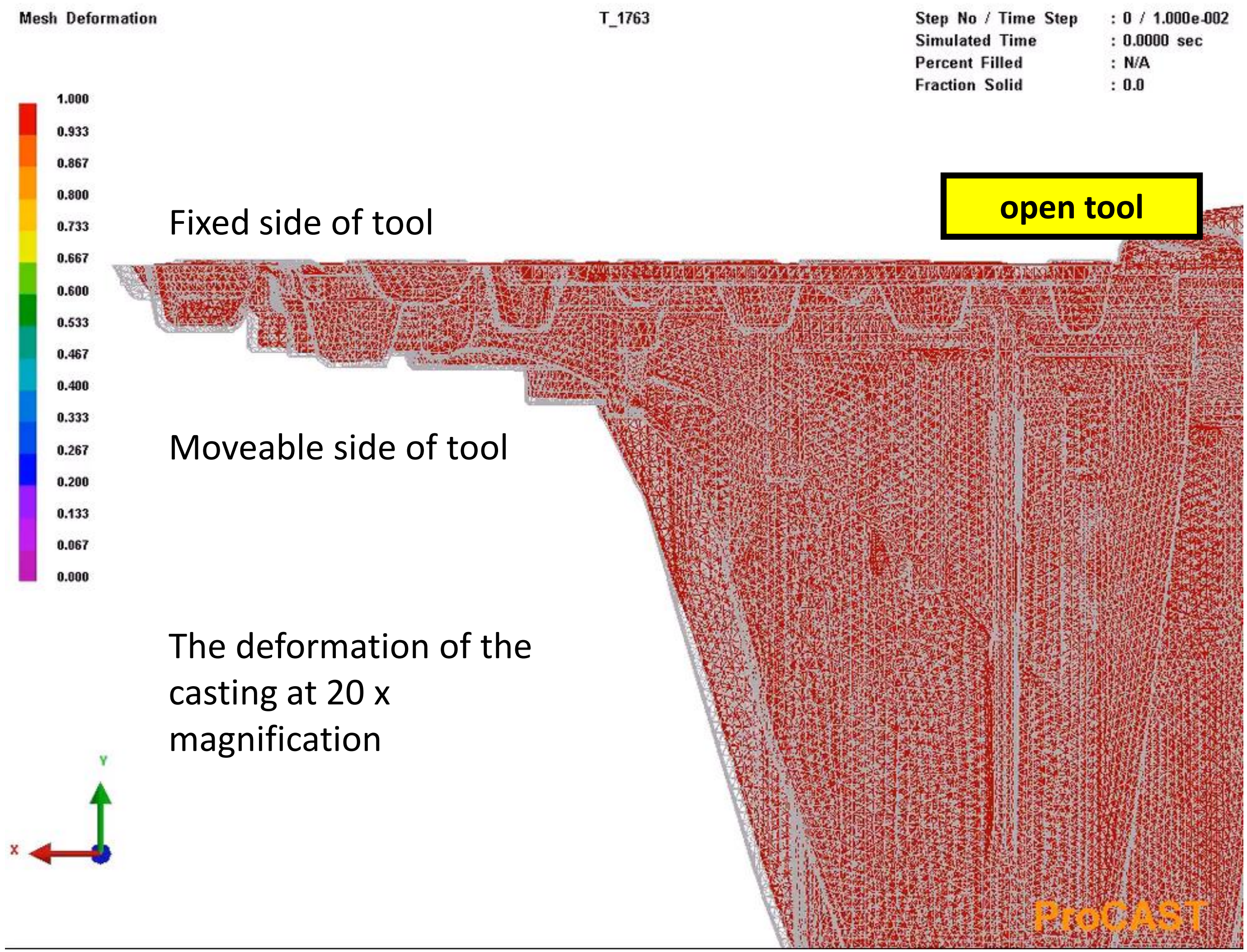
closed tool



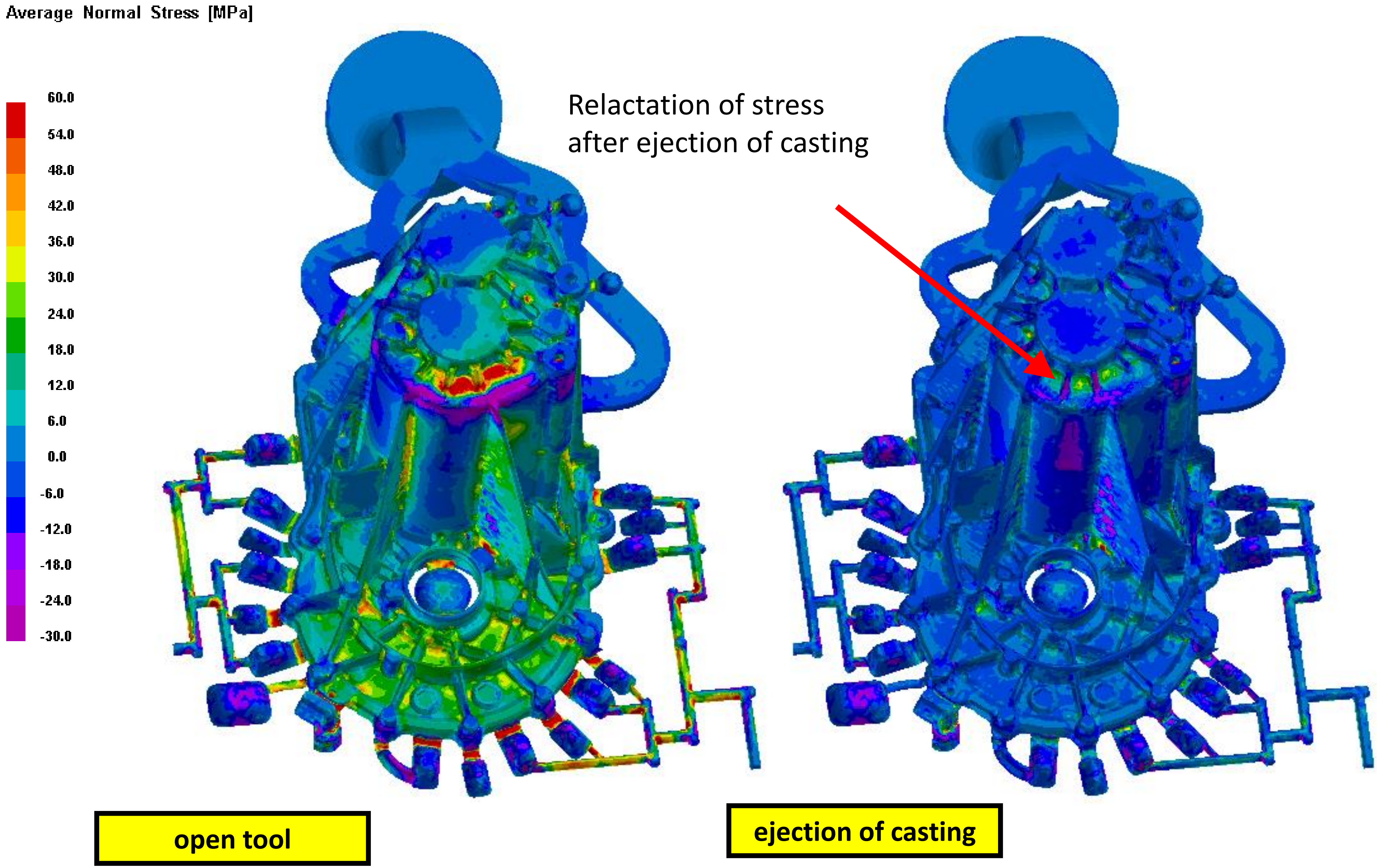
Deformation of casting



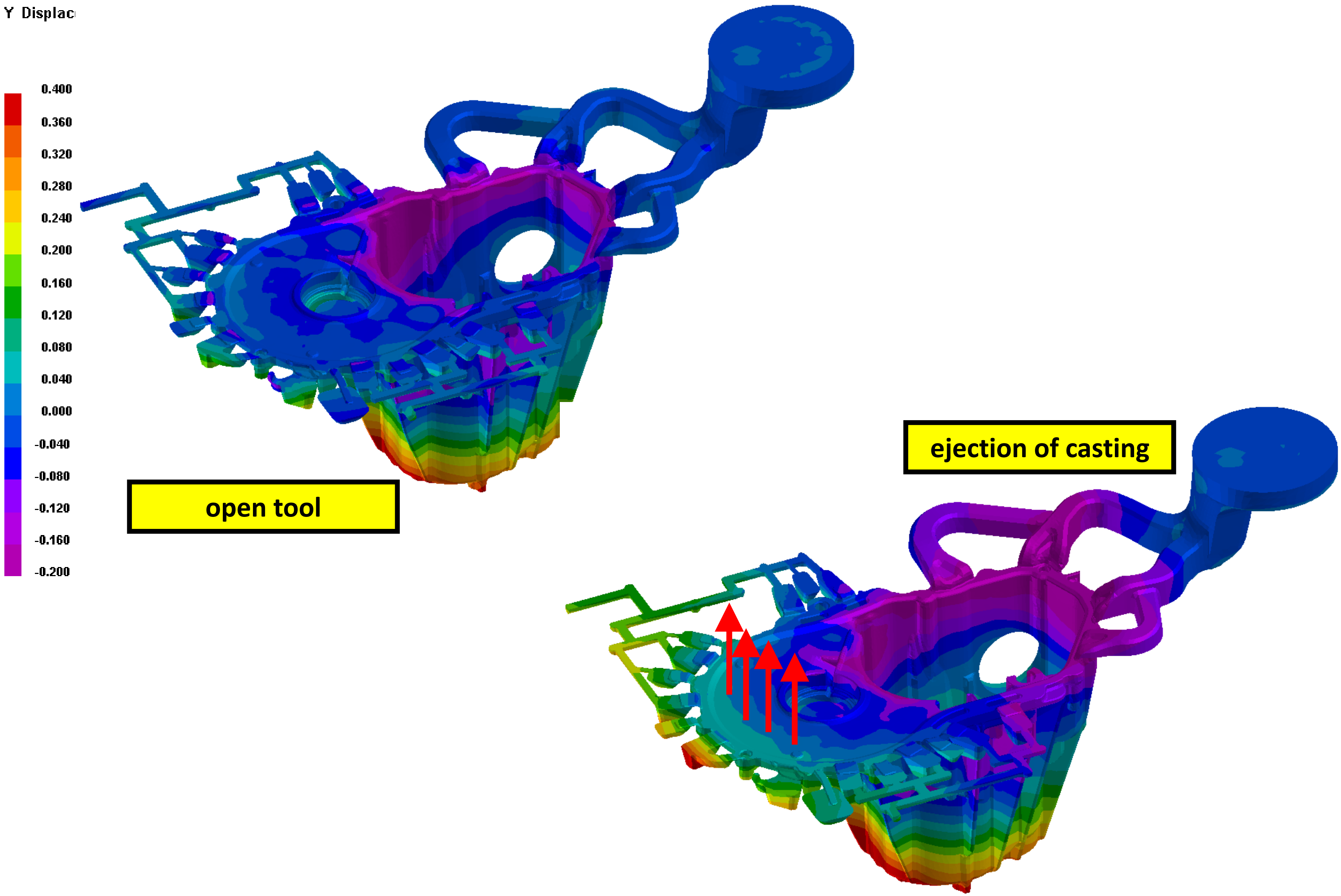
Note: Reference is sliding away tools



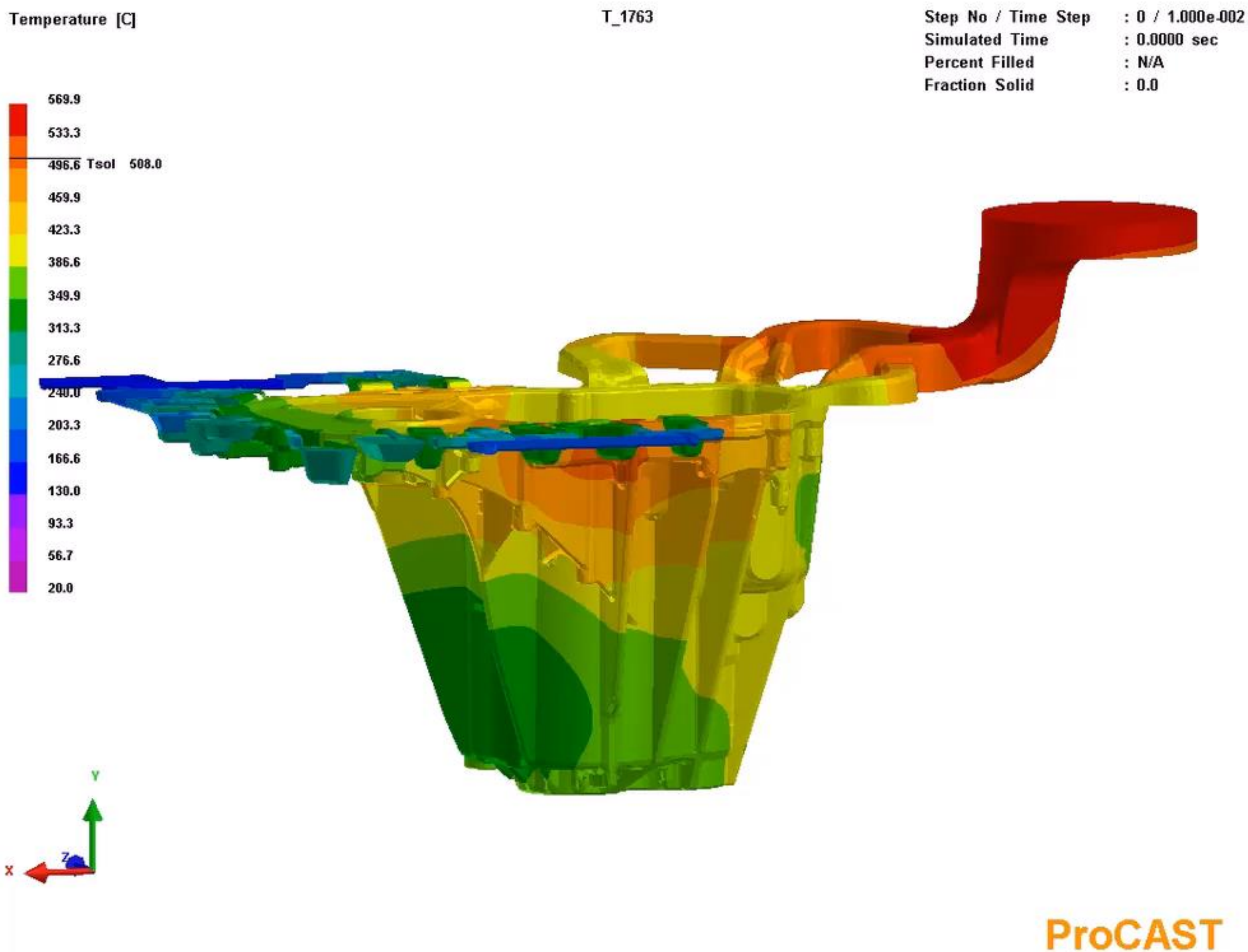
Relaxation of normal stresses in the casting



The deformation of the casting in Y direction

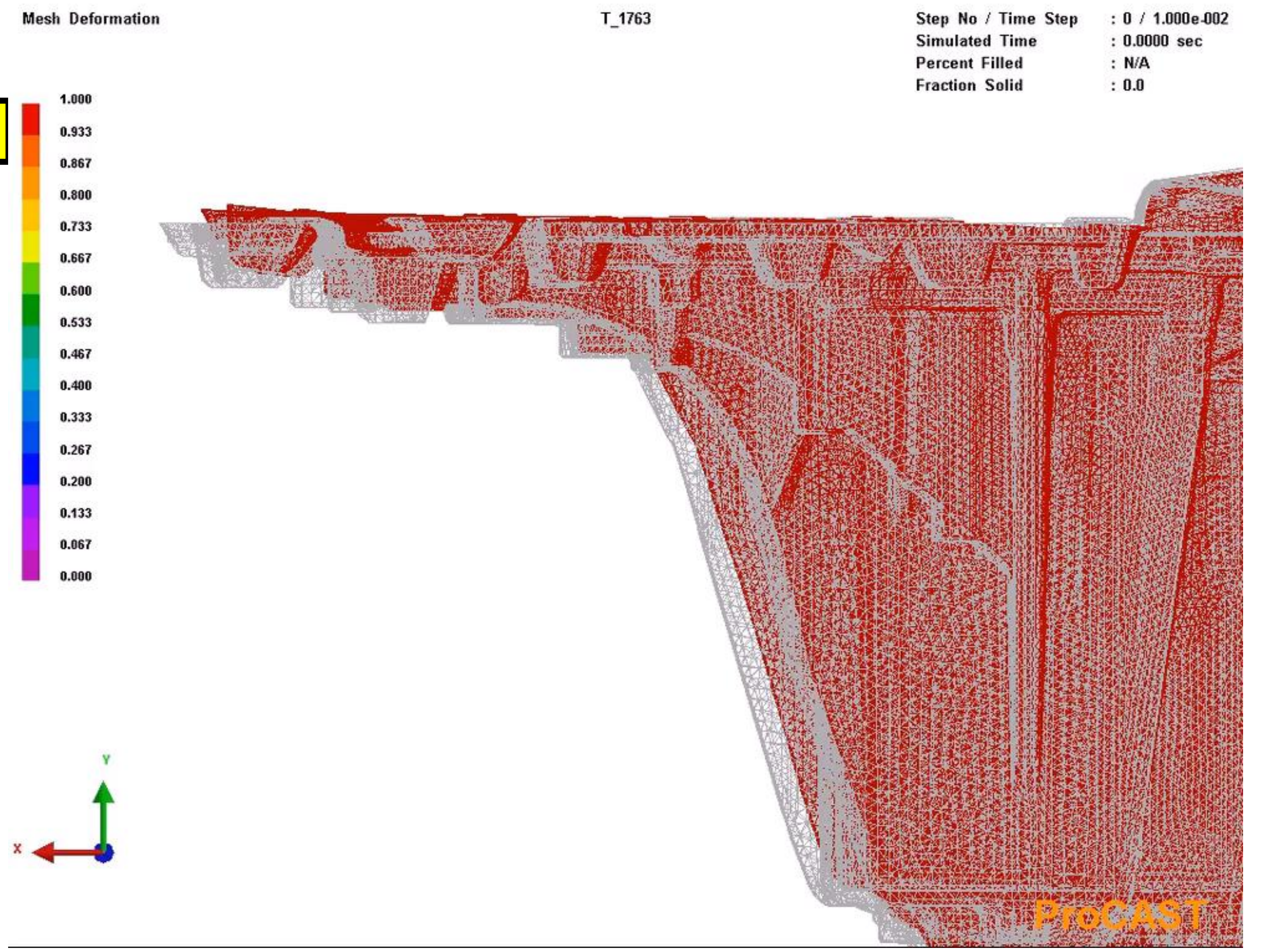


Calculation of the temperature field for the cooling of the cast part in the water



Deformation during submerging cast part in the water

Cooling in water

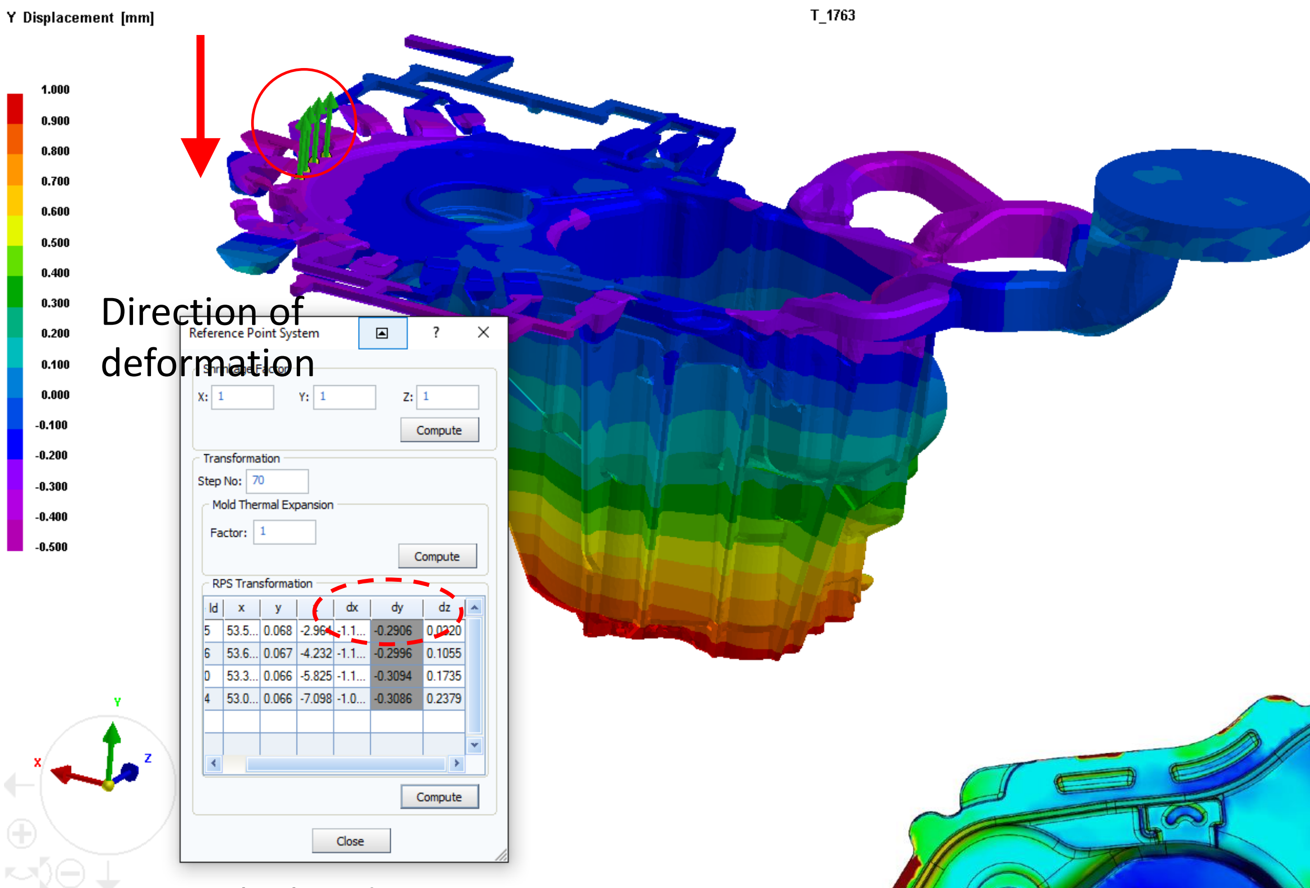


We can see how the casting during the cooling in water is deformed downward.

The deformation of the casting at 15 x magnification

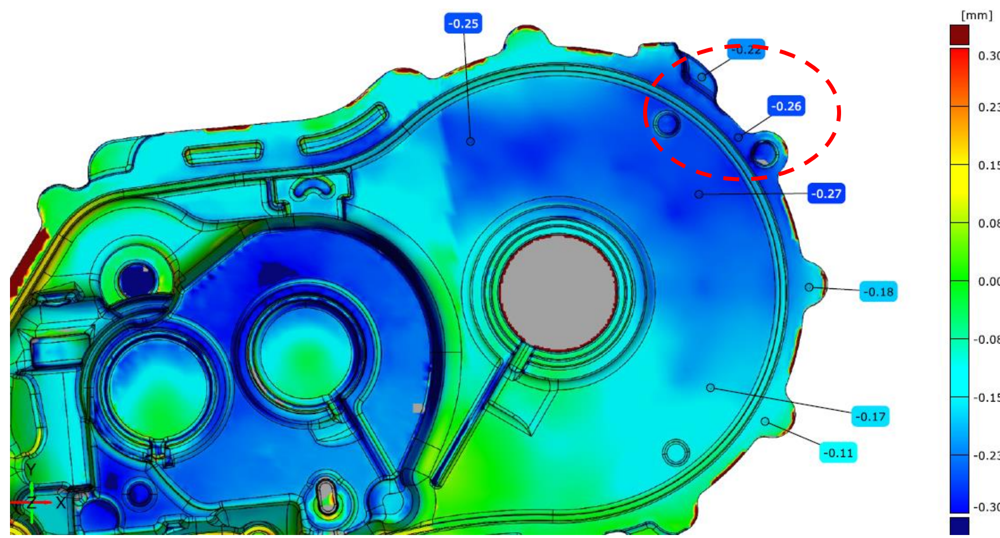
Note: Reference is a biscuit

Deformation of casting, after cooling in water

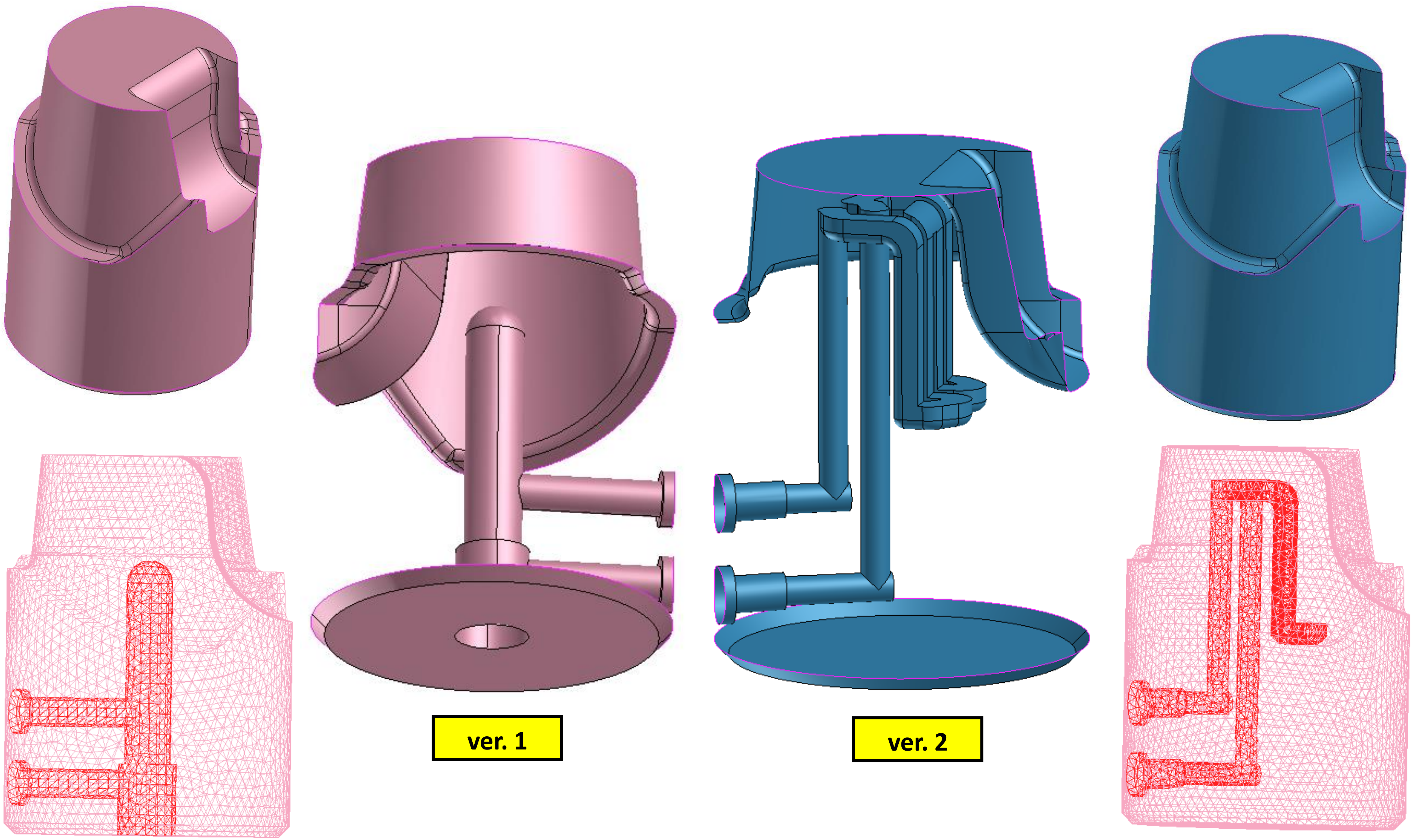


calculated deformations

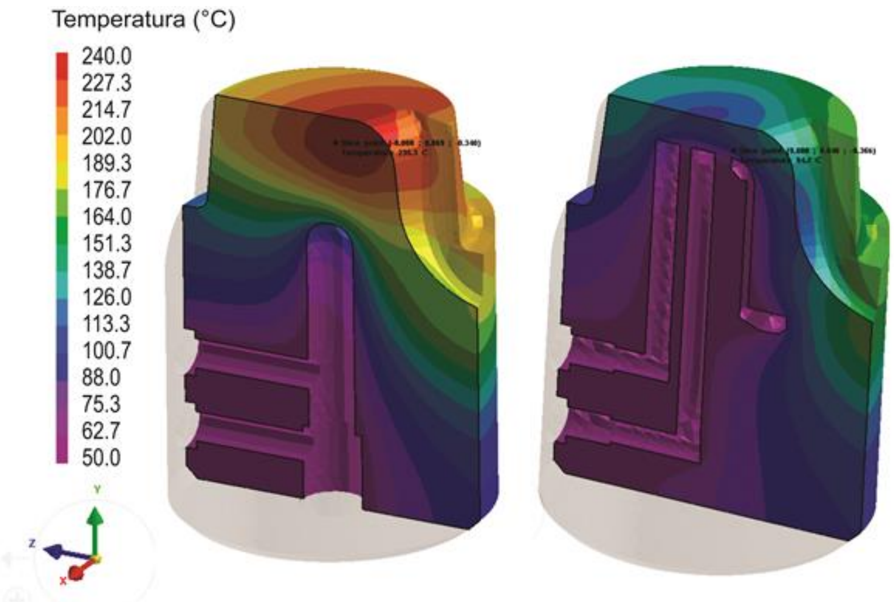
measured deformation



Technology optimization - distributor



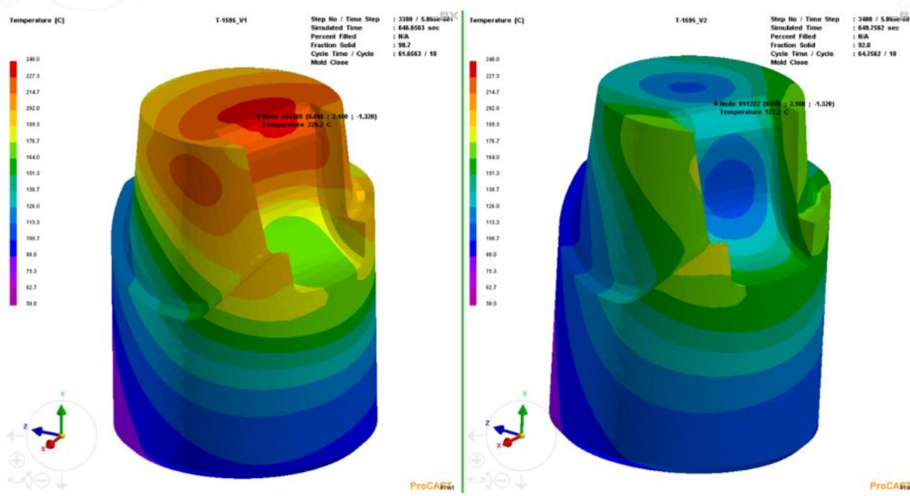
Technology optimization - distributor

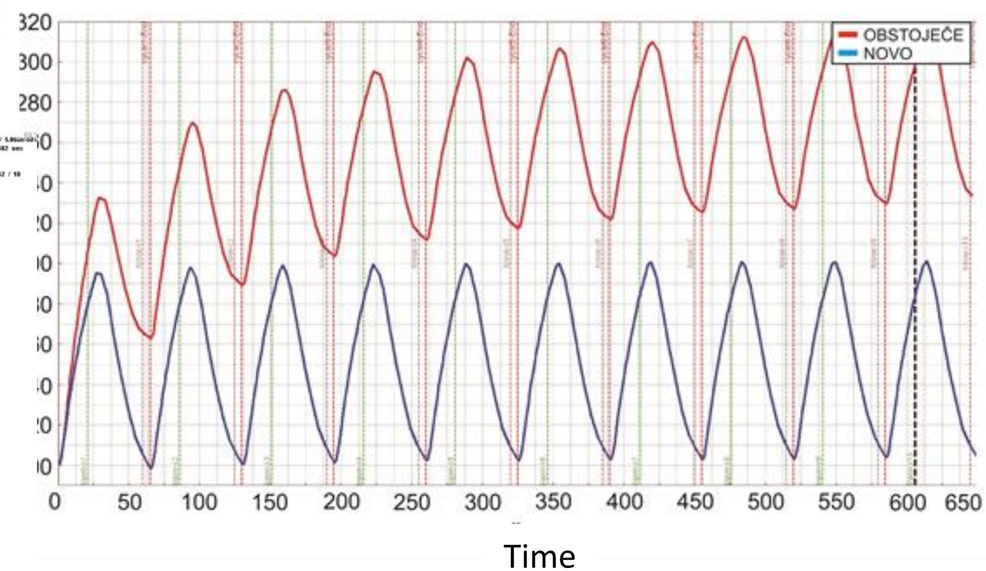


Temperature in critical area was in ver. 1 235,3 °C, with new cooling system the temperature was 94,7 °C

Temperature drop with new cooling system was 60 %.
Stresses with new cooling system were lower for 47 %.

Distributor with version 1 cooling system made 65080 cycles, new distributor made 79129 cycles. Life time prolongated for 21 %.





Conclusions

Including numerical simulations in early technology development phase can reduce costs:
- optimal casting technology can be defined before real testing
- casting defects under acceptable limits
- finding critical areas during design phase

With adequate process and technology optimization it is possible to:
- prolong the dies lifetime
- shorten production cycle of casting

The time from order to prototype products can be reduced.

SREČNO!

Good luck!