

Using numerical simulations to optimize quality and costs in HPDC foundries

prof. dr. Primož Mrvar¹, dr. Sebastjan Kastelic^{1,2}, Almir Mmahmutović², doc. dr. Mitja Petrič¹

¹ *University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Materials and Metallurgy, Foundry Chair, Aškerčeva 12, Ljubljana, Slovenija*

² *TC Livarstvo d.o.o., Teslova 30, Ljubljana, Slovenija*





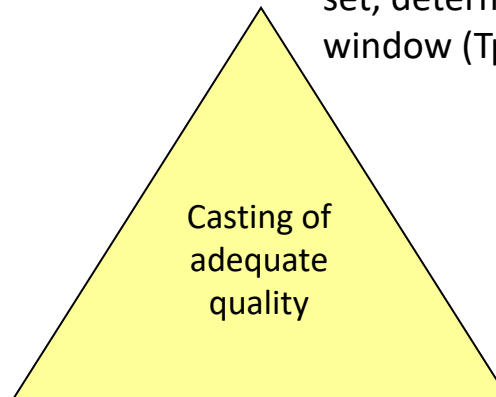
Casting technologies - basics

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 (T_p , ...))



Alloy

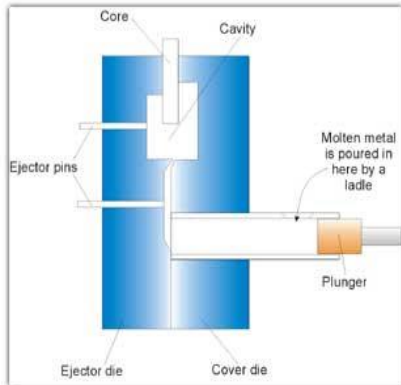
(raw material, degree of recycling, melt treatment, way of pouring, Chemical composition, NP)

Type of the mould

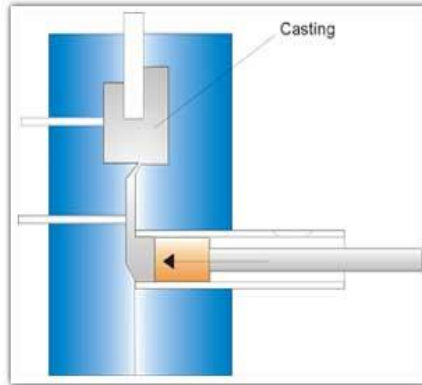
(selection of different hot working tool steel, W-alloy, heat treatment, properties)



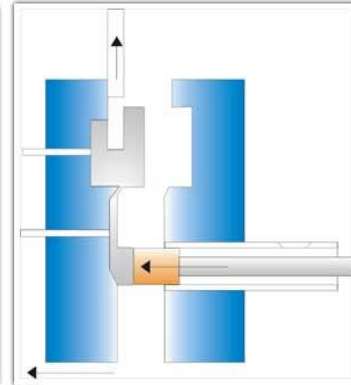
HPDC – basics



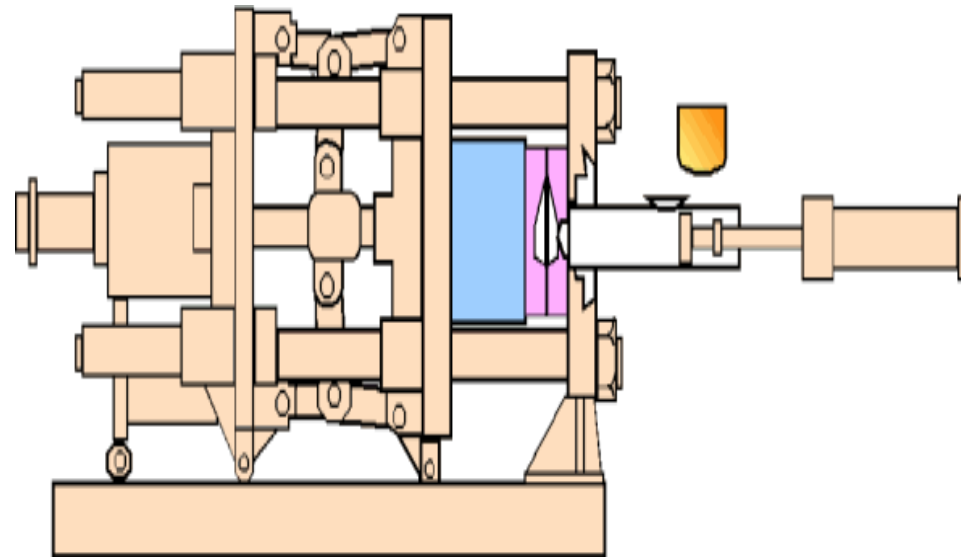
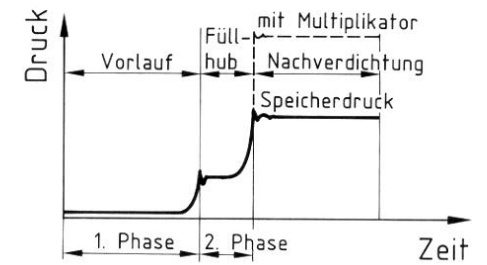
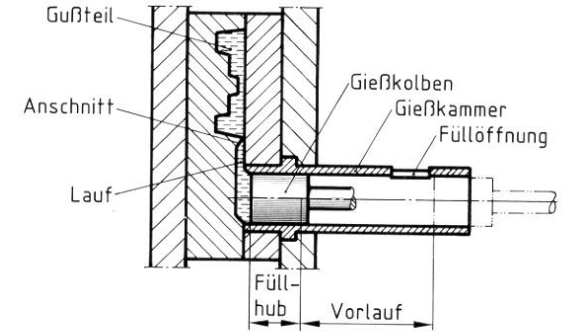
1st phase
piston motion



2nd phase
die cavity filling - shot

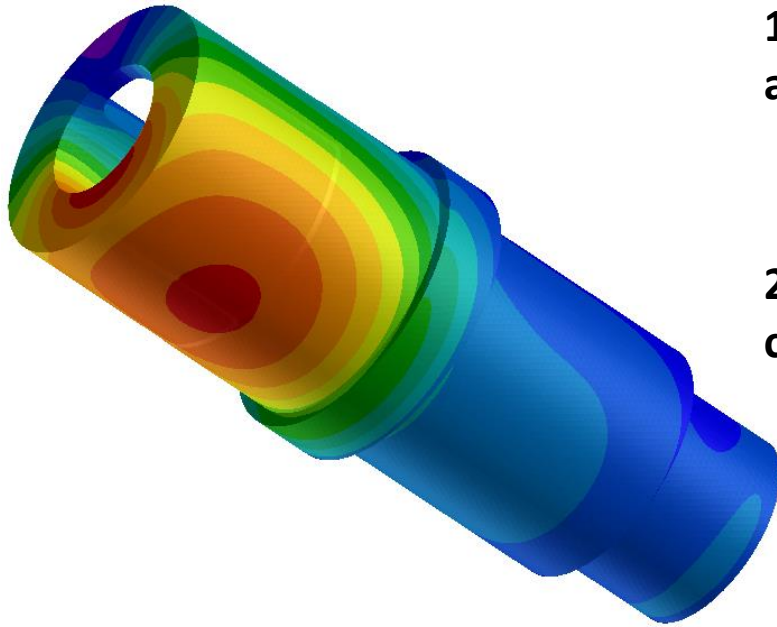


3rd phase
high pressure





HPDC- Cold chamber

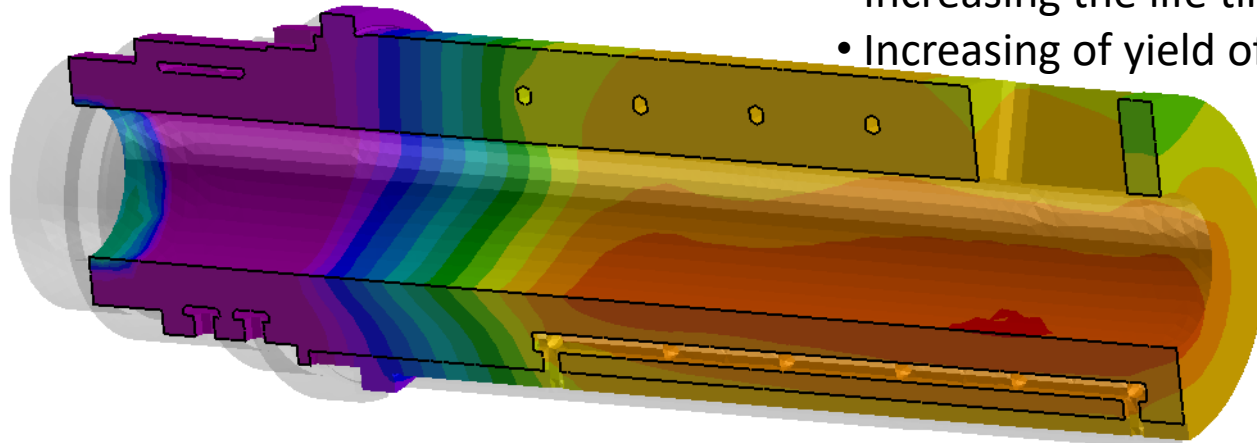


1. What is the main problem to pour the molten Al alloy?

- 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



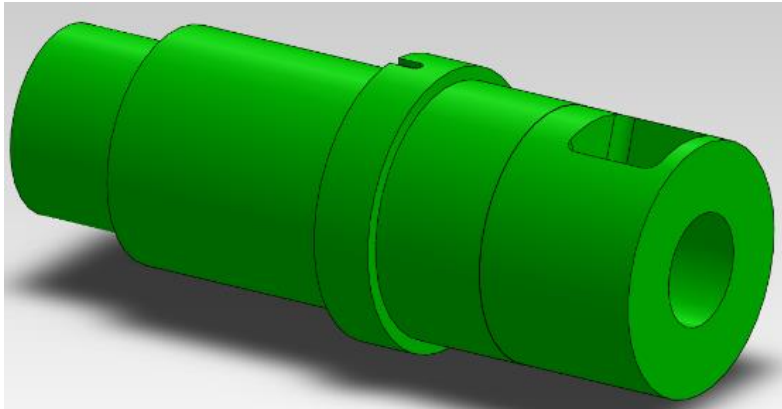


What is the main problem to prepare the accurate calculation of casting process for HPDC?

- It is necessary to choose and/or calculate or measure the real material properties:
 T_l , T_s , f_s - $f(T)$, ρ - $f(T)$, η - $f(T)$, 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
-

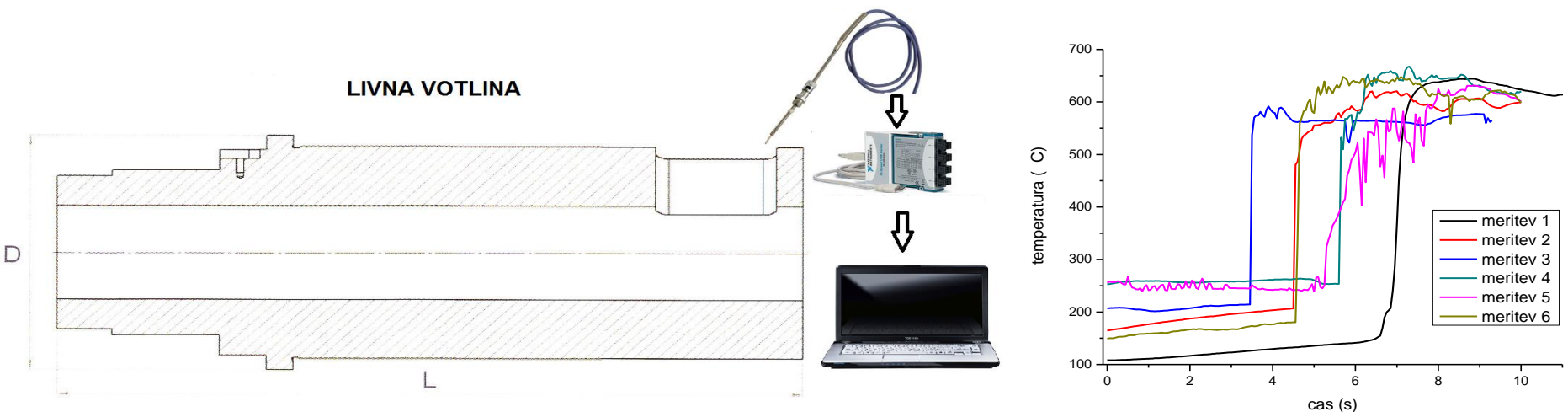


HPDC- Cold chamber



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

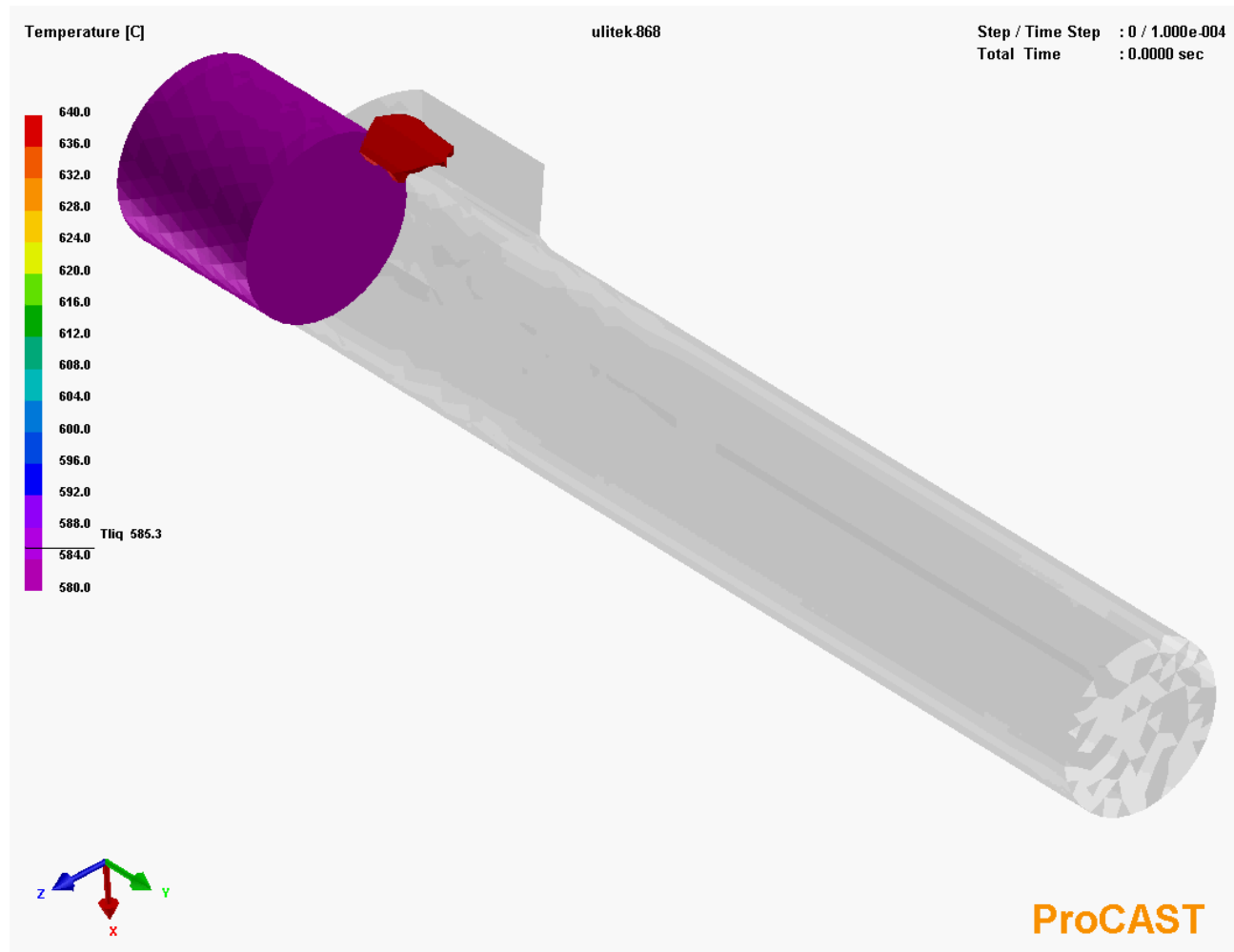
Measurements of melt temperature in the casting chamber before the first stage starts





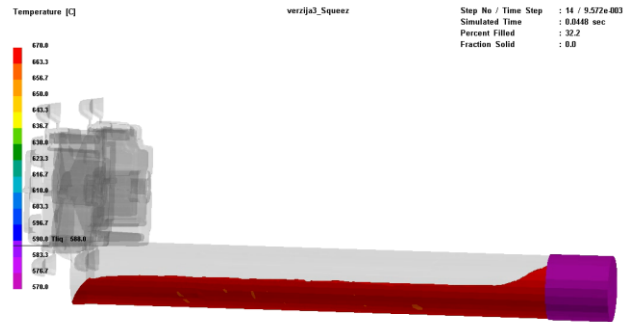
Simulation of melt flow and melt temperature drop from furnace to casting chamber

- 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.



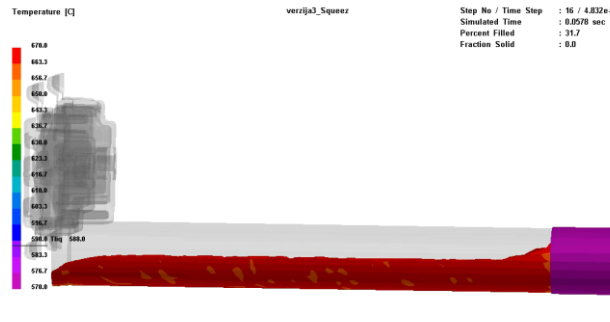
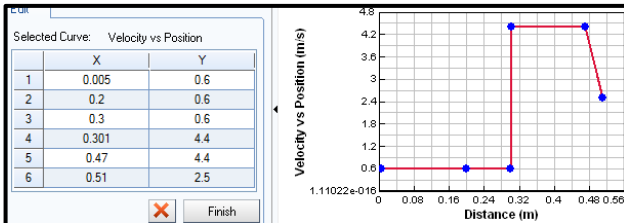


Example: Optimization of phase I and II



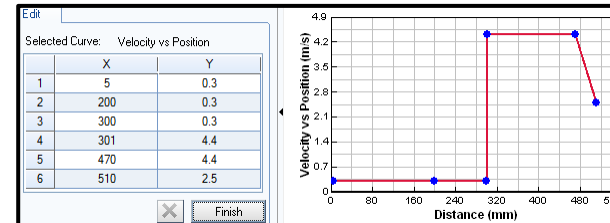
ProCAST

$V_1 = 0,6 \text{ m/s}$



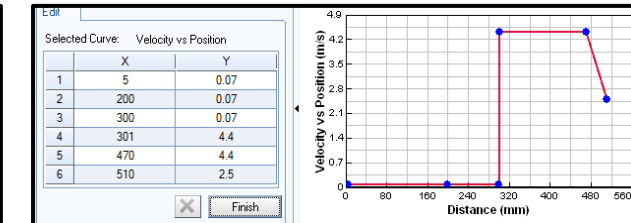
ProCAST

$V_1 = 0,3 \text{ m/s}$



ProCAST

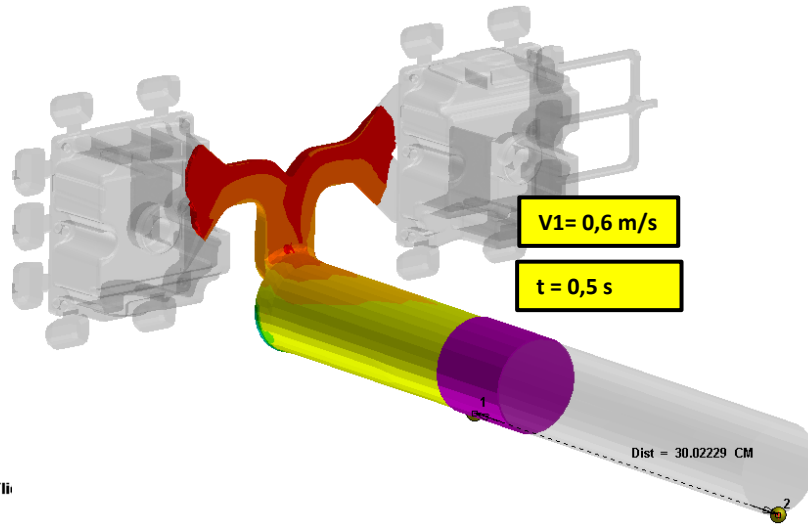
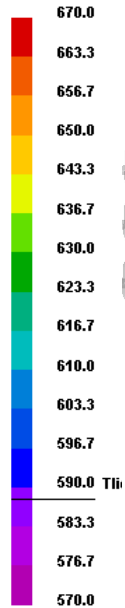
$V_1 = 0,07 \text{ m/s}$





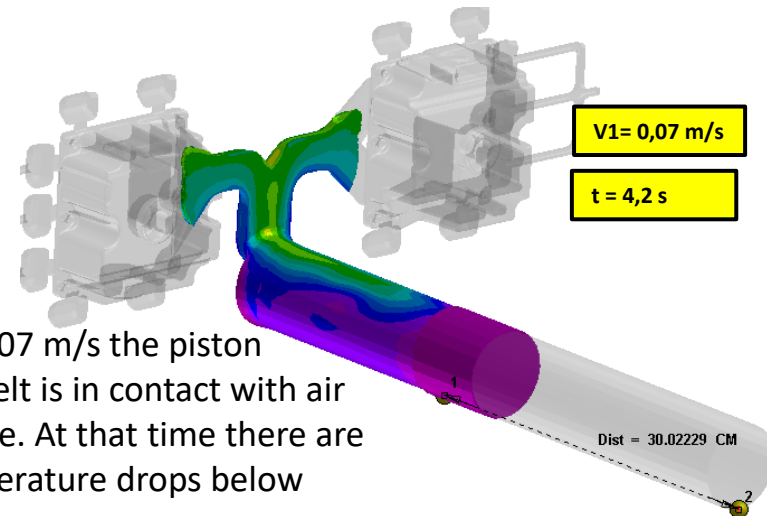
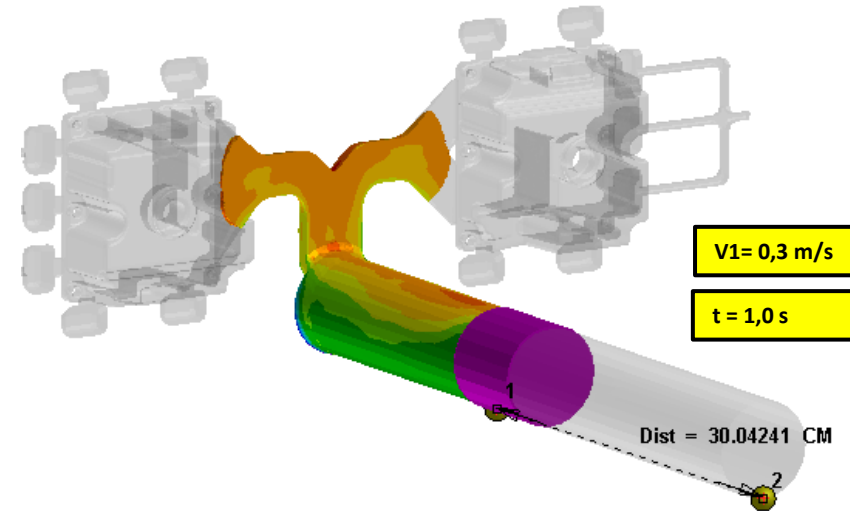
Example: Cooling of molten metal in the cold chamber in the first phase

Temperature [C]



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.

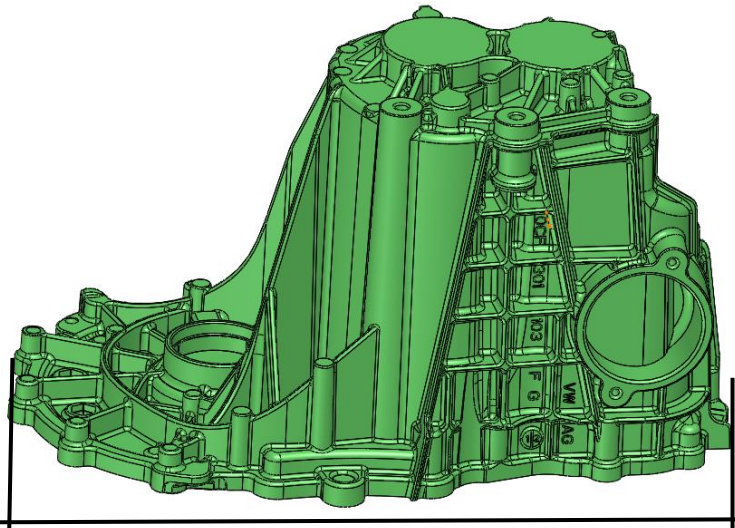
When the speed of the first phase is 0,3 m/s hold-wave accures.



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



390 mm

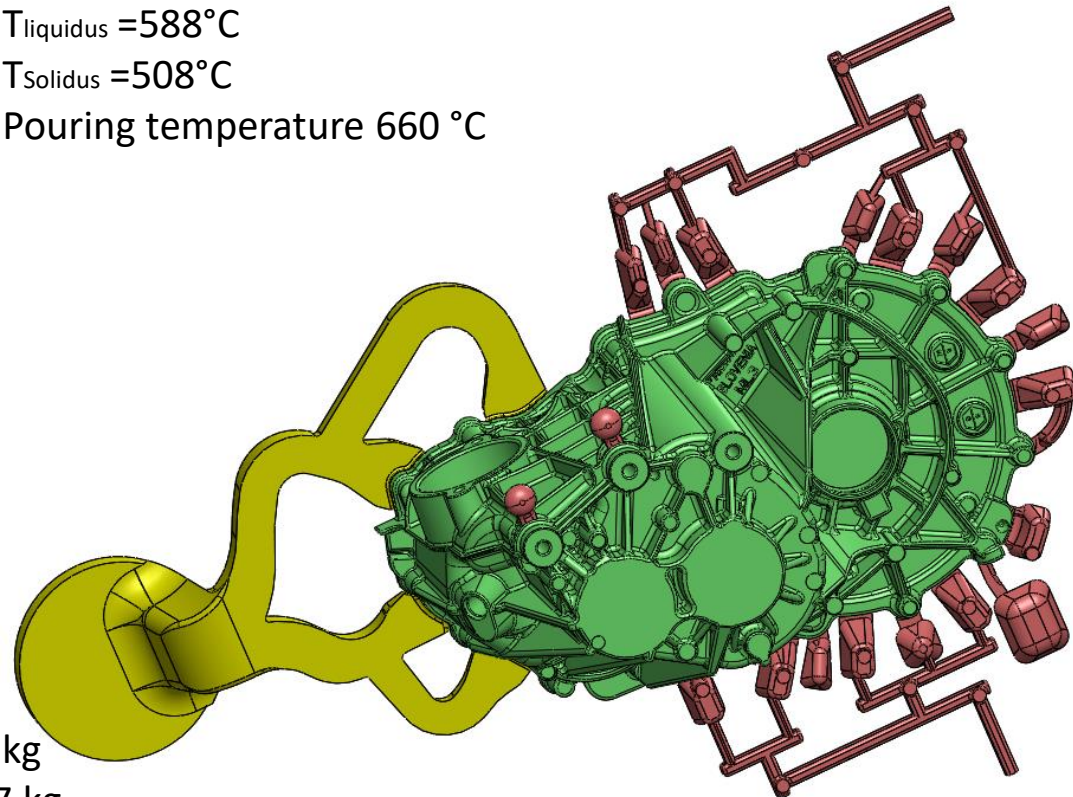
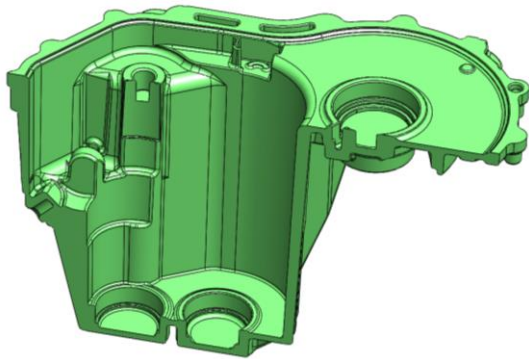
Investigated geometry of gearbox casting and their gating system

Alloy: AlSi9Cu3

$T_{\text{liquidus}} = 588^{\circ}\text{C}$

$T_{\text{solidus}} = 508^{\circ}\text{C}$

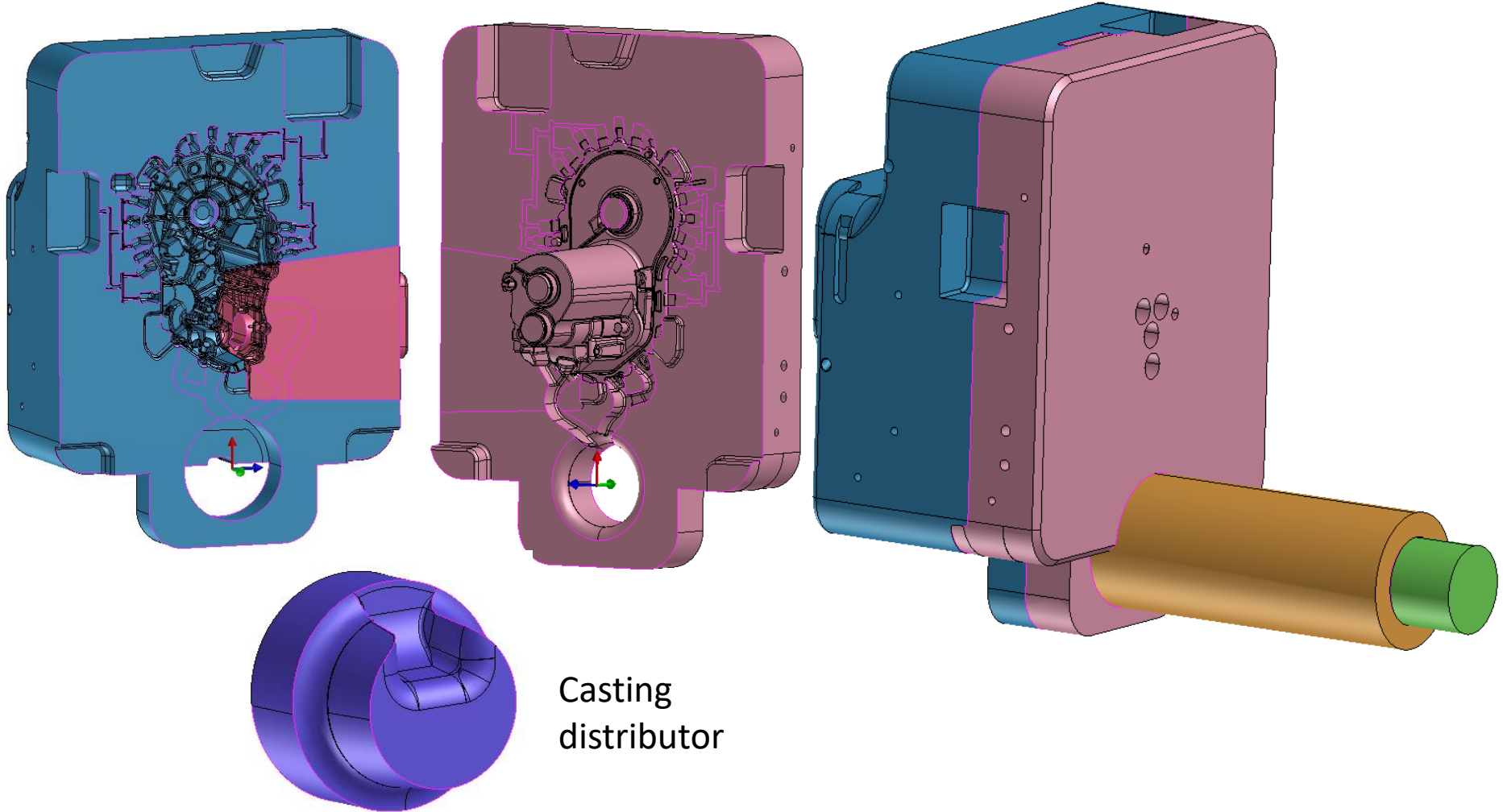
Pouring temperature 660°C



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



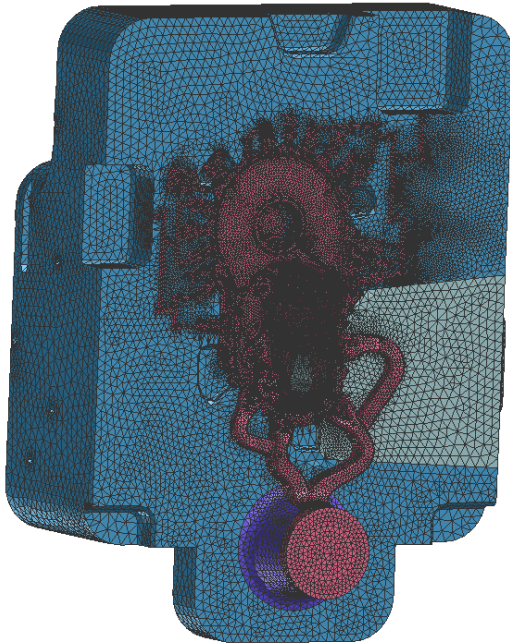
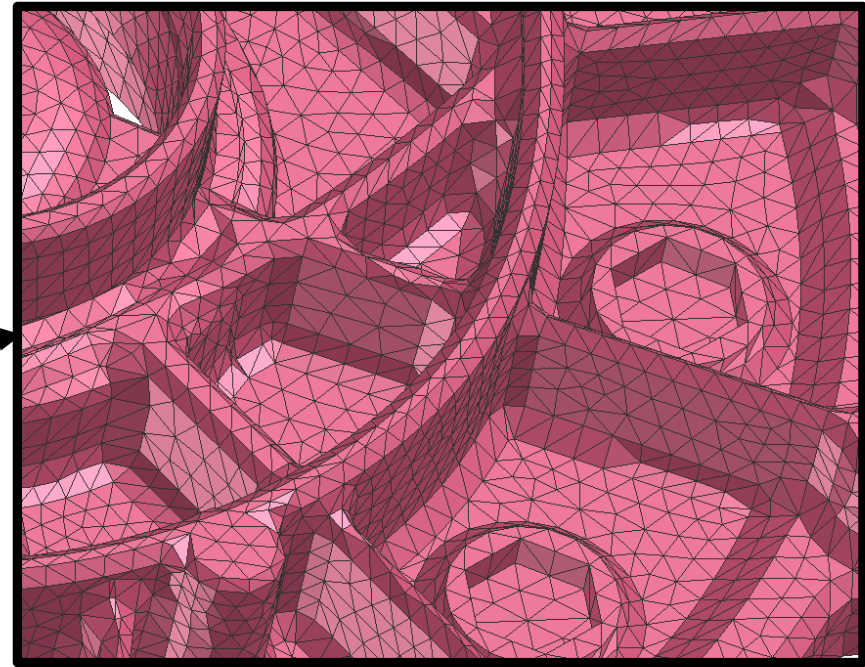
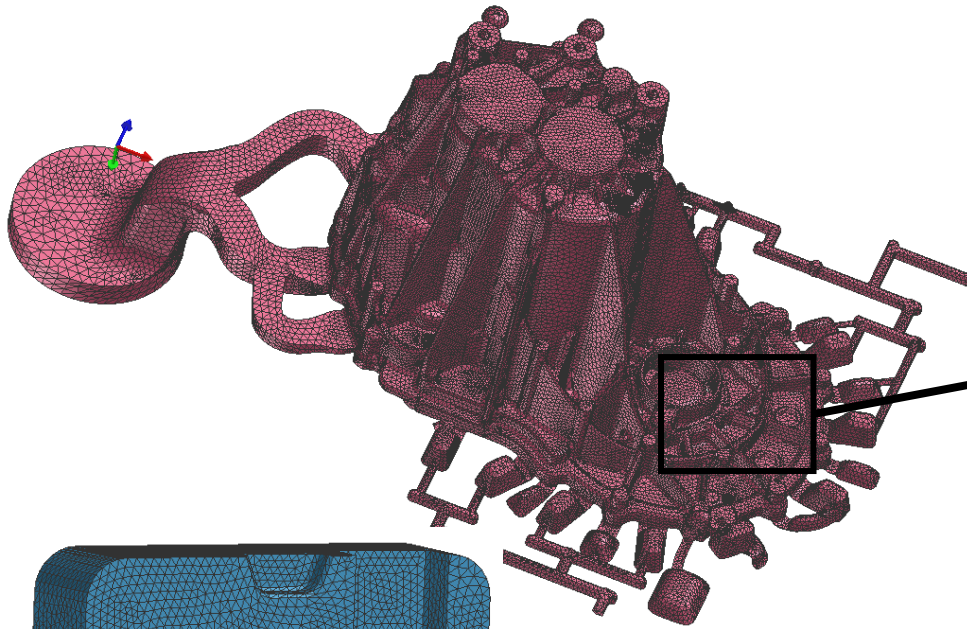
Geometry of tool assembled with cold chamber set



Casting distributor

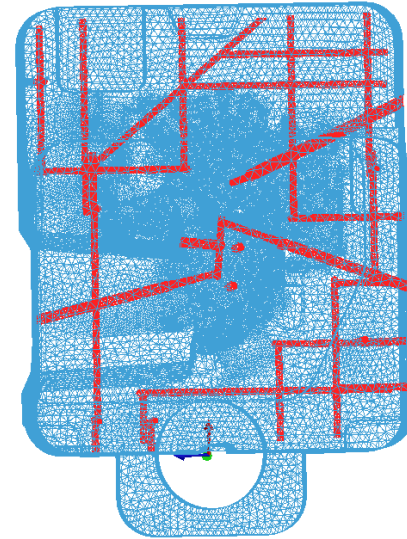
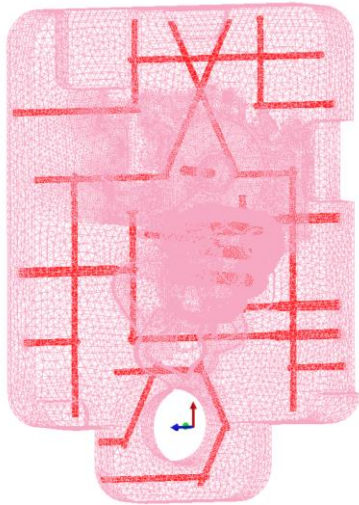
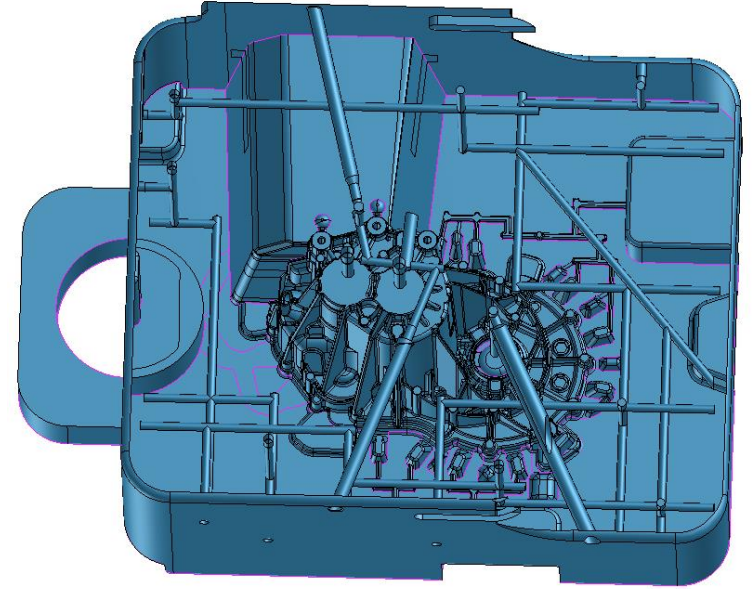
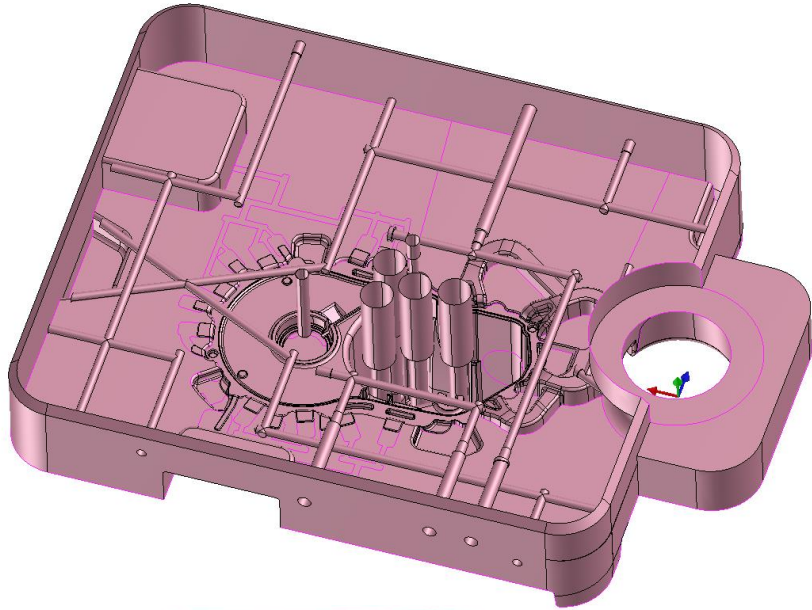


Surface mash for FEM analyses





The layout of cooling and heating channels



Fixed side of die

Moveable side of die



Boundary conditions

Heat transfer condition
Temperature

File Database Options

DieCombo

Public User Model

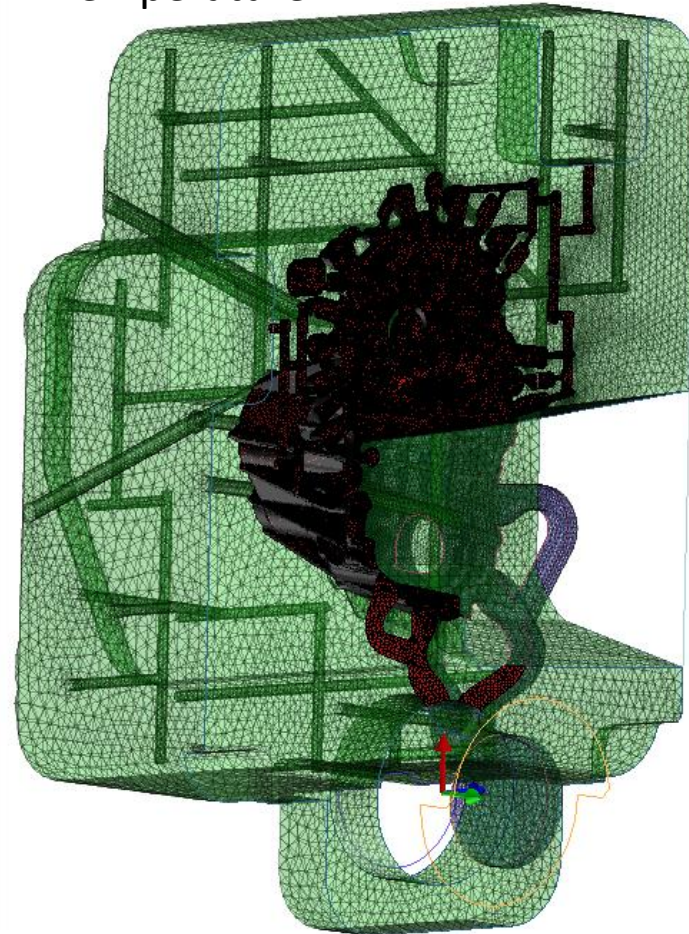
DieCombo

- pomicna_MLM
- fiksna_MLM

Name	pomicna_MLM		
User/Date	AmirHP 5/25/2015		
Note			

Property	Value	Temp	Time
H. T. Coefficient	1.5000e+003	W/m ² -K	sec
Air Coefficient	2.0000e+001	W/m ² -K	
Air Temperature	2.0000e+001	C	
Spray Coefficient	8.0000e+002	W/m ² -K	
Spray Temperature	2.0000e+001	C	
Blow Coefficient		W/m ² -K	
Blow Temperature		C	
Attach until ejection	Yes		
Time Details			
Mold Open	sec		
Mold Close			
Spray Start			
Spray End			
Blow Start			
Blow End			

Save Cancel Close



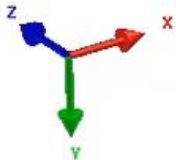
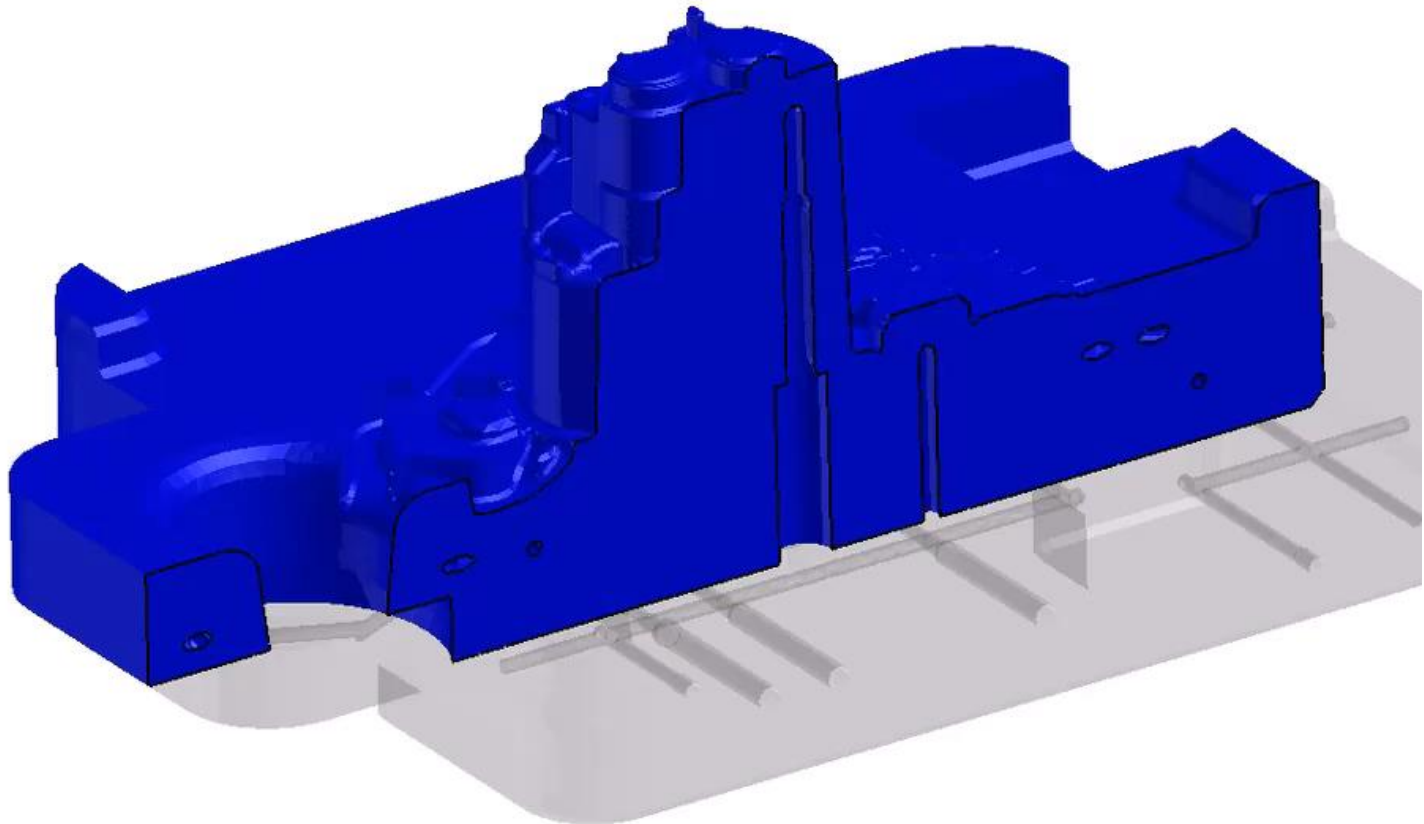


Cycling calculation, fixed side of the toll

Temperature [C]

T_1763

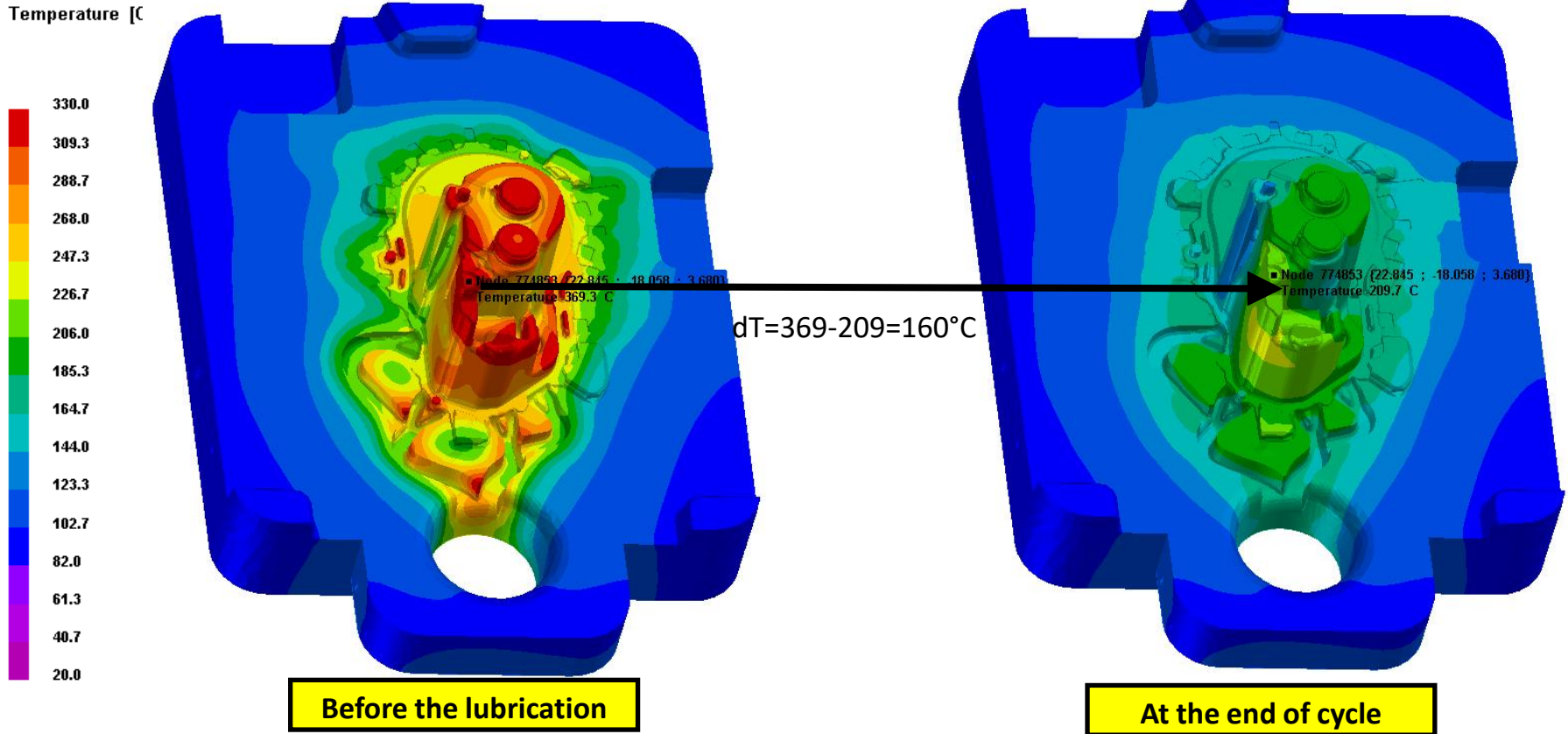
Step No / Time Step : 0 / 1.000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0
Cycle Time / Cycle : 0.0000 / 1



ProCAST



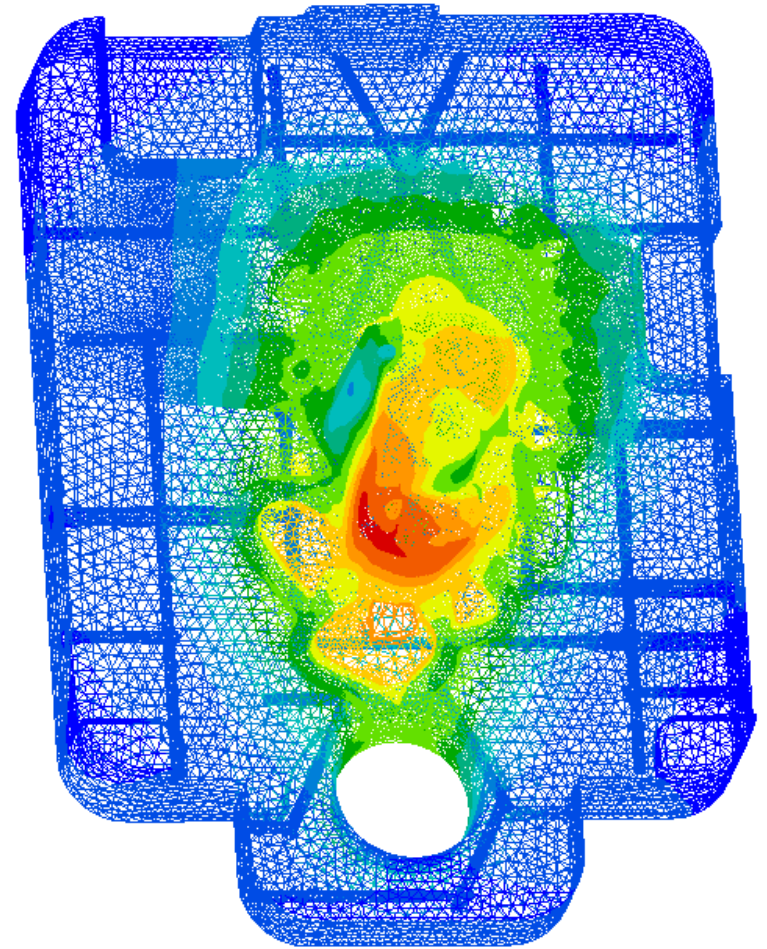
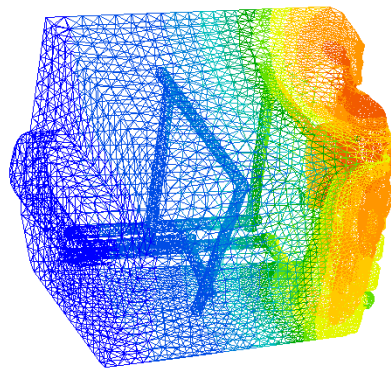
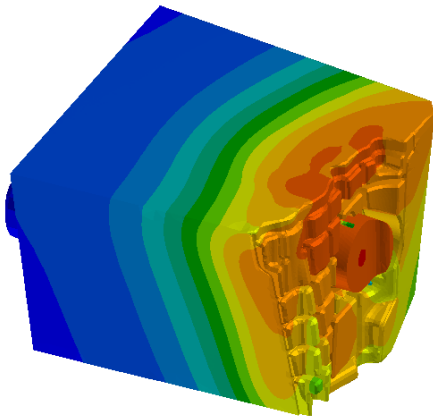
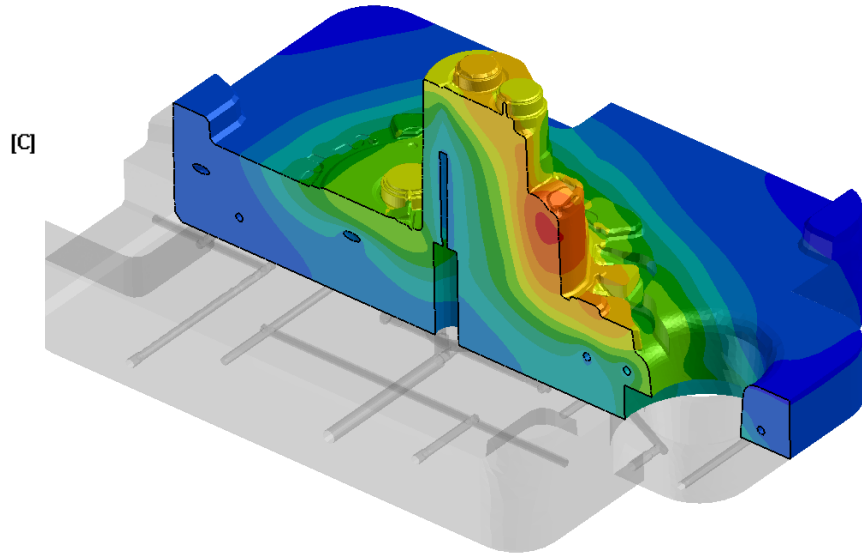
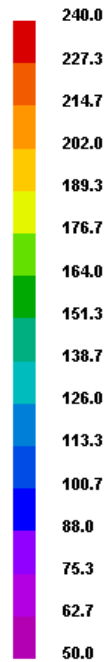
Cycling calculation on fixed side of die after 10 cycle





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

Temperature [C]



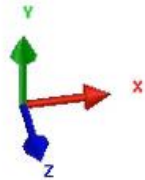
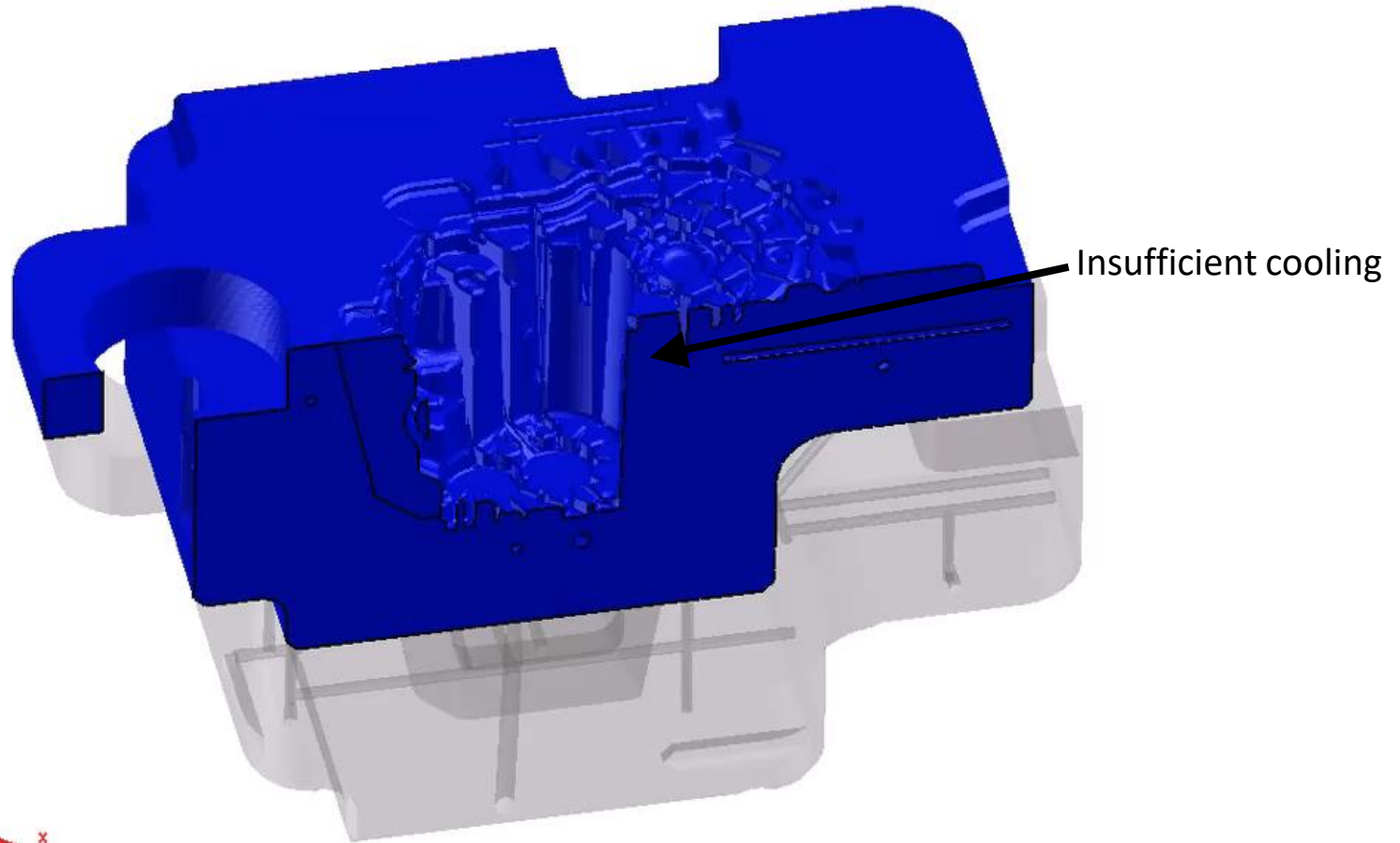


Cycling calculation on moveable side of die for 10 cycles

Temperature [C]

T_1763

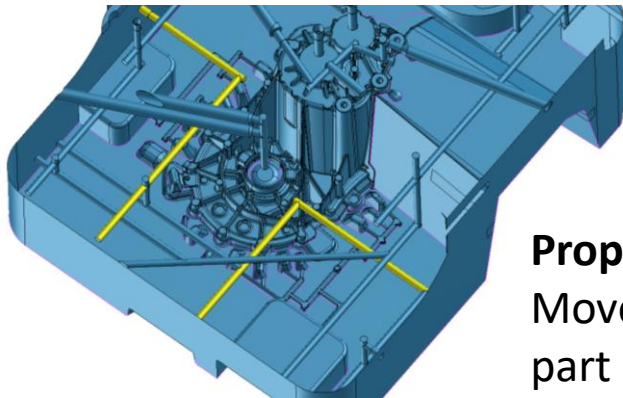
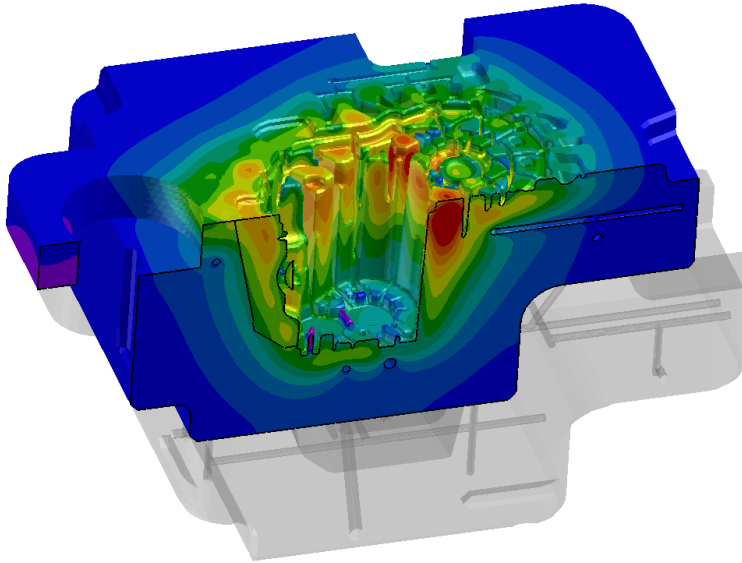
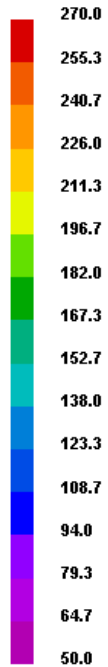
Step No / Time Step : 0 / 1.000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0
Cycle Time / Cycle : 0.0000 / 1





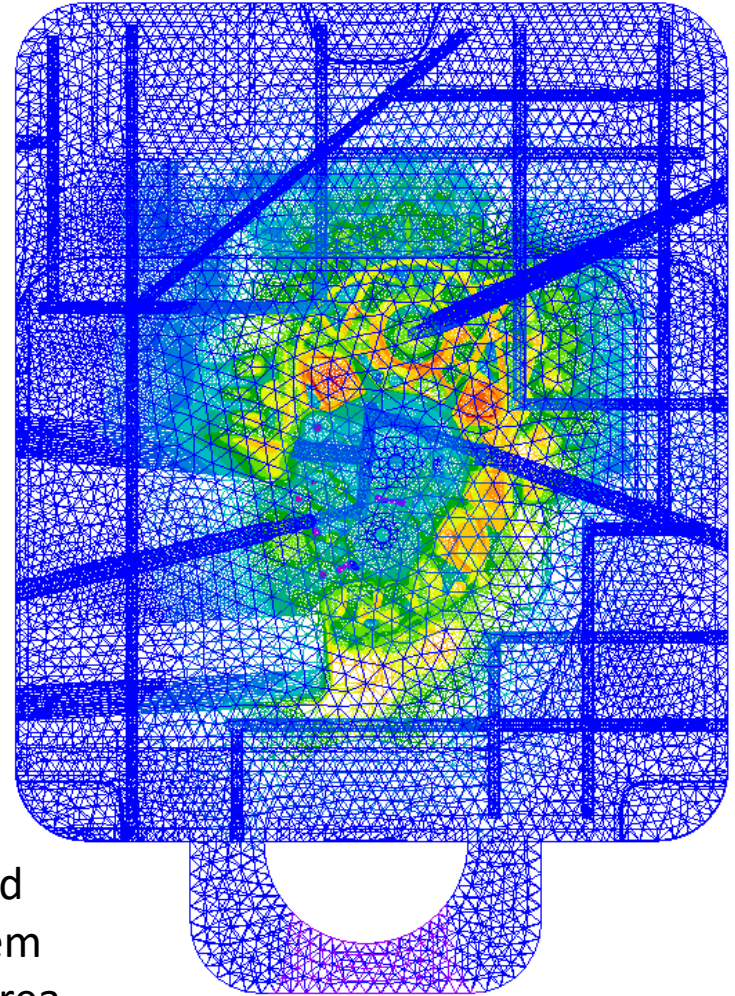
Cycling calculation on moveable side of die for 10 cycles - steady state temperature field

Temperature [C]



Proposed solution

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





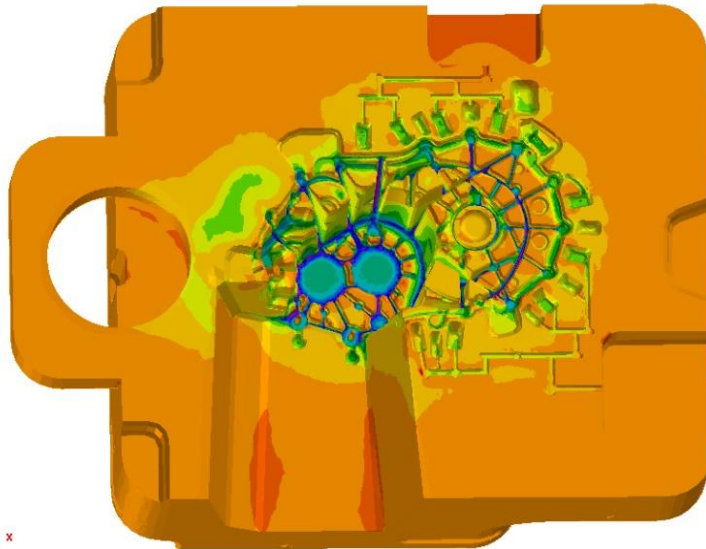
The calculation of normal stresses in the tool

Average Normal Stress [MPa]

T_1763

Step No / Time Step : 120 / 2.500e-001
Simulated Time : 18.2050 sec
Percent Filled : N/A
Fraction Solid : 91,4
Cycle Time / Cycle : 18.2050 / 1

t = 18s



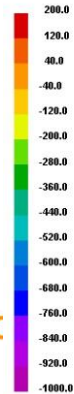
ProCAST

Average Normal Stress [MPa]

T_1763

Step No / Time Step : 320 / 2.500e-001
Simulated Time : 51.9550 sec
Percent Filled : N/A
Fraction Solid : 98,4
Cycle Time / Cycle : 51.9550 / 1
Begin Spray

t = 52s



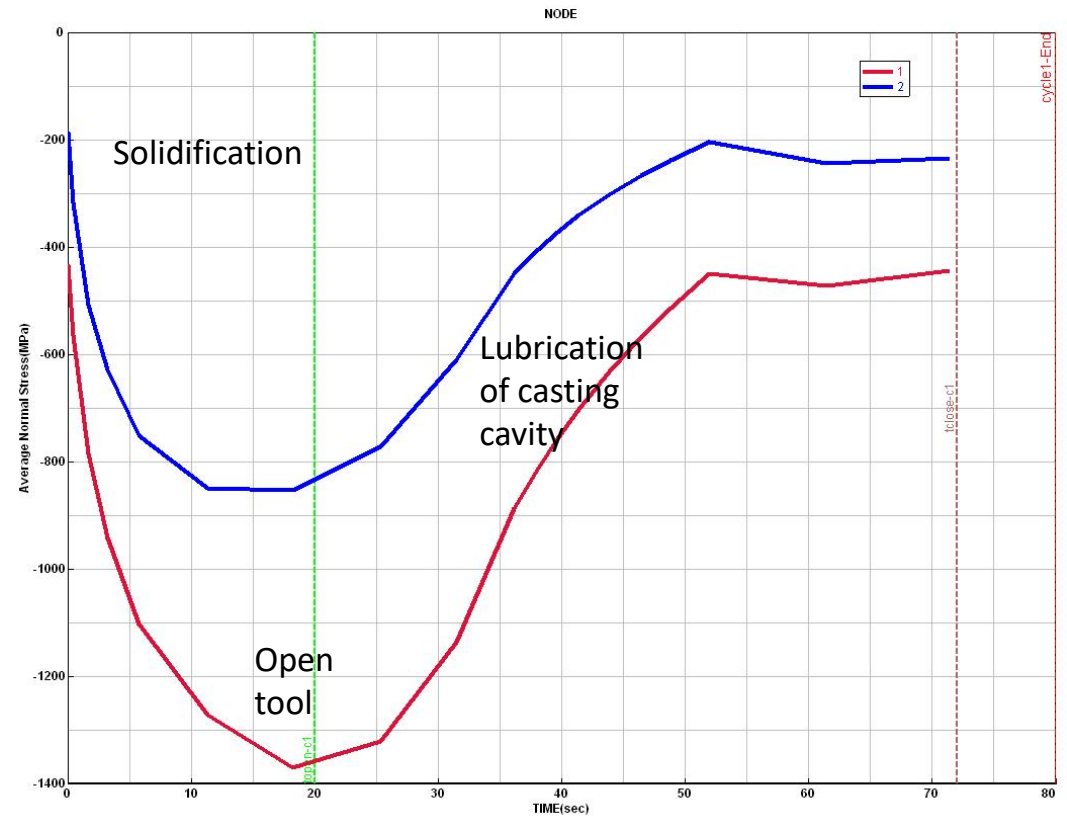
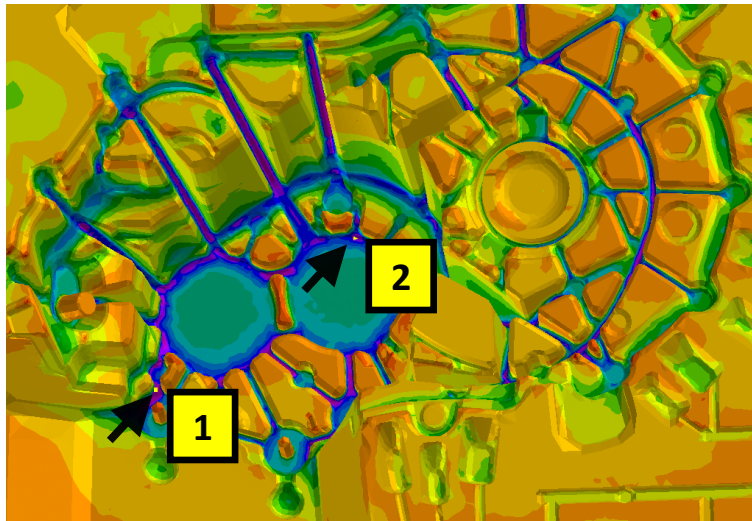
ProCAST

At the end of cycle

Before the lubrication

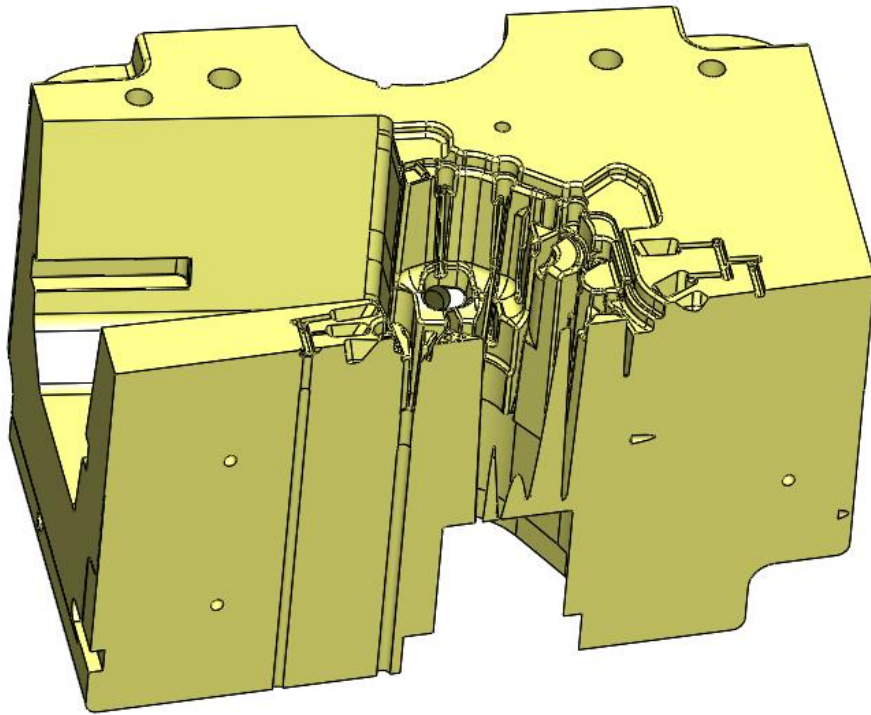


The calculation of normal stresses in the tool – stable side of the tool

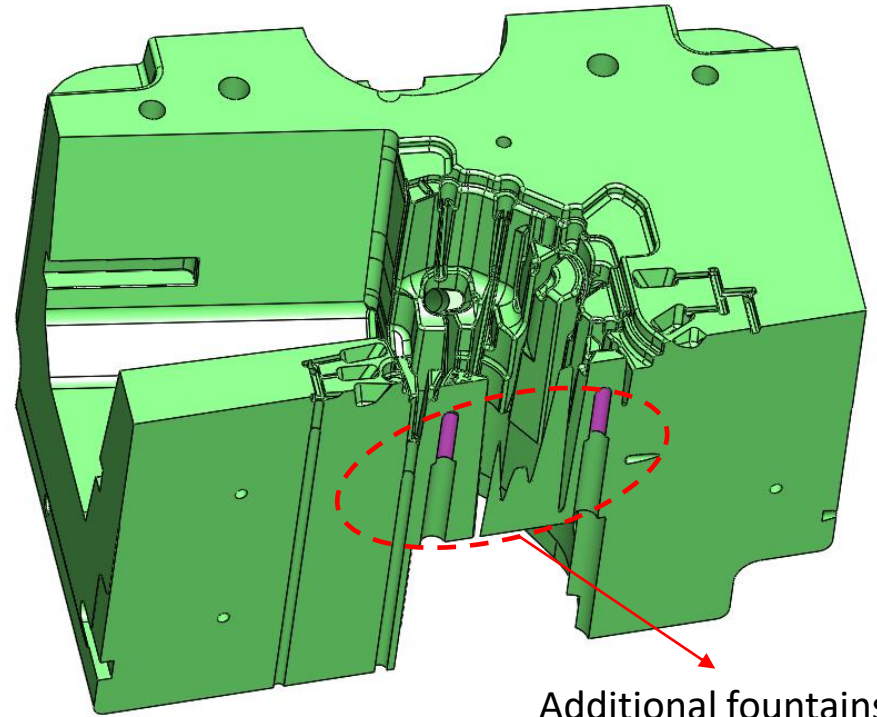




Optimization of the movable side of the tool



Ver. 1

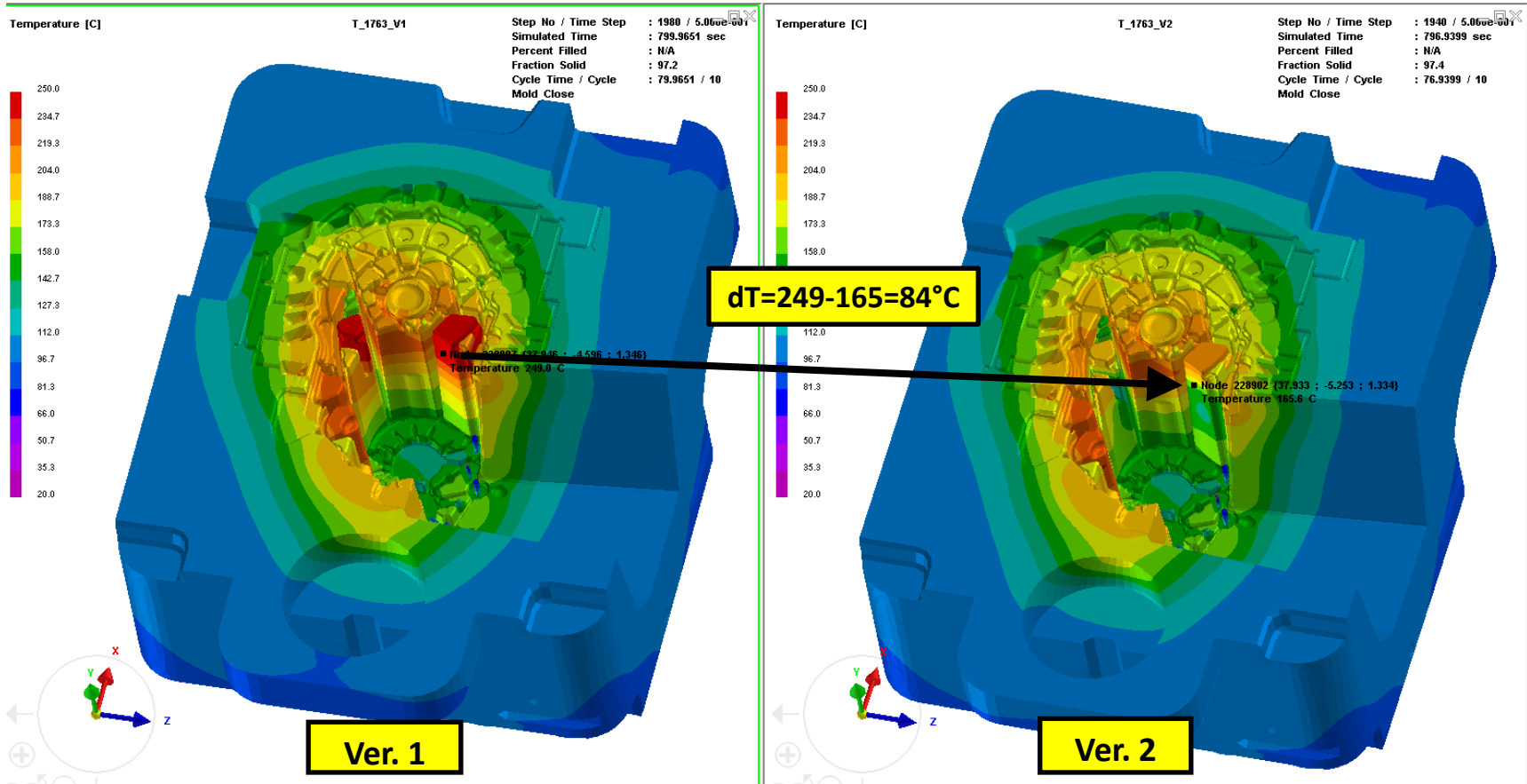


Additional fountains

Ver. 2

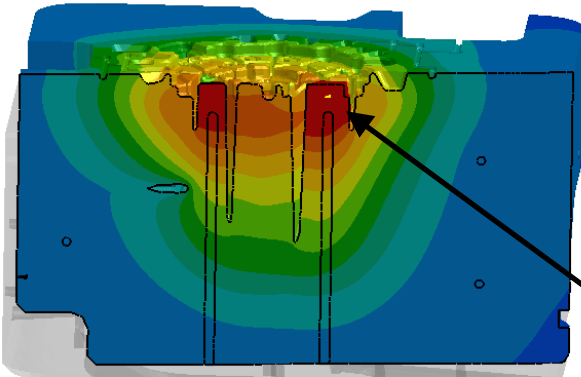


The calculation of the temperature field after 10th cycle

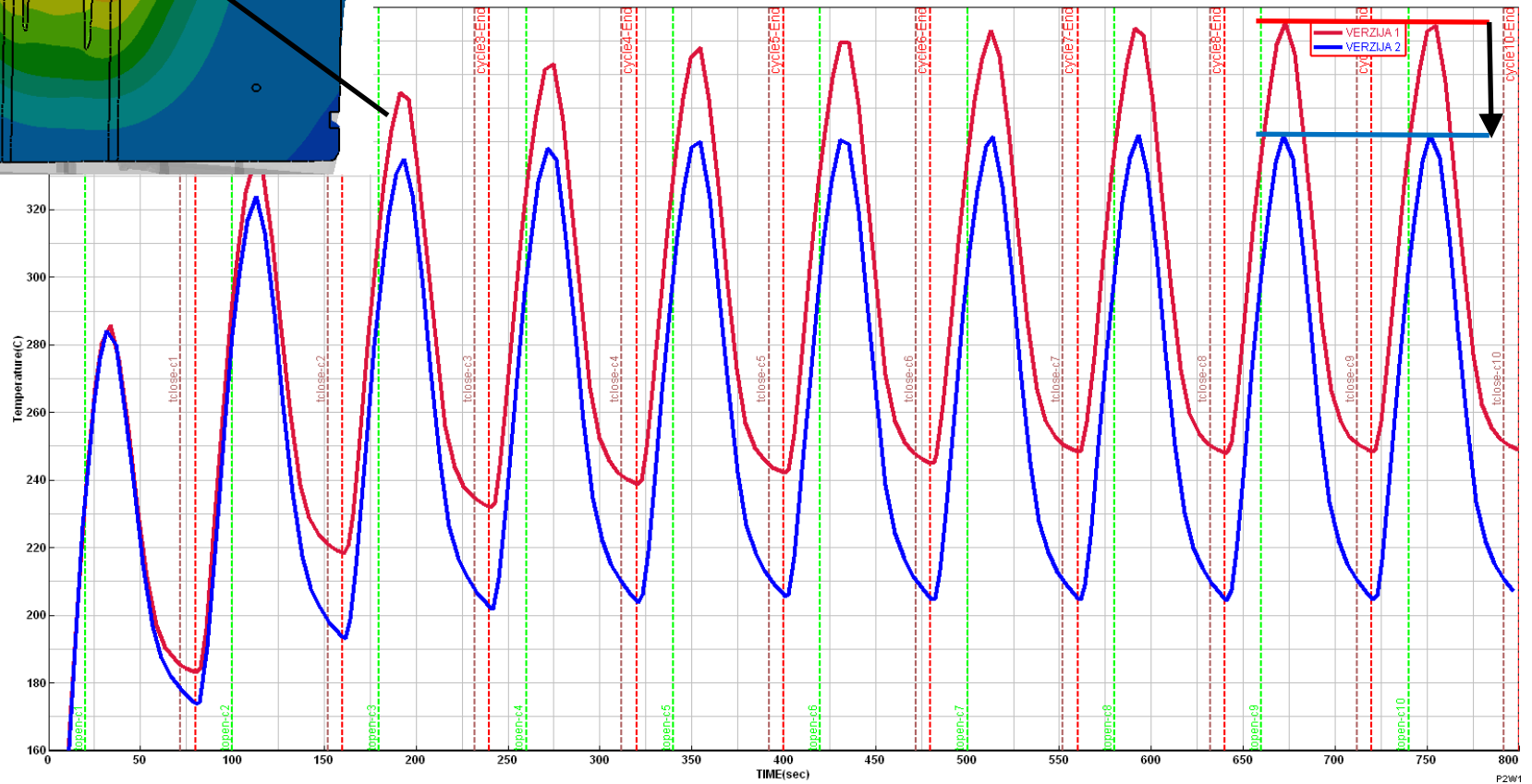




Calculation of temperature for variant 1 and 2

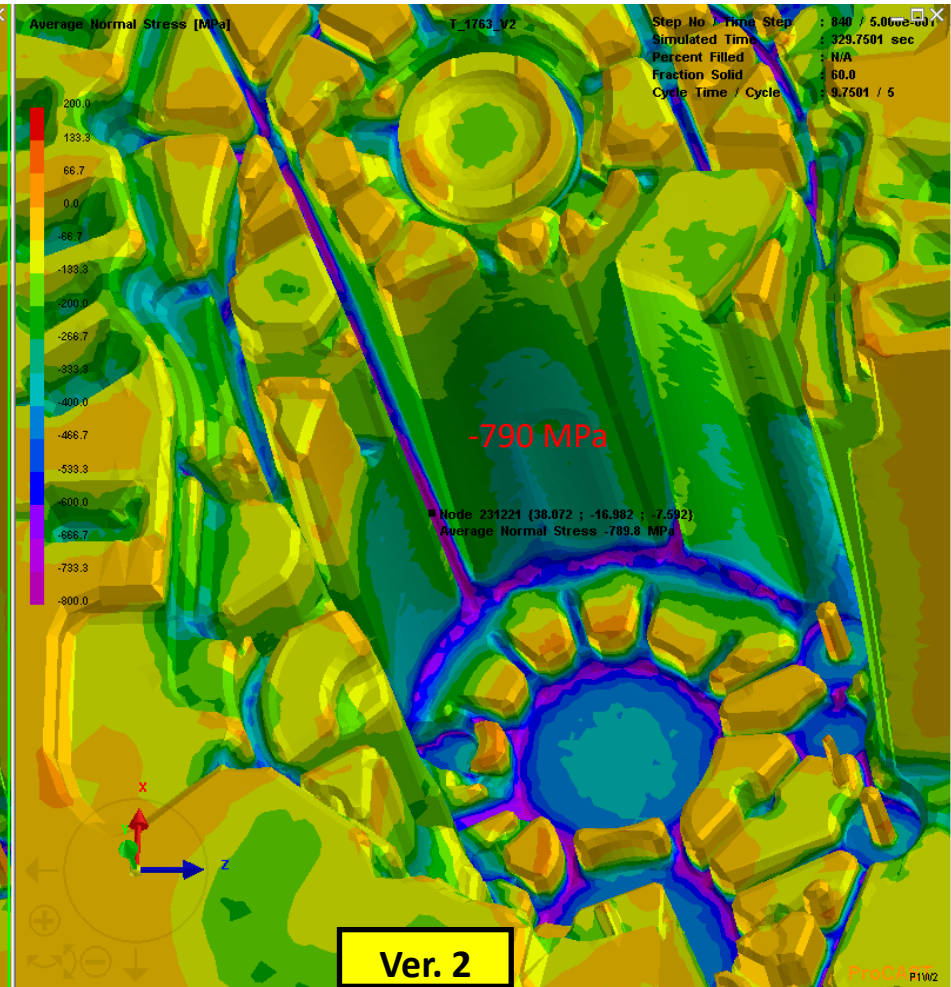
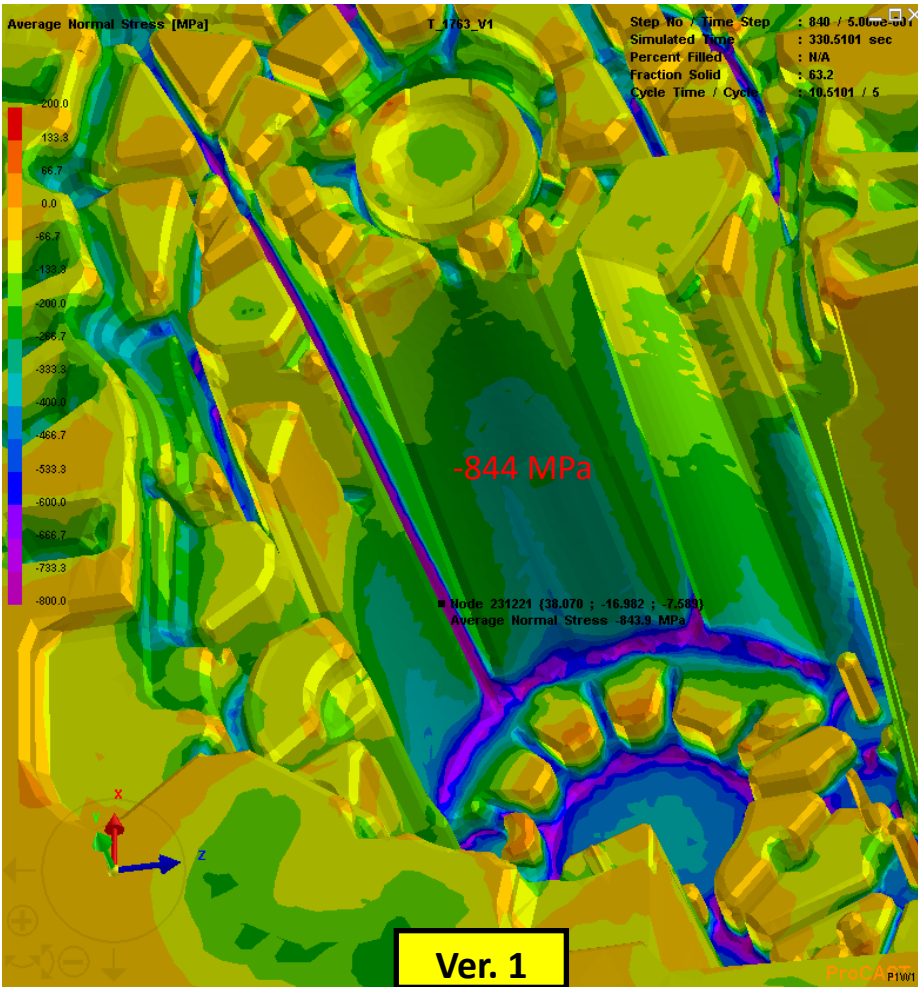


$dT=375-341=34^{\circ}\text{C}$



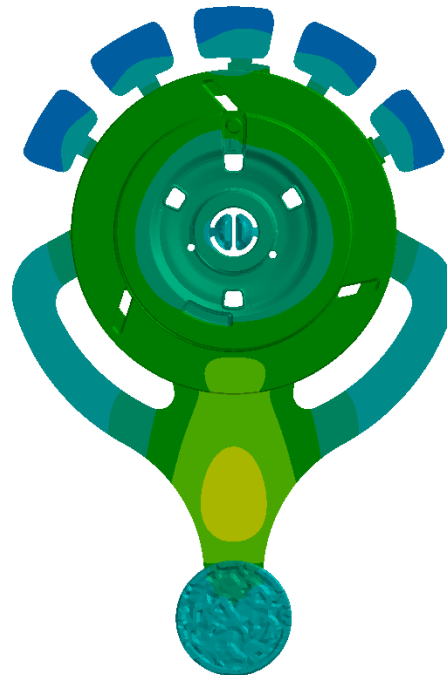
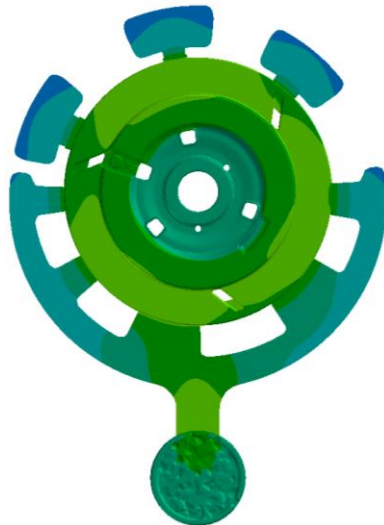
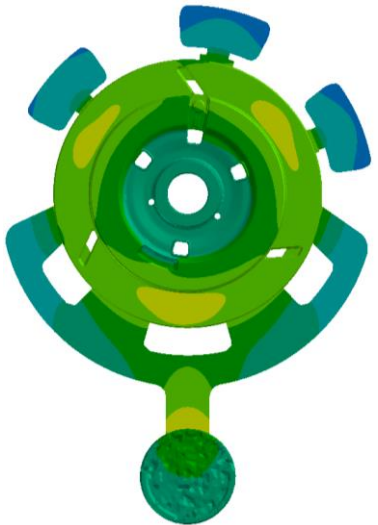
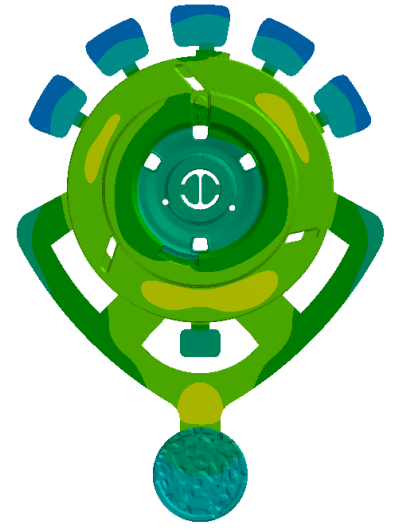
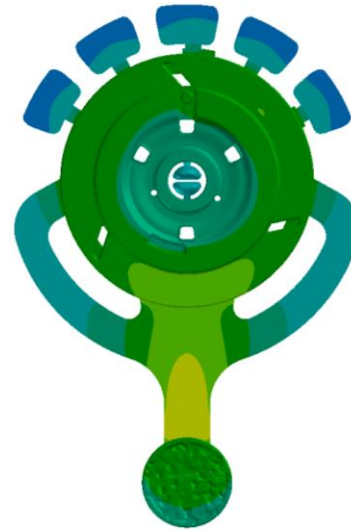
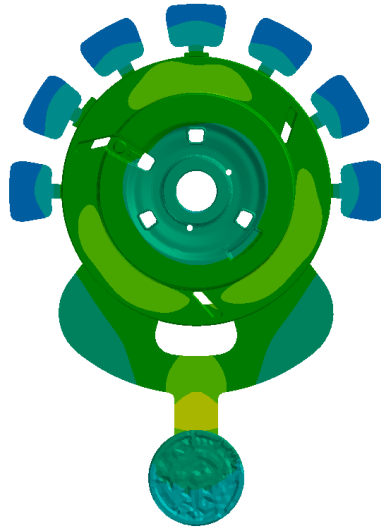


The calculation of normal stresses in the tool





Calculation of pouring – different gating system



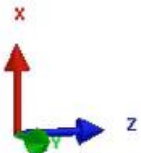
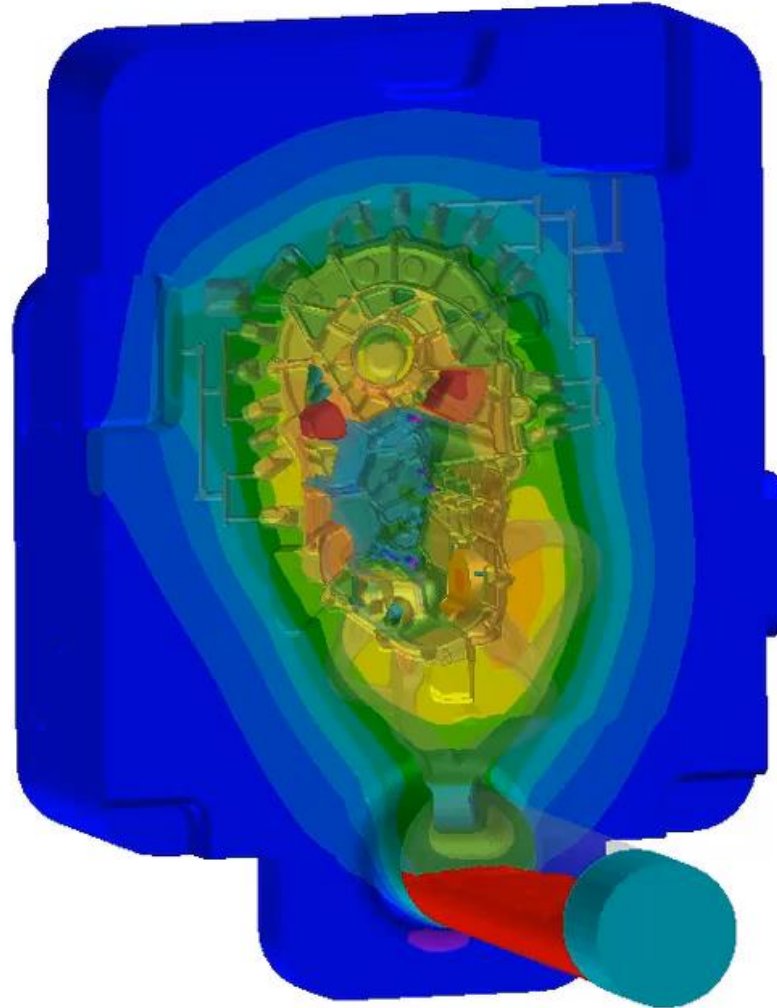
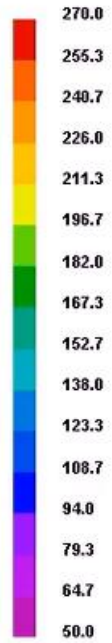


Calculation of pouring

Temperature [C]

T_1763

Step No / Time Step : 24 / 7.235e-003
Simulated Time : 0.1126 sec
Percent Filled : 32.7
Fraction Solid : 0.0



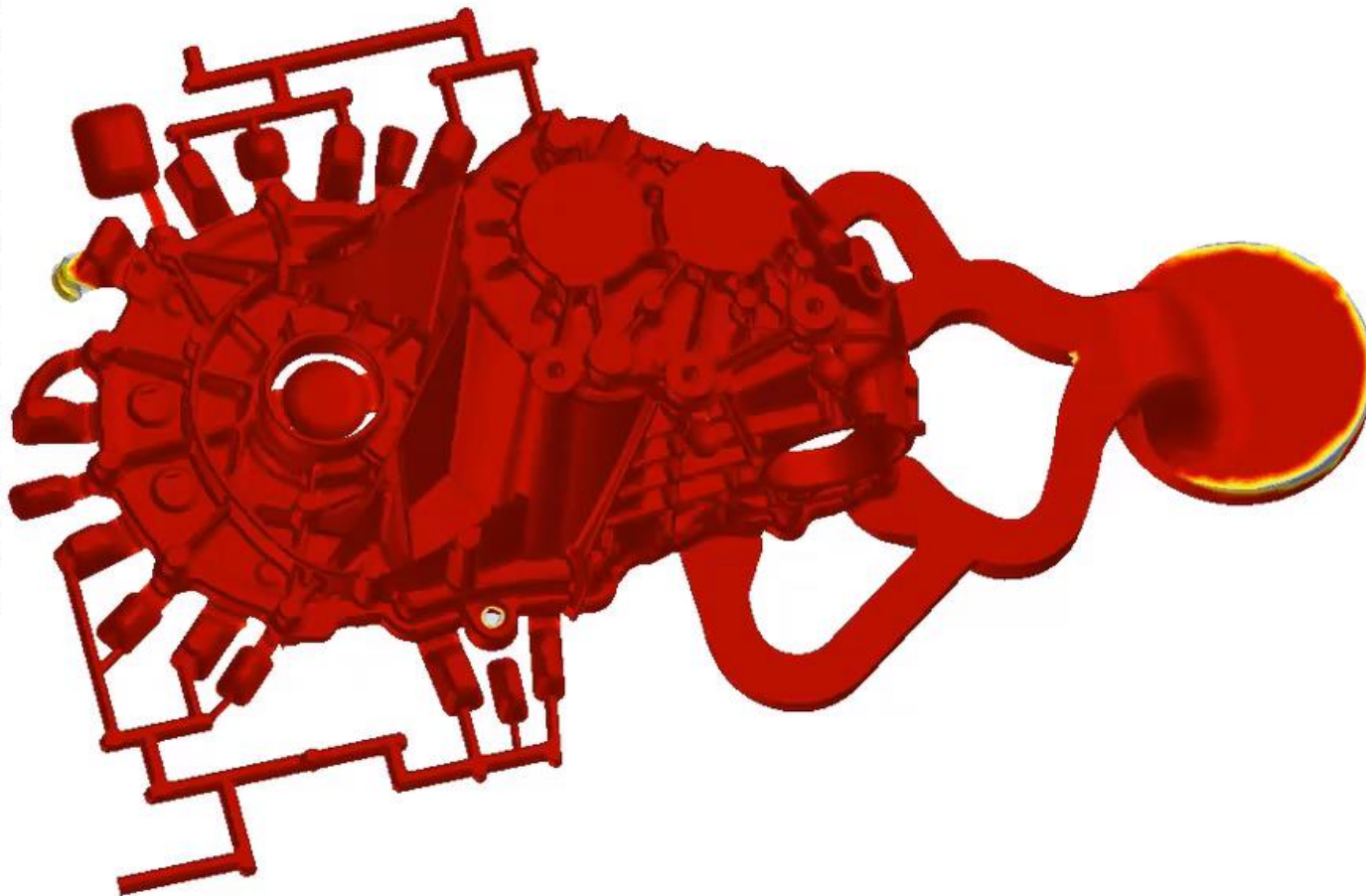
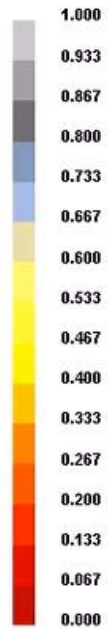


Calculation of solidification sequence

Fraction Solid

T_1763

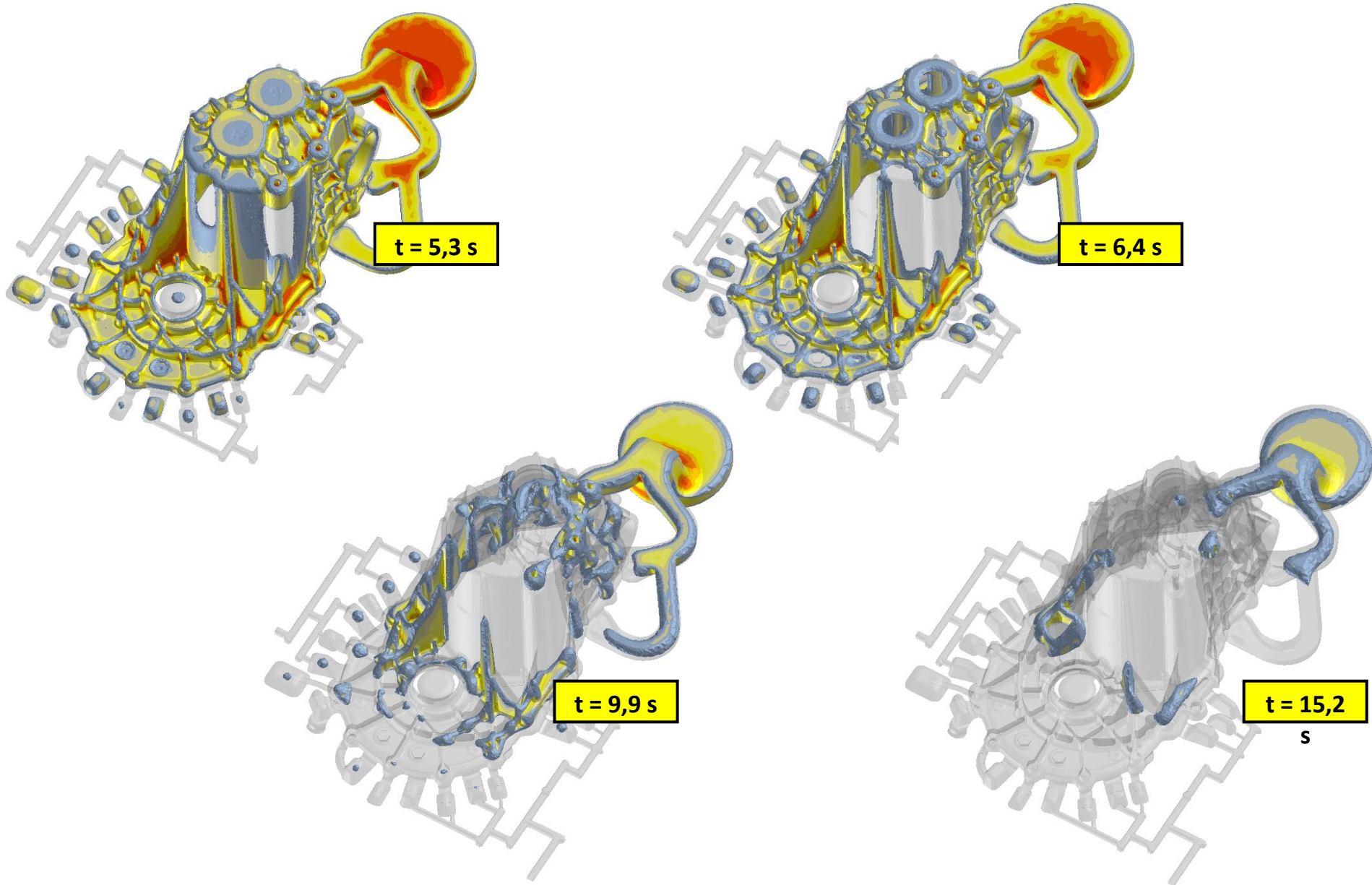
Step No / Time Step : 14 / 4.000e-002
Simulated Time : 0.2250 sec
Percent Filled : N/A
Fraction Solid : 0.1



ProCAST



Calculation of solidification sequence versus time

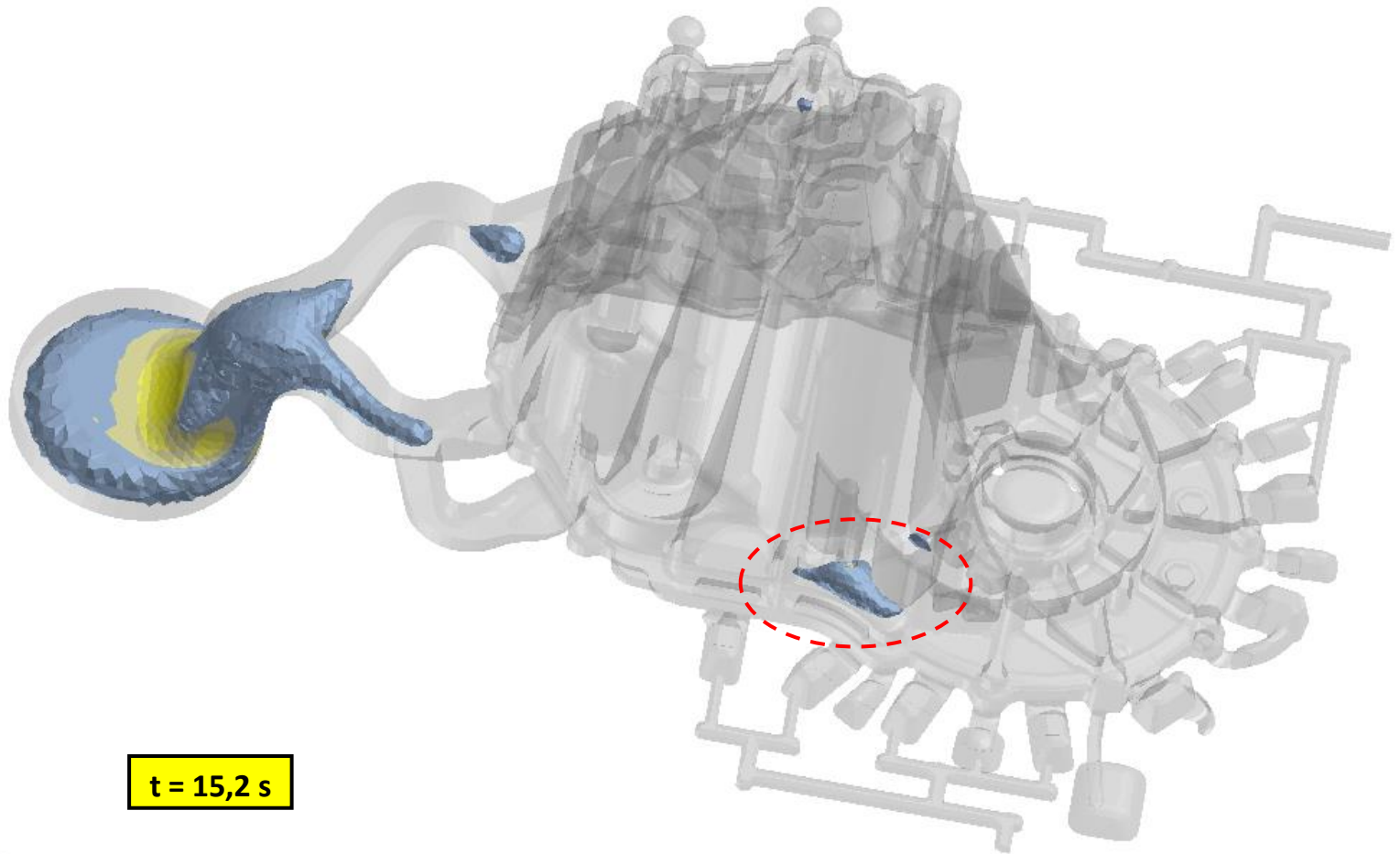
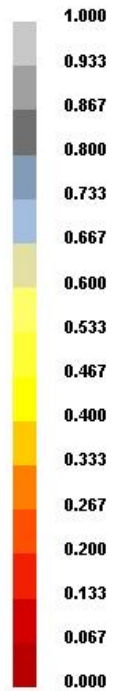




Last solidified areas in the casting

Fraction Solid

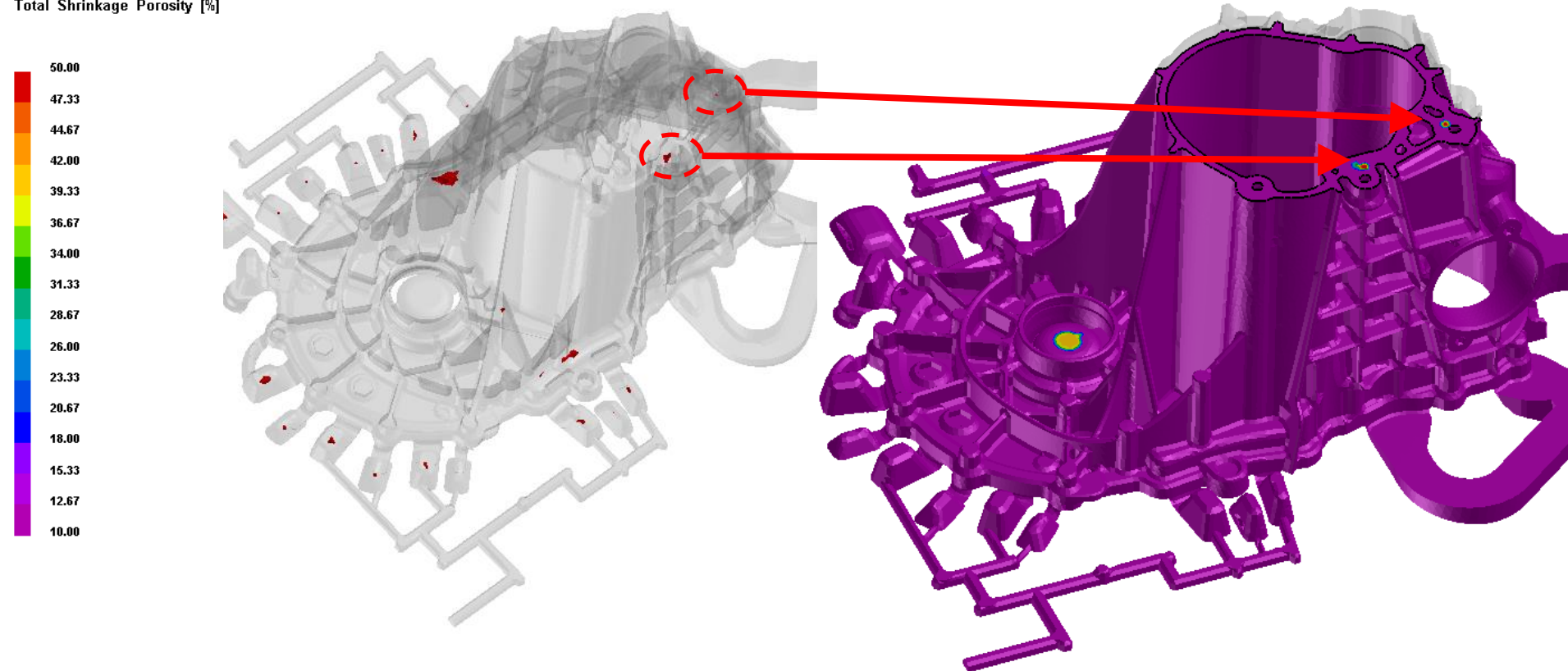
T_1763





Calculation of porosity

Total Shrinkage Porosity [%]

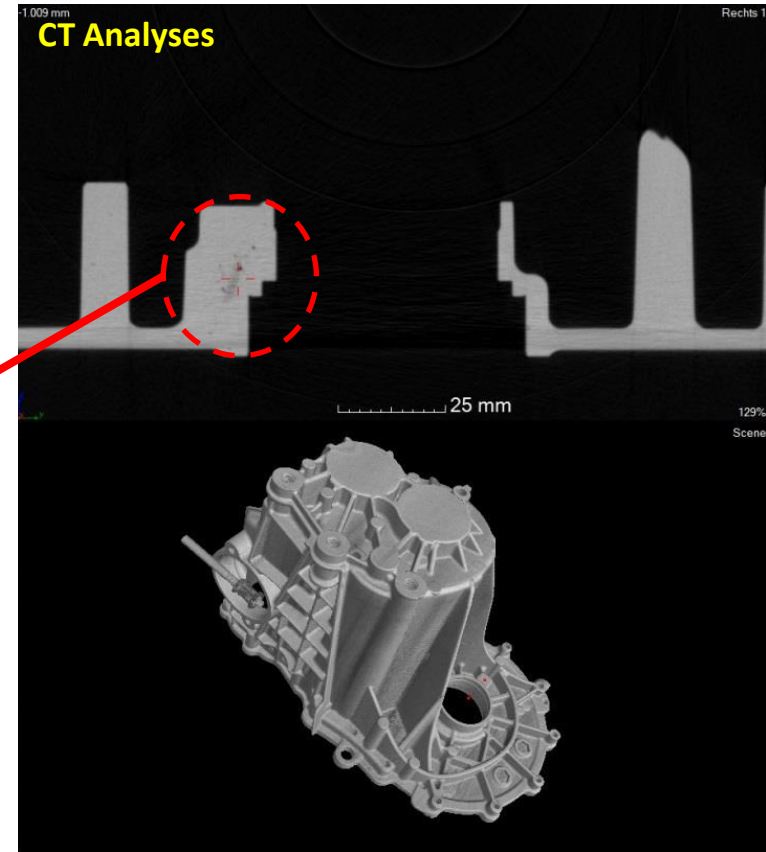
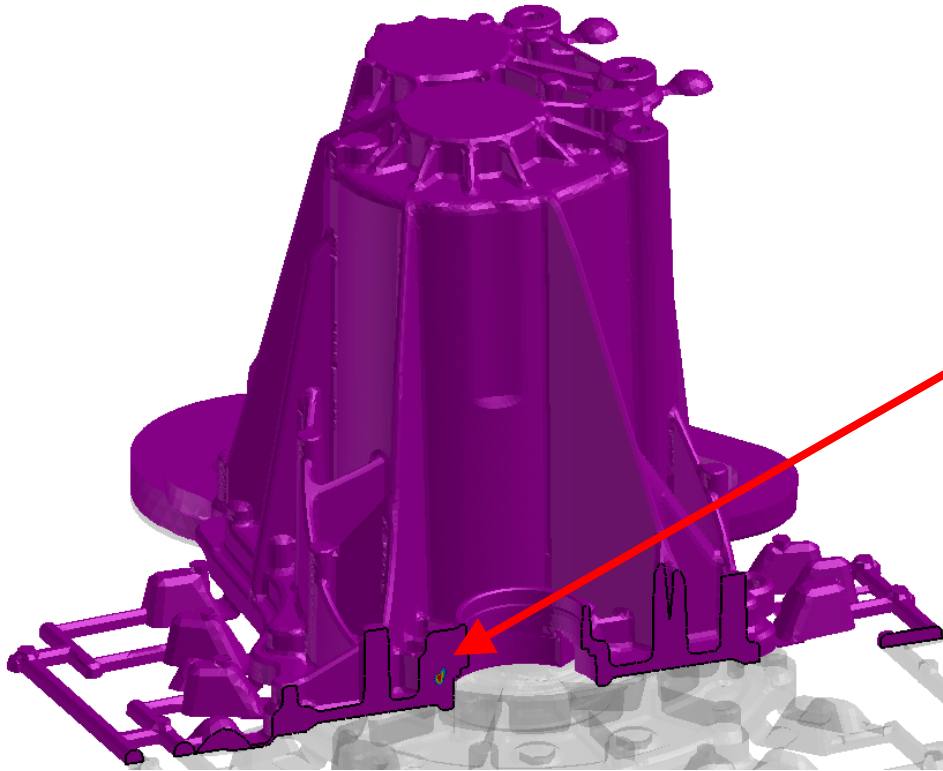
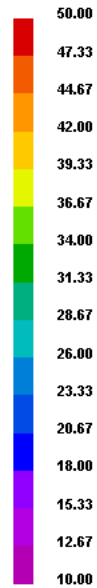


Presented shrinkage porosity areas are not allowed, with local squeezing technique can be eliminated.



Comparison of calculated and experimental shrinkage porosity

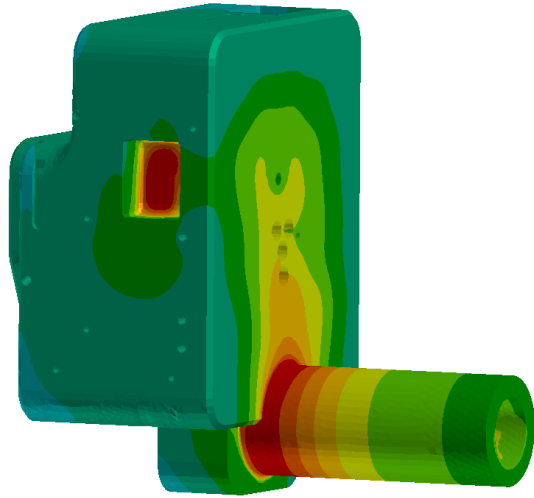
Total Shrink



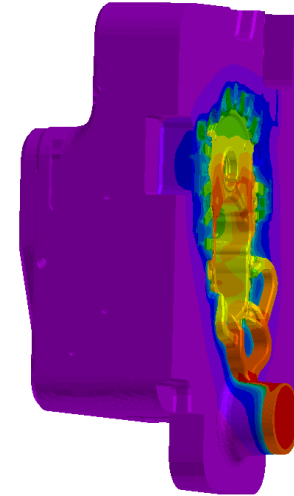


Calculation of the stress and deformation for each sequences after the solidification

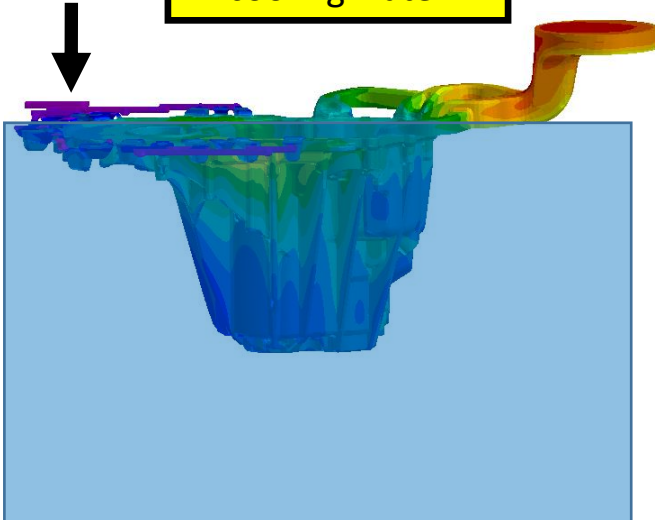
closed tool



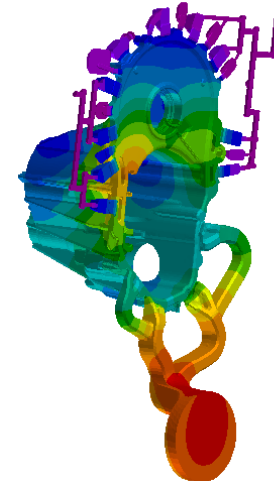
open tool



cooling water



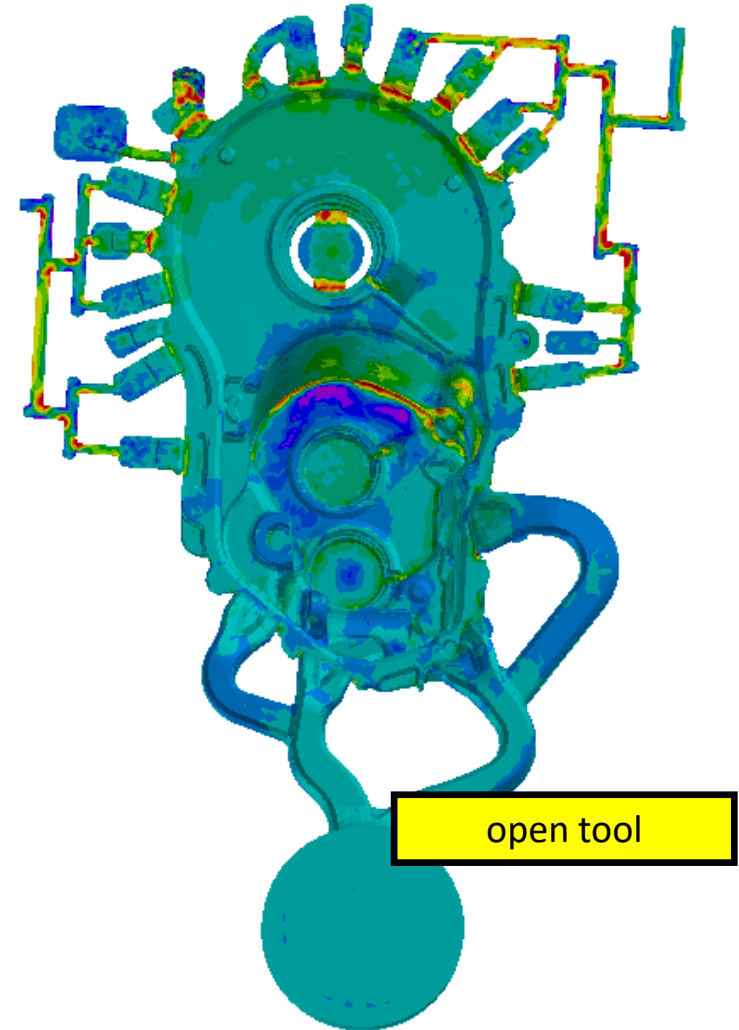
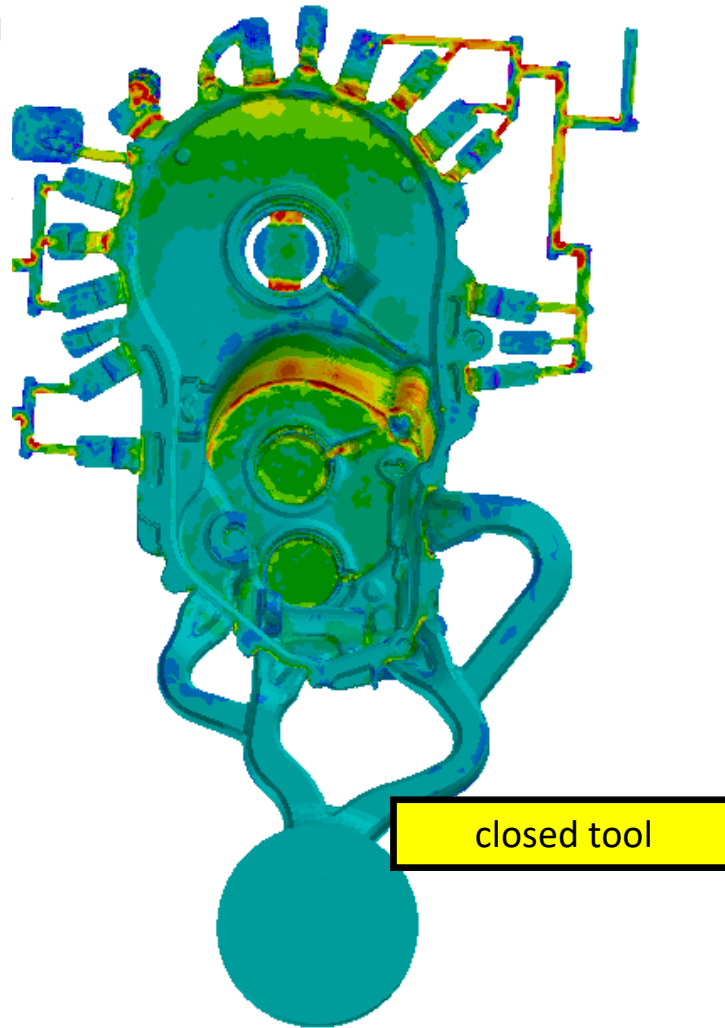
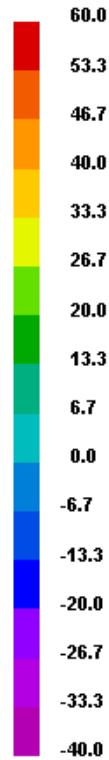
ejection of casting





Relaxation of normal stresses in the casting after the die opening

Average Normal Stress [MPa]

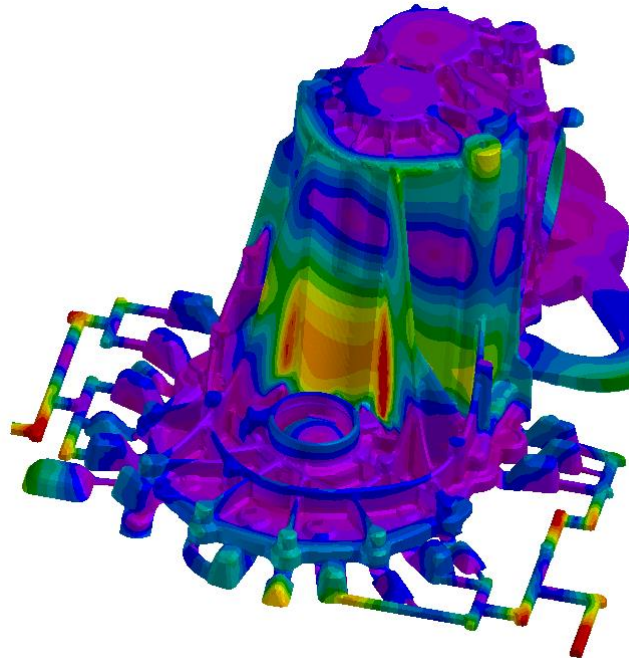




Calculation of the shrinkage of the casting and the formation of an air gap between the solidification

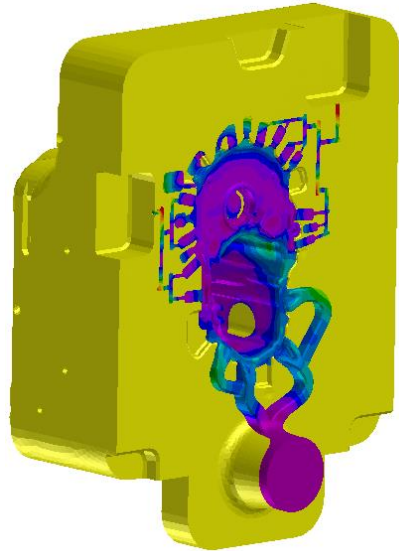
closed tool

Total Displacement [mm]





Deformation of casting

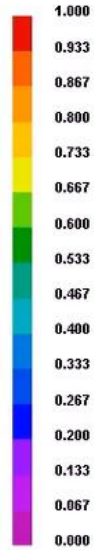


Note: Reference
is sliding away
tools

Mesh Deformation

T_1763

Step No / Time Step : 0 / 1.000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0

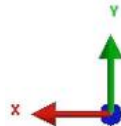


Fixed side of tool

open tool

Moveable side of tool

The deformation of the
casting at 20 x
magnification



ProCAST

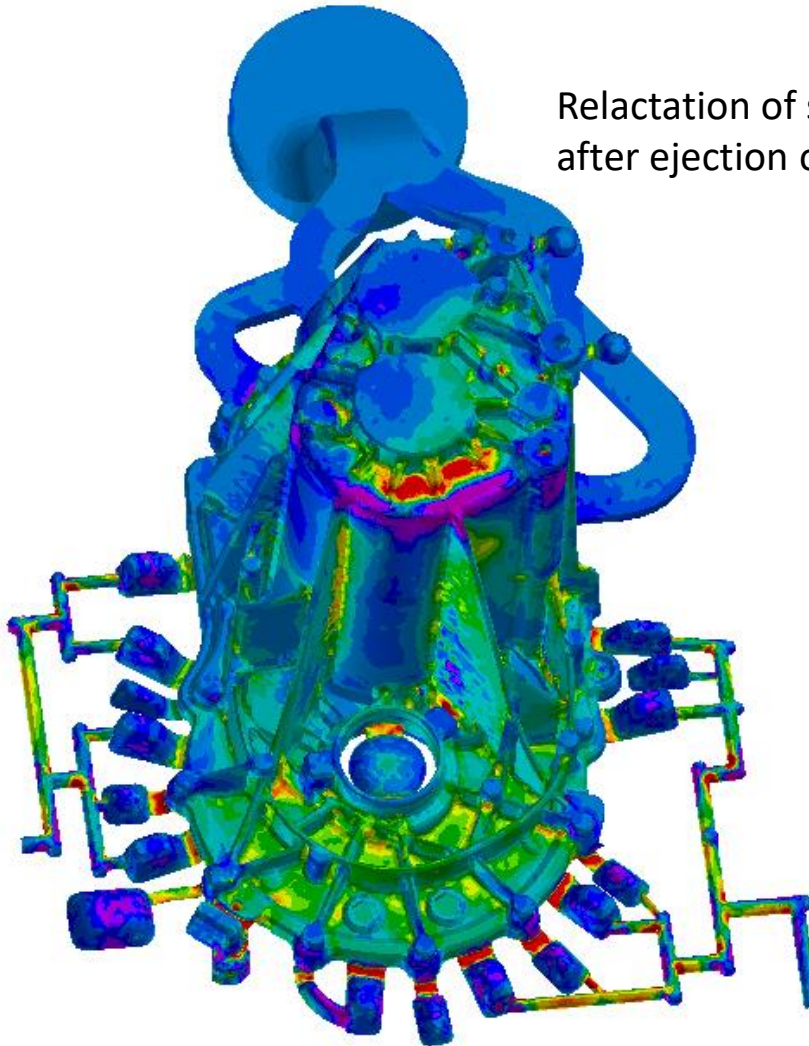


Relaxation of normal stresses in the casting

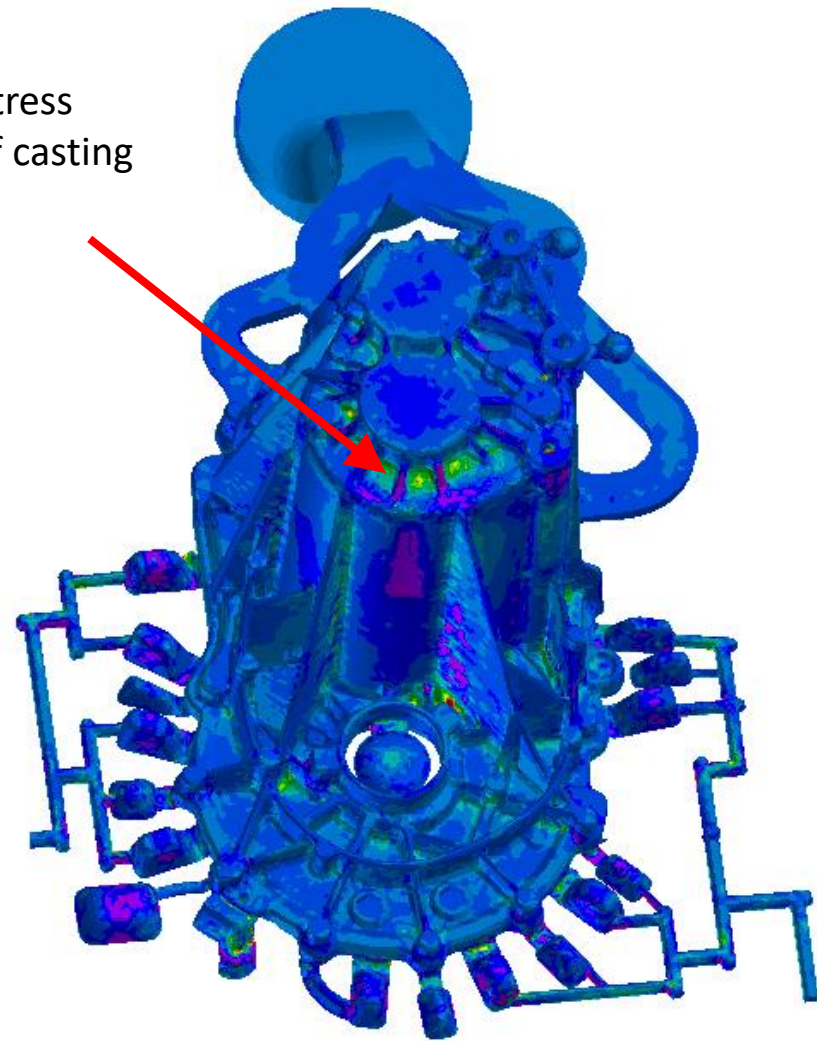
Average Normal Stress [MPa]



Relactation of stress
after ejection of casting



open tool

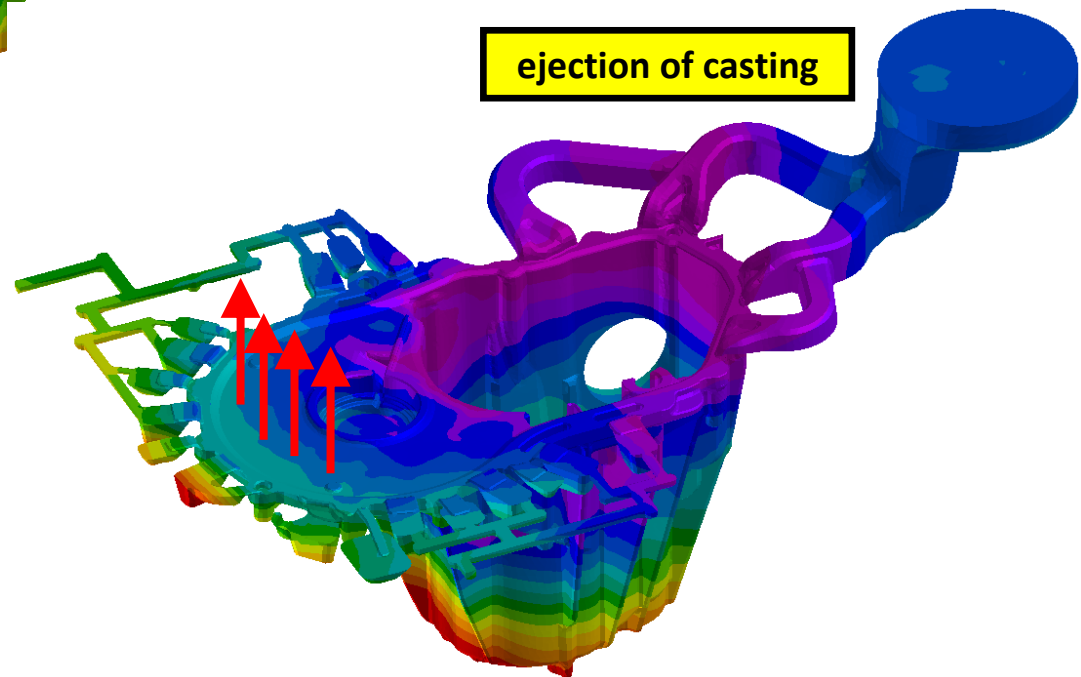
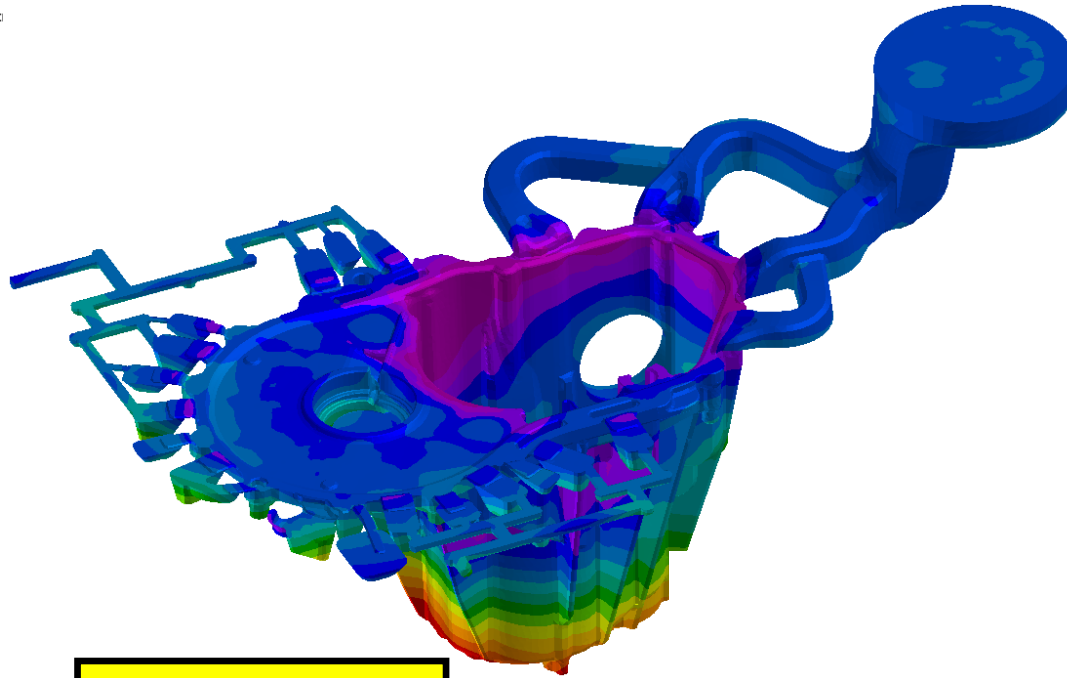
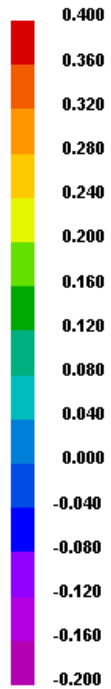


ejection of casting



The deformation of the casting in Y direction

Y Displac



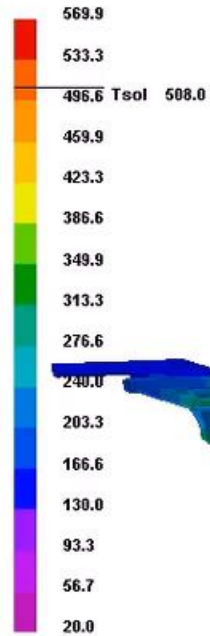


Calculation of the temperature field for the cooling of the cast part in the water

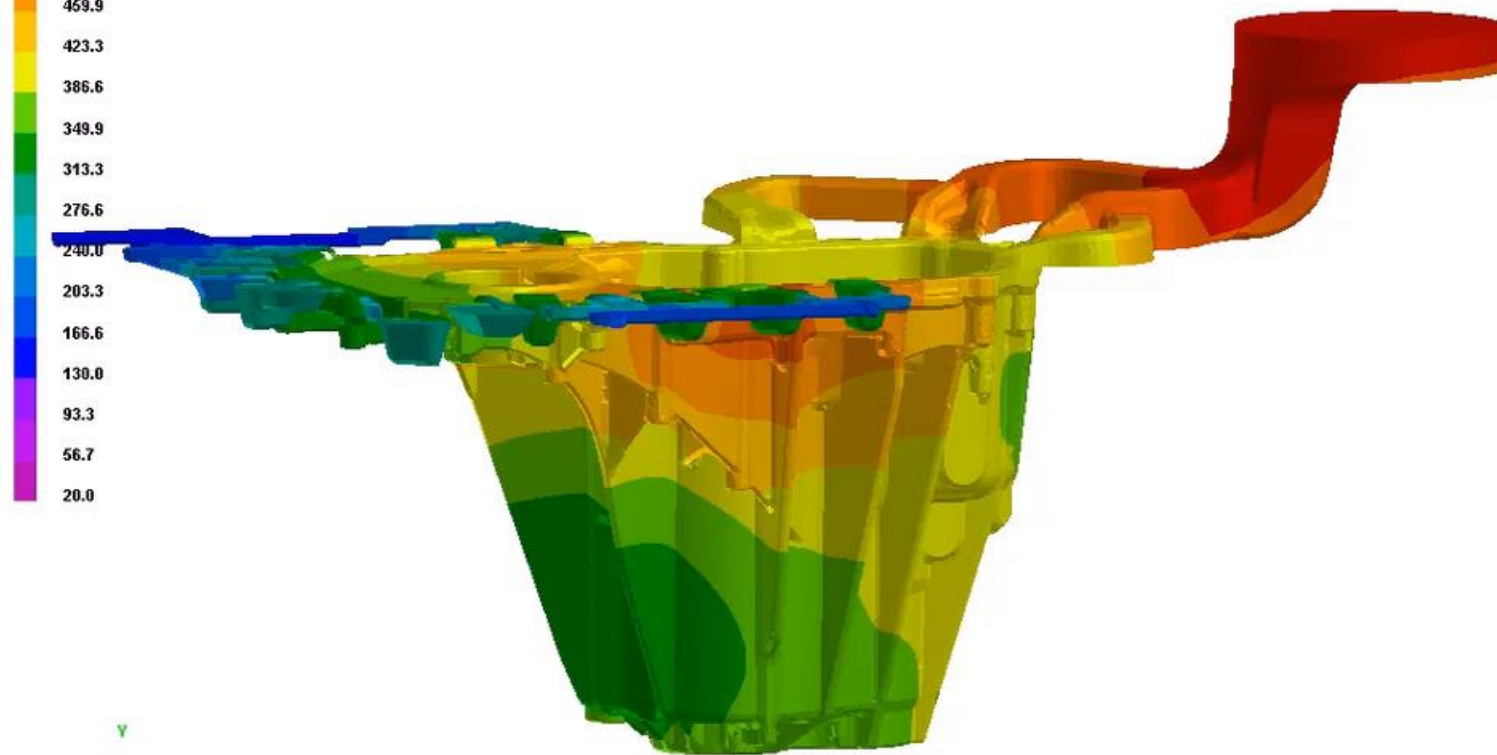
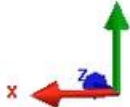
Temperature [C]

T_1763

Step No / Time Step : 0 / 1.000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0



y





Deformation during submerging cast part in the water

Cooling in water

Mesh Deformation

T_1763

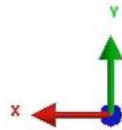
Step No / Time Step : 0 / 1.000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0



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

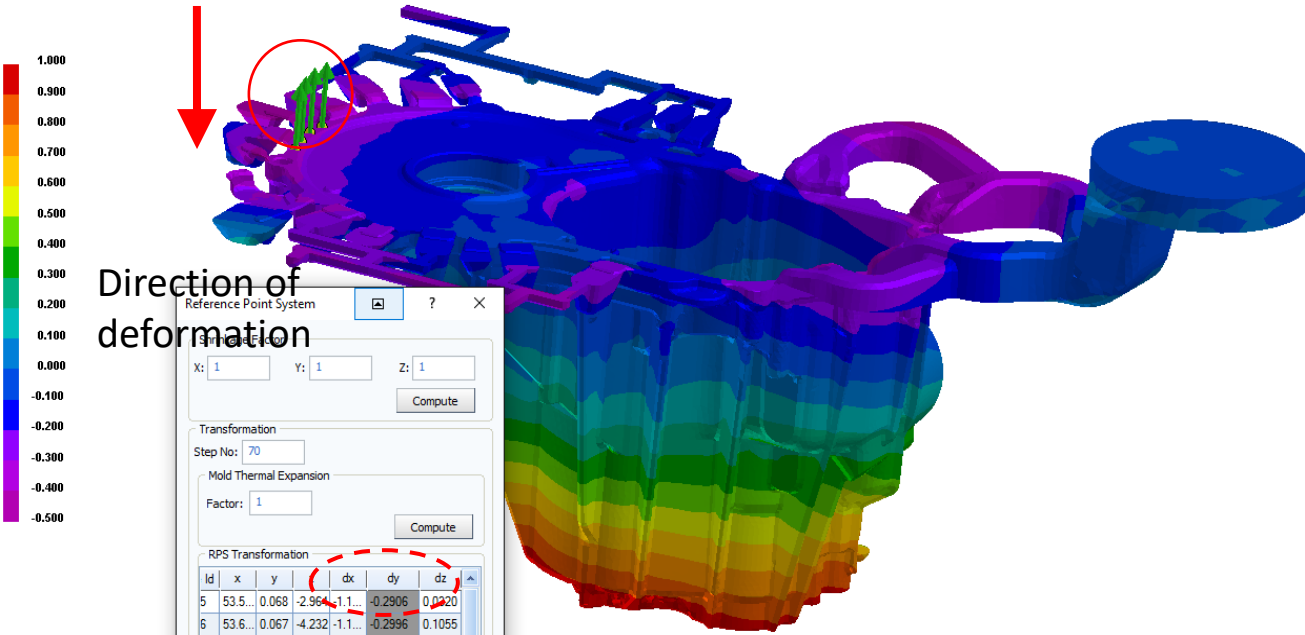




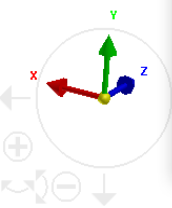
Deformation of casting, after cooling in water

Y Displacement [mm]

T_1763



Direction of deformation



Reference Point System

X: 1 Y: 1 Z: 1

Compute

Transformation

Step No: 70

Mold Thermal Expansion

Factor: 1

Compute

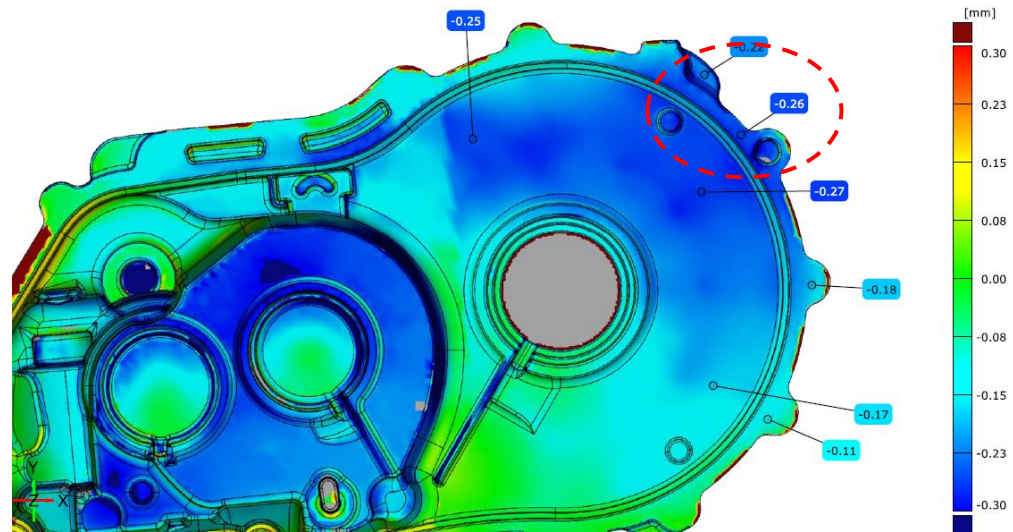
Id	x	y	dx	dy	dz	
5	53.5...	0.068	-2.96...	-1.1...	-0.2906	0.0220
6	53.6...	0.067	-4.232	-1.1...	-0.2996	0.1055
0	53.3...	0.066	-5.825	-1.1...	-0.3094	0.1735
4	53.0...	0.066	-7.098	-1.0...	-0.3086	0.2379

Compute

Close

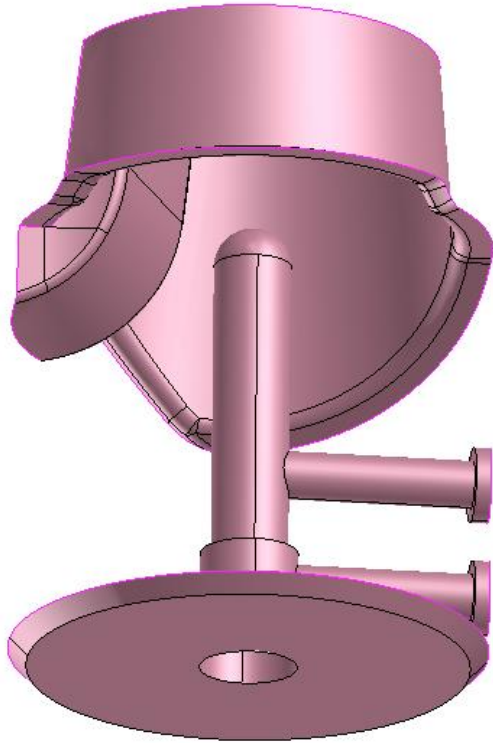
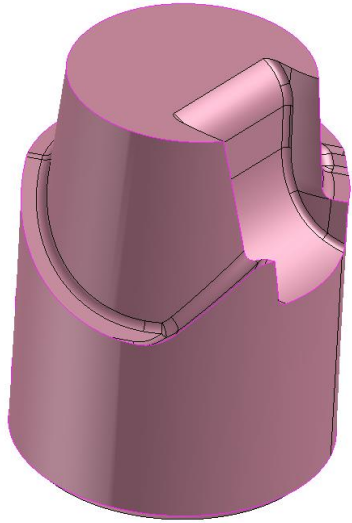
calculated deformations

measured deformation

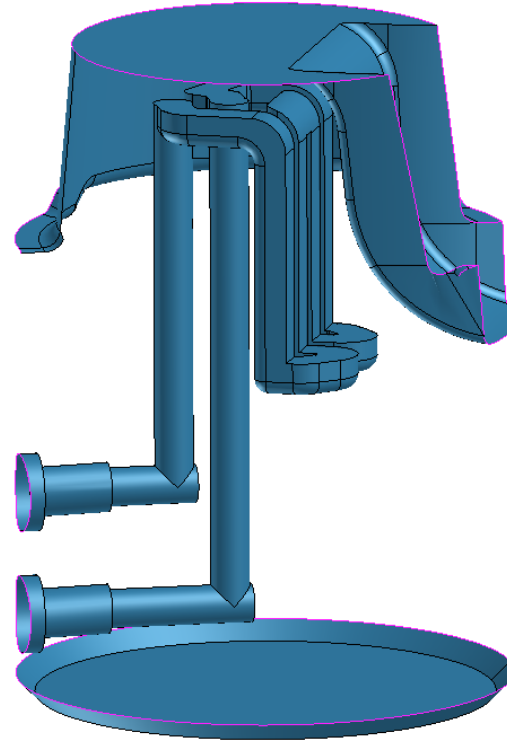




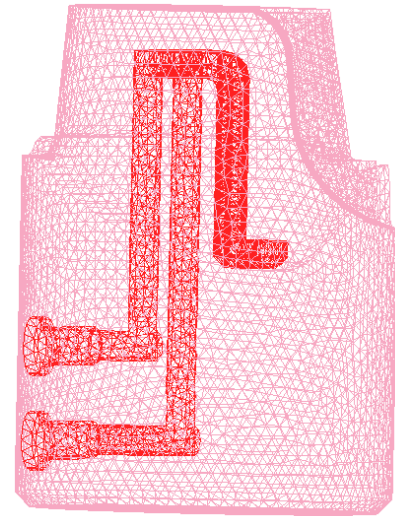
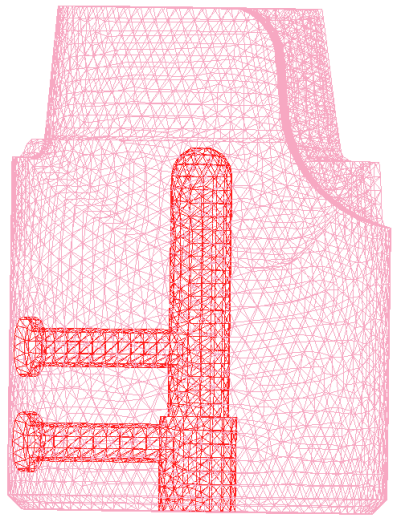
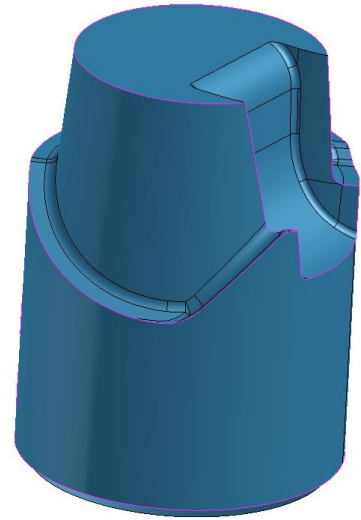
Technology optimization - distributor



ver. 1



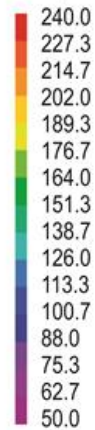
ver. 2





Technology optimization - distributor

Temperatura (°C)



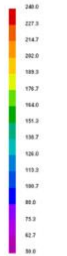
Temperature in critical area was in ver. 1 235,3 °C, with new cooling system the temperature was 94,7 °C

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 prolonged for 21 %.

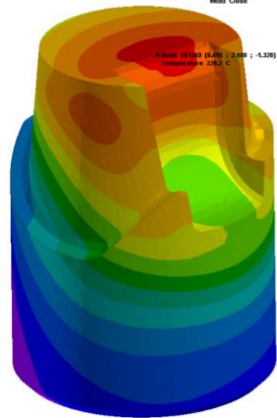
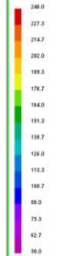


Temperature [C]



T-1595_V1
Step No / Time Step : 3380 / 5.896e+05
Simulated Time : 648.6562 sec
Percent Filled : 98.8
Fraction Solid : 98.2
Cycle Time / Cycle : 64.6063 / 18
Mold Close

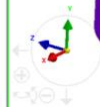
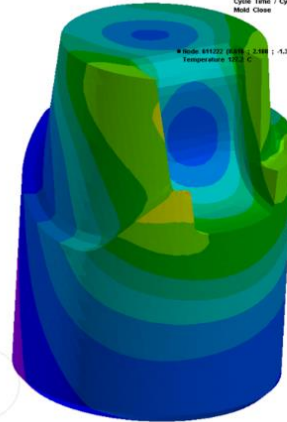
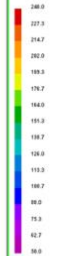
Temperature [C]



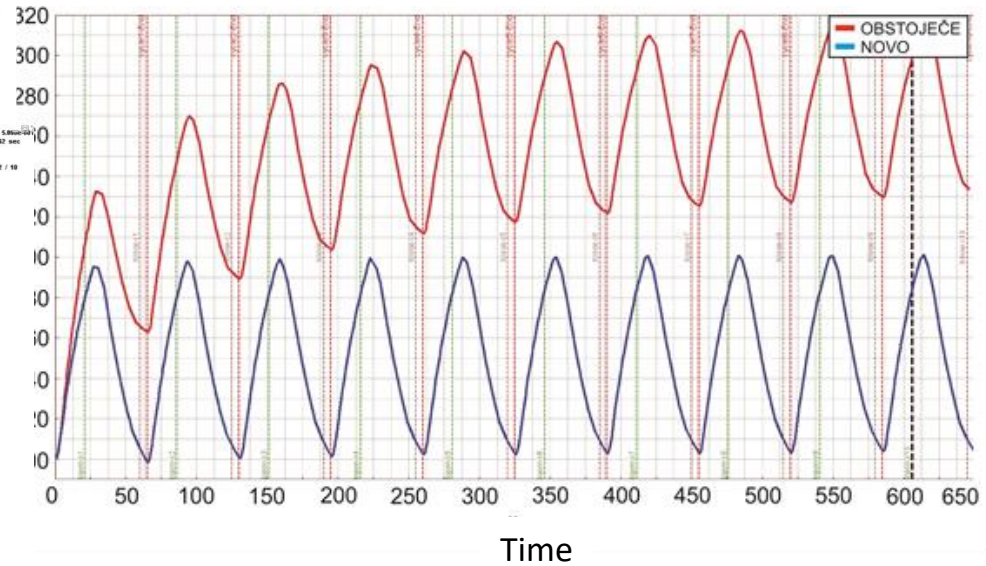
ProCAST

T-1595_V2
Step No / Time Step : 3488 / 5.896e+05
Simulated Time : 648.7562 sec
Percent Filled : 98.8
Fraction Solid : 98.2
Cycle Time / Cycle : 64.6062 / 18
Mold Close

Temperature [C]



ProCAST





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!
ЗВЕСНО!

Good luck!
GOOD LUCK!