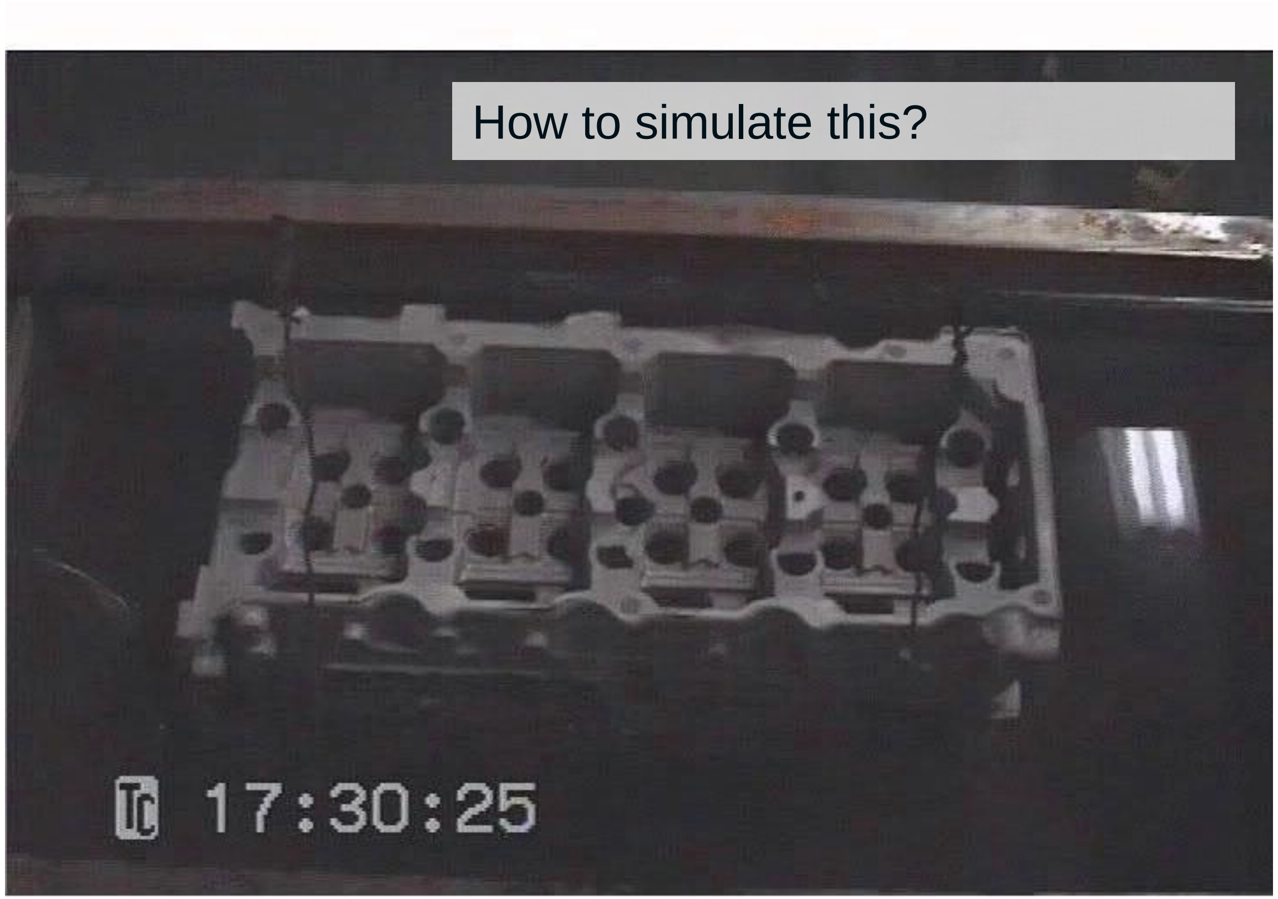
AVL List GmbH (Headquarters)

Avoid distortion and residual stress - Introduction to quenching analysis

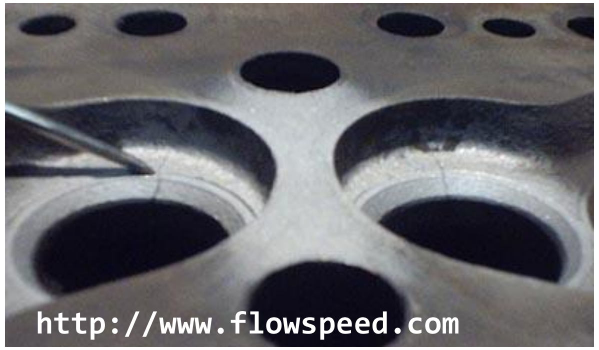
David Greif

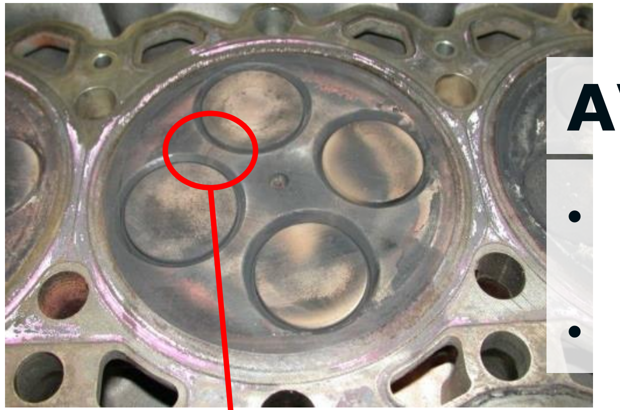
Quenching complexity



Capturing different boiling regimes is crucial.

Why simulate quenching?





Structural failure in valve bridge area

Cracks can appear at various locations on cylinder head structure

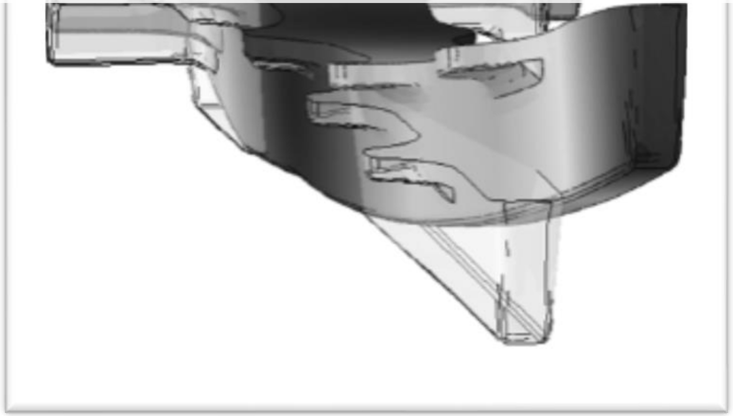
Warpage of large components is possible

Possible reasons:

- high load
- quenching characteristics
- or **residual stresses** from thermal treatment following casting

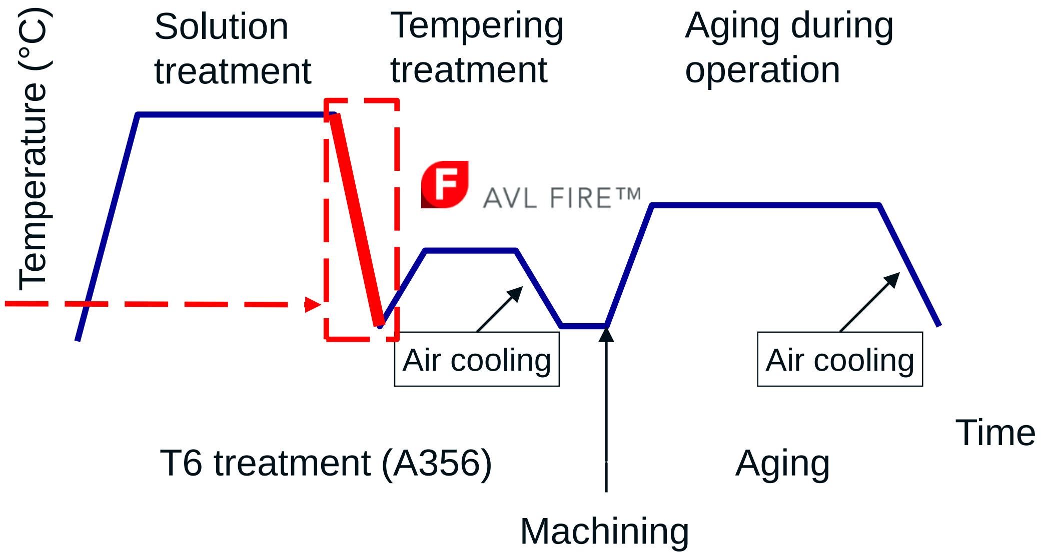
AVL’s solution

- Simulation based residual stresses reduction
- Optimization of heat treatment



Heat treatment

- Casting or forging
- Cooling of parts
- Reheating to about 500°C
- Quenching
- Reheating to about 250°C
- Aging



Quenching in AVL FIRE™

Proceedings of IMECE 2002,ASME International Mechanical Engineering Congress & Exposition
November 17 - 22, 2002, New Orleans, Louisiana

First publication November, 2002

NUMERICAL MODELING OF QUENCH COOLING USING EULERIAN TWO-FLUID METHOD

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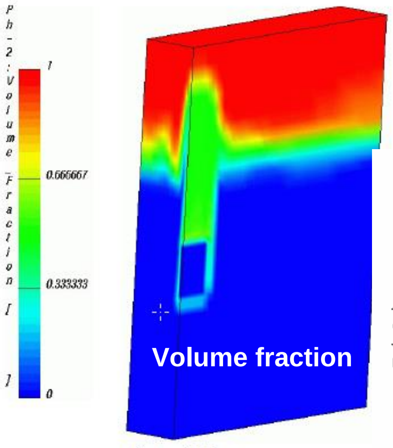
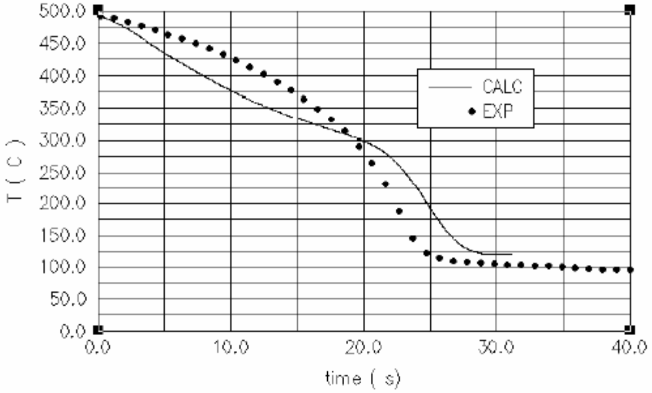
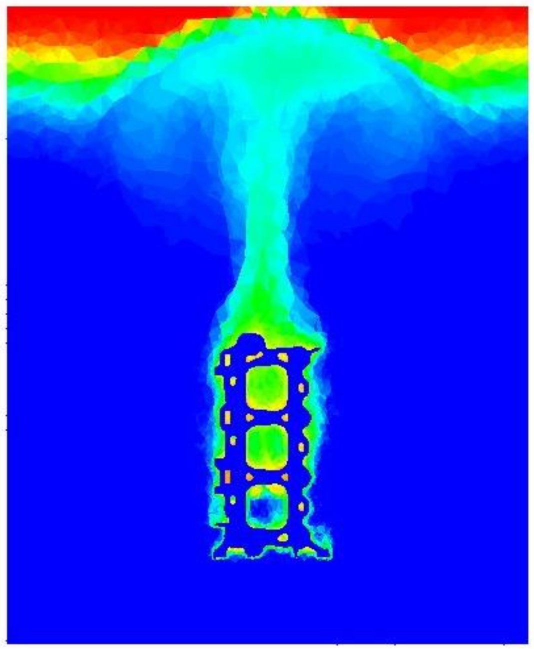
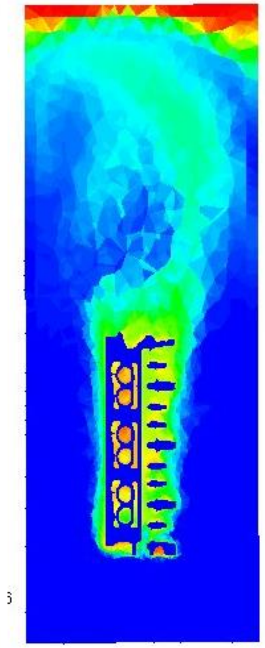


a) t =2.2s



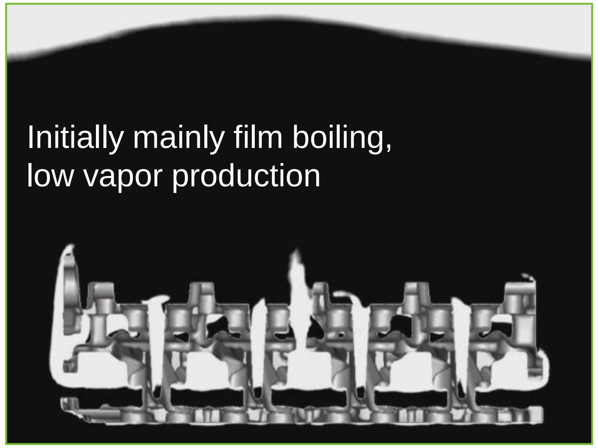


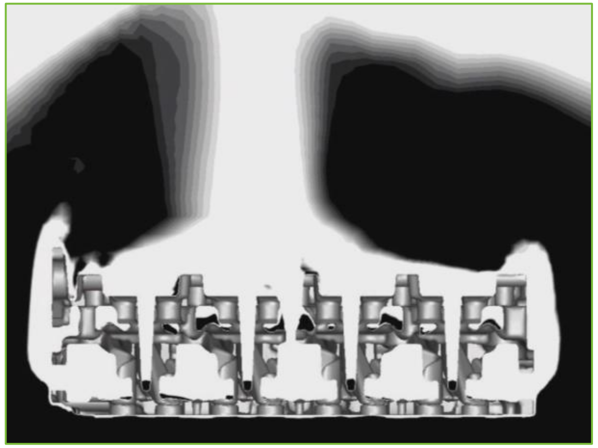


Quenching

100% Liquid water

100% Water vapor





Intensive vapor production during transition boiling

Simulation of the quenching process

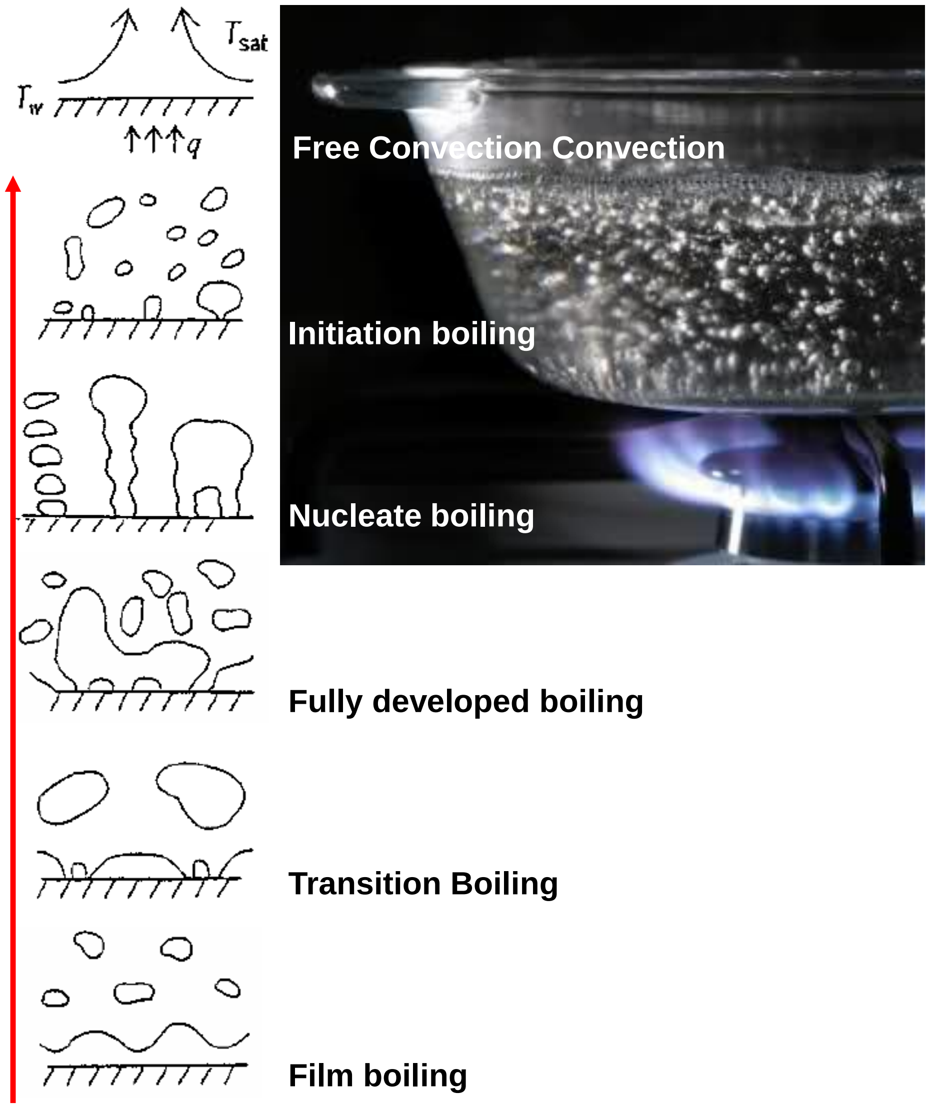
Simultaneous calculation of the transient temperature field in the solid material during the cool down process accounting for

- film boiling
- transition boiling
- nucleate boiling
- convective cooling

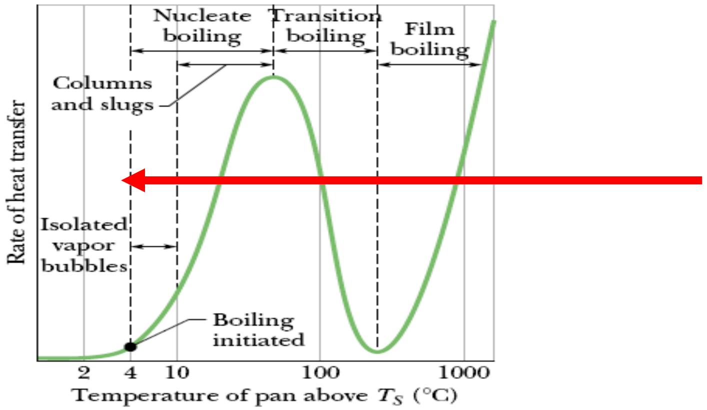
Providing the input / boundary conditions for FEA

Thermal treatment optimization (quechant selection, coolant temperature, stacking, forced cooling etc.)

Quenching simulation with CFD

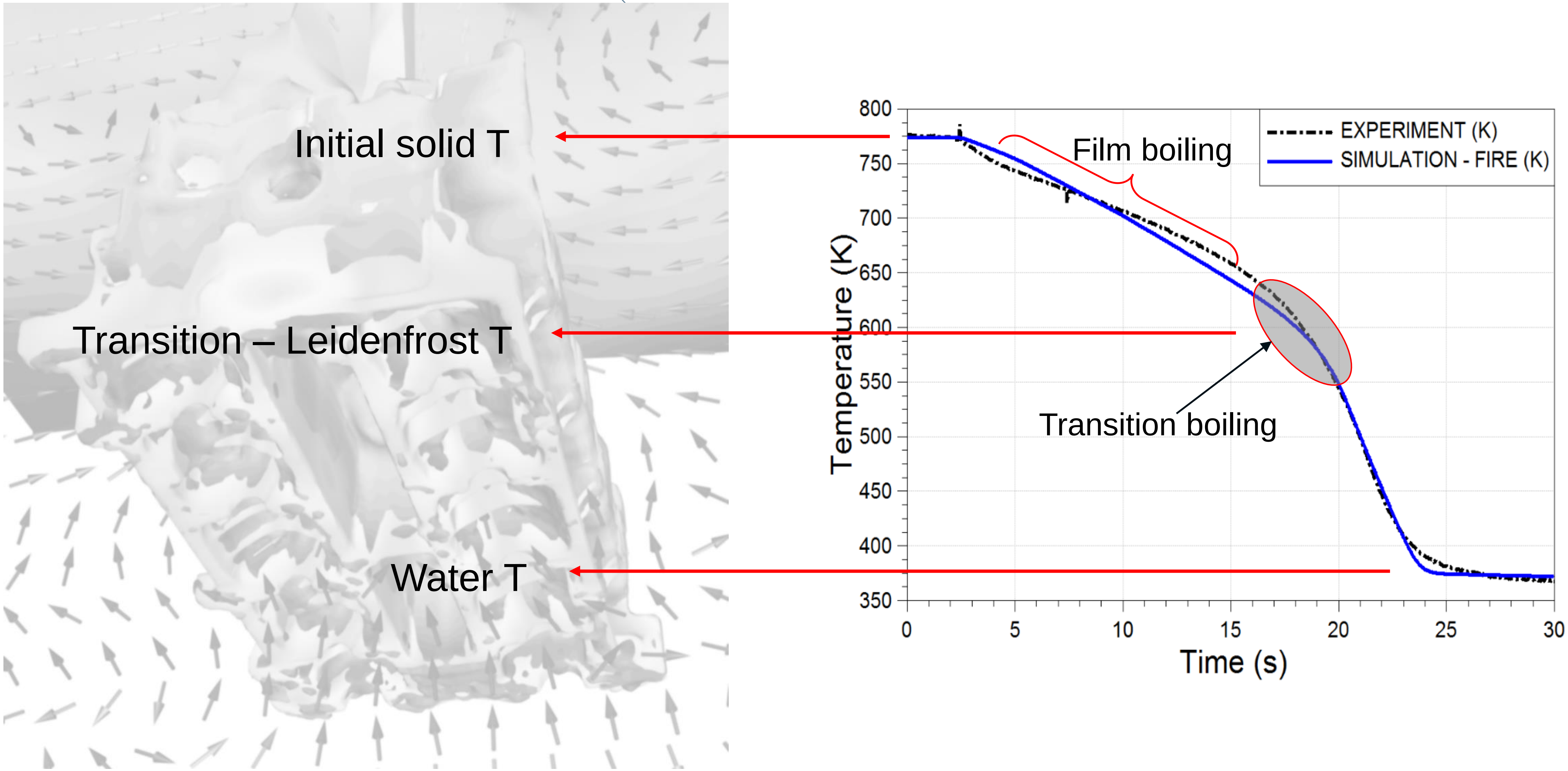


- Structure and liquid domains considered simultaneously
- The analysis covers heat transfer evaluation over the complete quenching process
- Different boiling regimes require different modelling strategies



Jearl Walker, Cleveland State University:
Boiling and the Leidenfrost effect

Boiling regimes



Workflow illustration (Aluminum)

Model setup

AVL FIRE™

Fluid / Structure Simulation
Fluid (T_{fluid}, vf_{liquid}, vf_{vapor})
Solid (T_{solid})

Data processing
T_{solid}, …

→ *file.T_001s*
→ *file.T_002s*
→ …
→ *file.T_Ns*

file.T_001s →
file.T_002s →
… →
file.T_Ns →

FEA Simulation
stresses, deformat

Abaqus, NASTRAN, …

Integrated Fluid / Structure Simulation

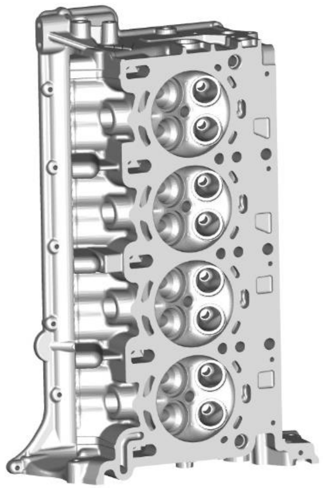
Applicable to

- Direct quenching in water, oil
- Spray quenching
- Air quenching
- ...

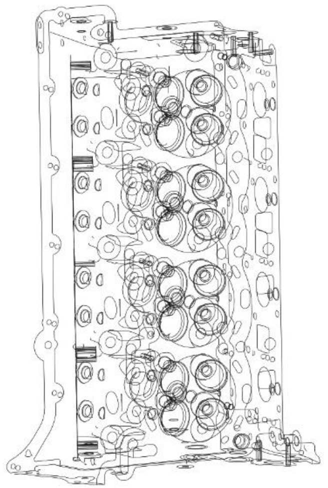
Immersion quenching

CAD

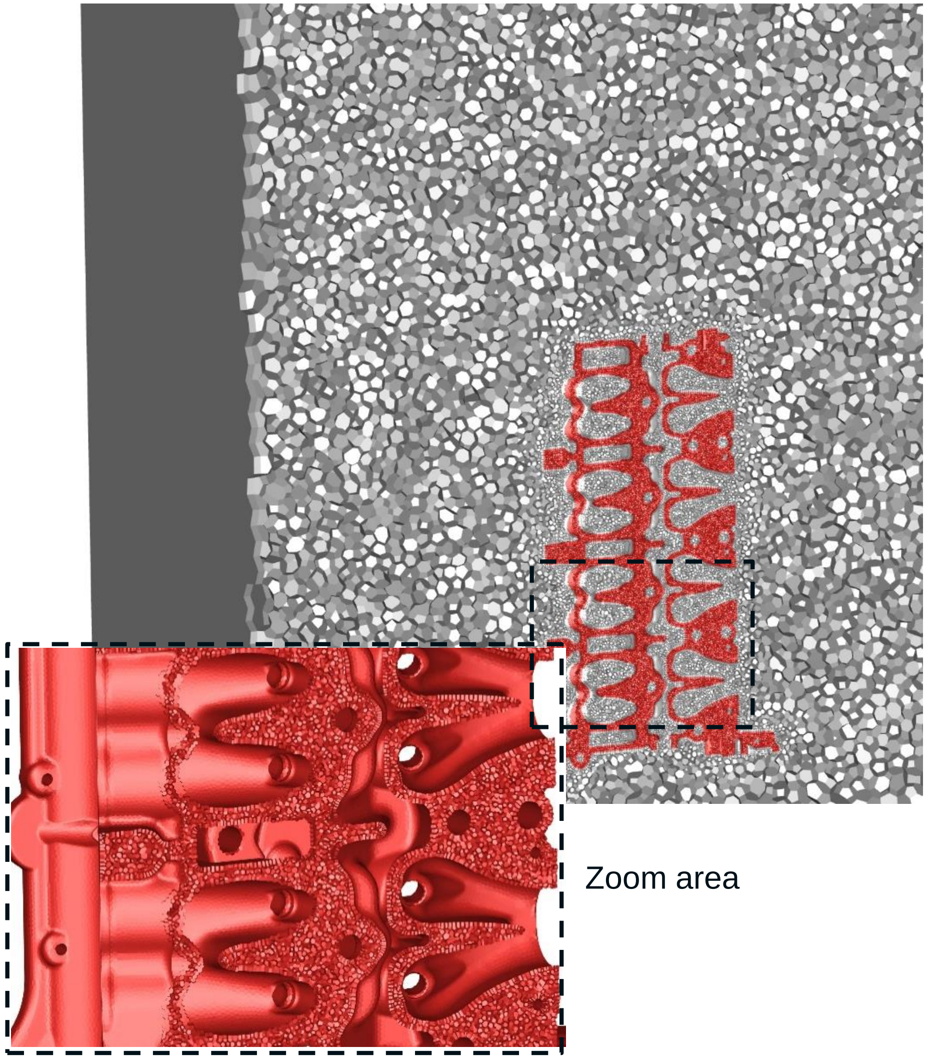
Surface



Edges

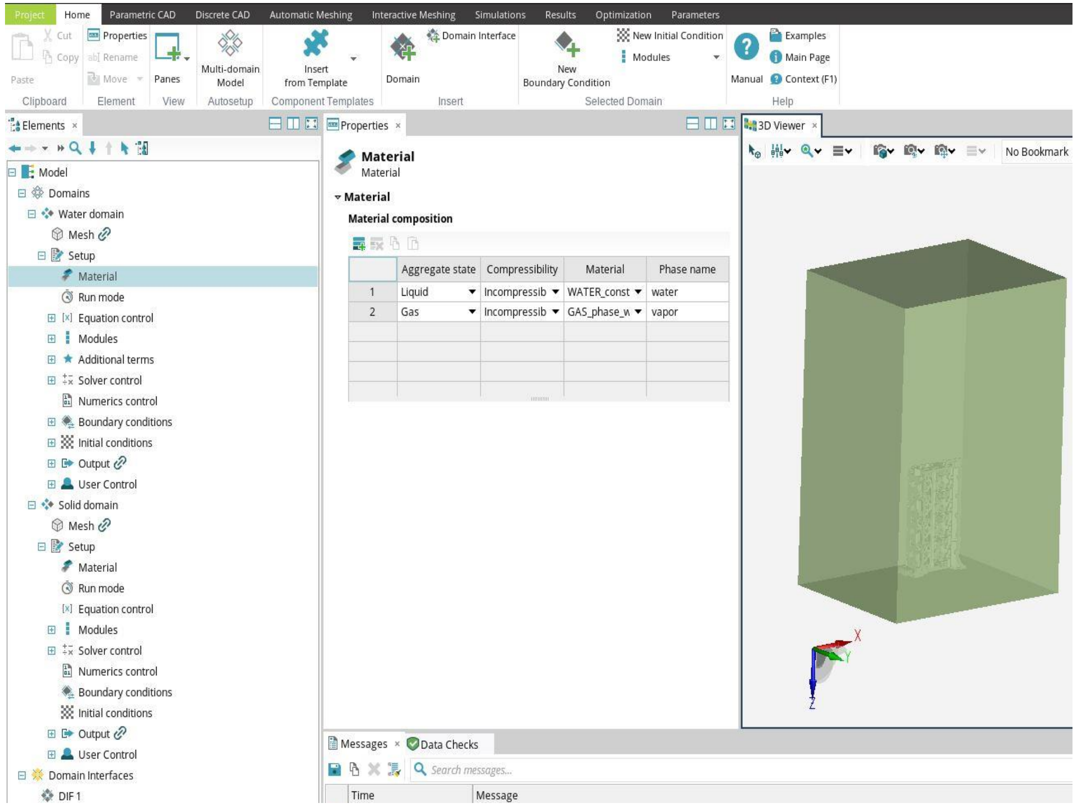


CFD mesh



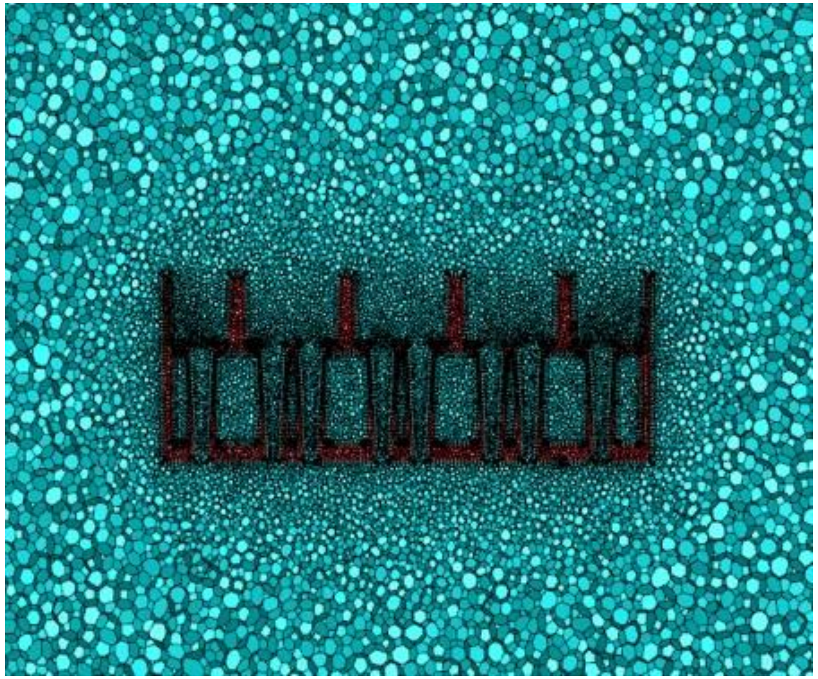
Zoom area

FIRE™ M modeling



Immersion quenching

Now available in FIRE™ M



Benefit from FAME™ Poly

single step polyhedral grid generation

accurate, fast & reliable

easy to use through new GUI

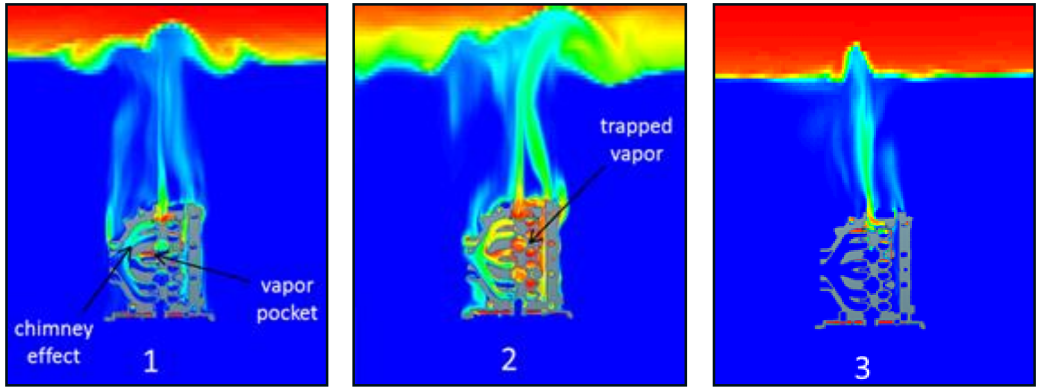
Benefit from FIRE™ M Multi-domain solution

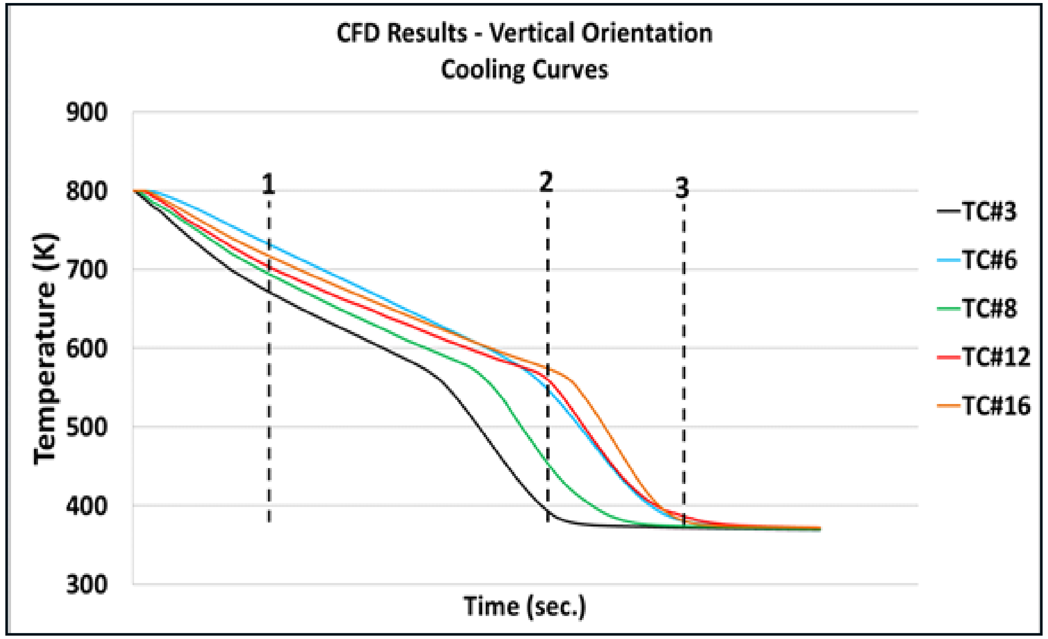
fluid and solid domains in one model

no co-simulation required

Immersion quenching @FORD

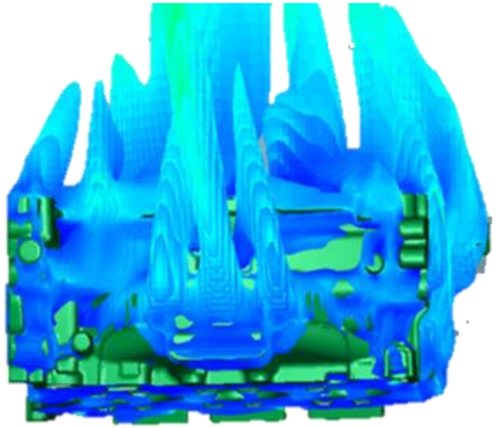
Engine cylinder head on different time frames





Measurement

Simulation

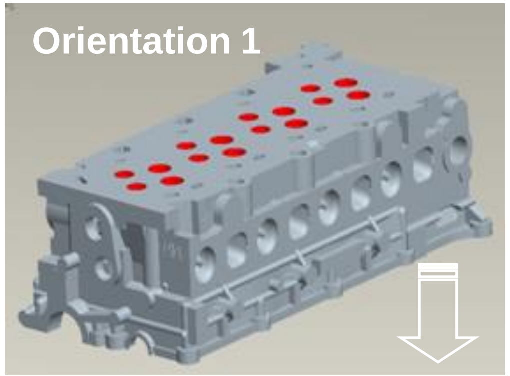


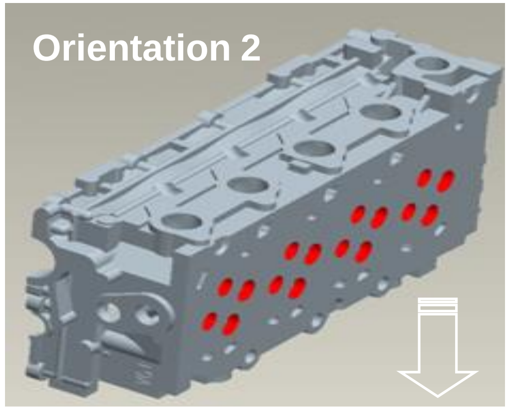
Good correlation in terms of vapor formation!

Mulayim Kaynar, A., Eroglu, S., Weiss, U., Prabhu, E., Jan, J., Lasecki, J., Kopun, R., Greif, D., Experimental and Numerical Investigation of Water Quench Cooling of Aluminum Cylinder Heads, 5th International Conference on Thermal Process Modeling and Computer Simulation, June 16-18, 2014, Florida, USA.

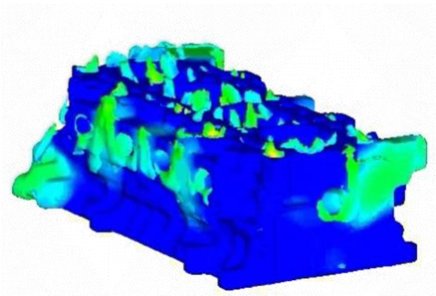
Full complexity quenching

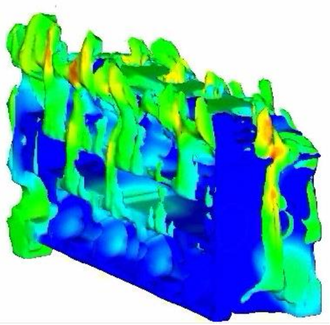
Effect of submerging direction on structure cooling





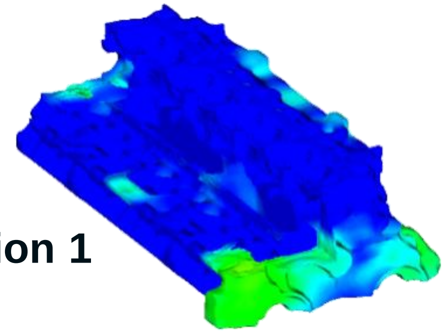
Temperature, vapor structures



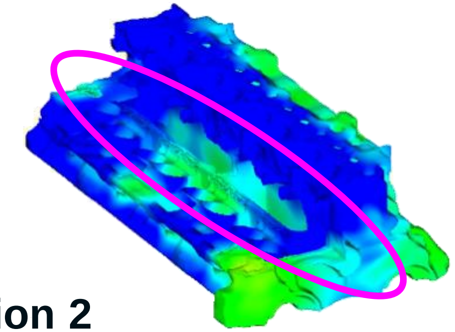


Temperature

Orientation 1

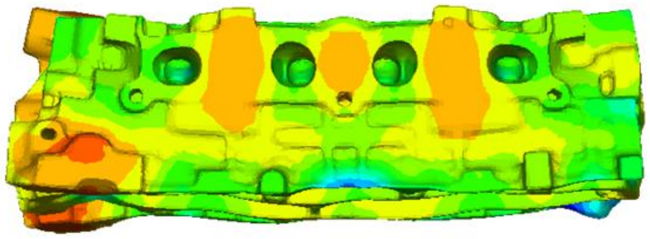


Orientation 2

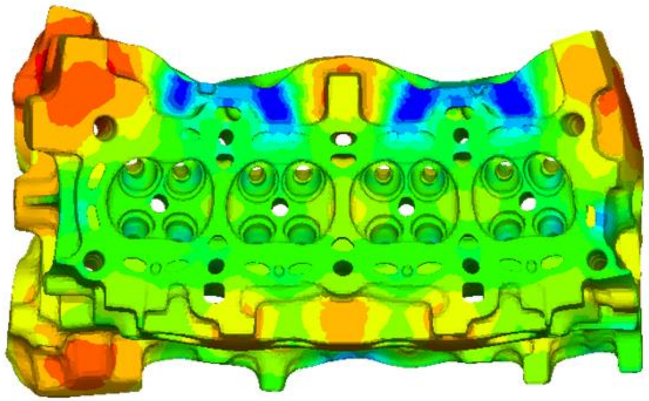


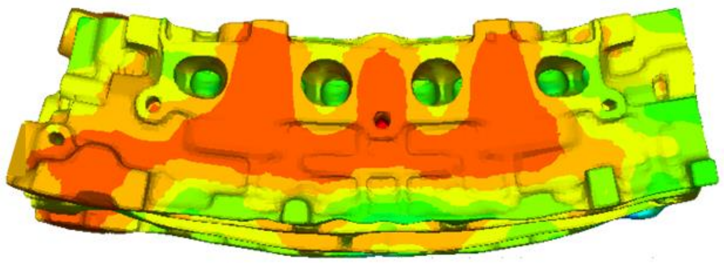
Orientation effect - deformation

Structural response prediction regardless of components' complexity and size!

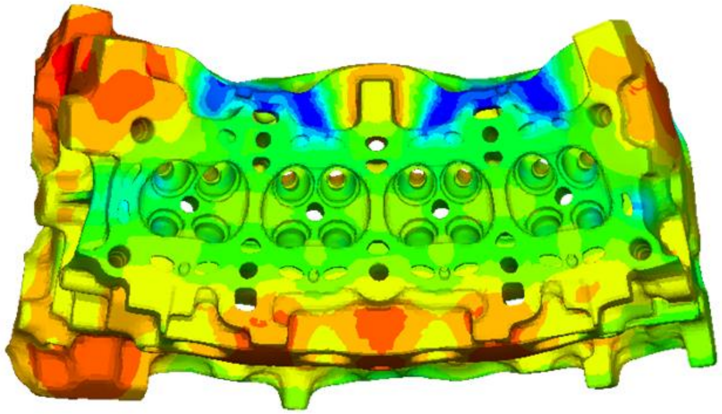


Submerging orientation I





Submerging orientation II

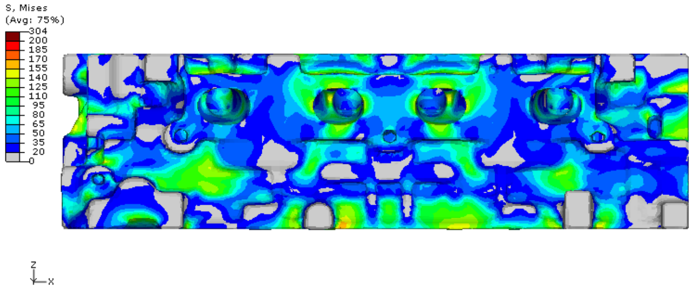


Stresses and deformations

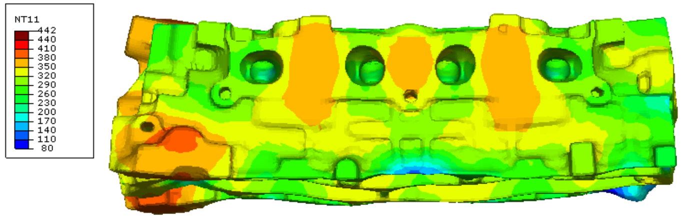
Effect of submerging direction

Orientation 1

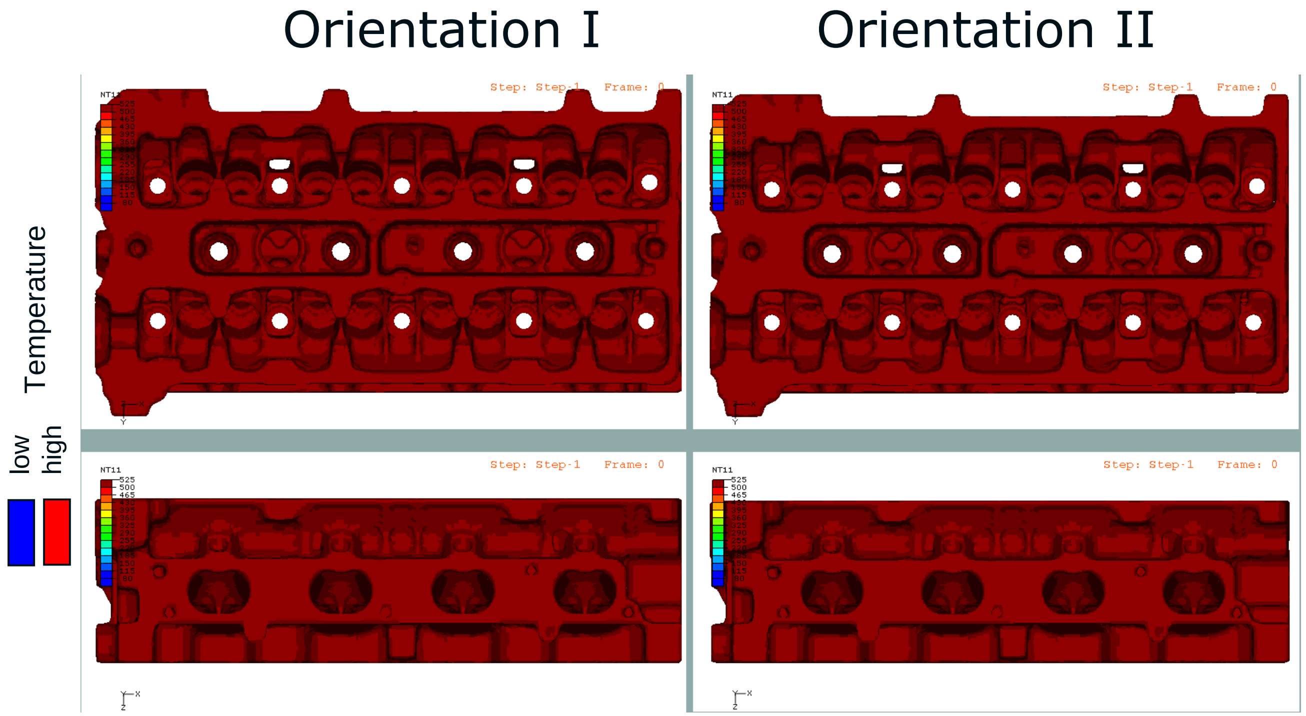
Stress



Temperature and deformation



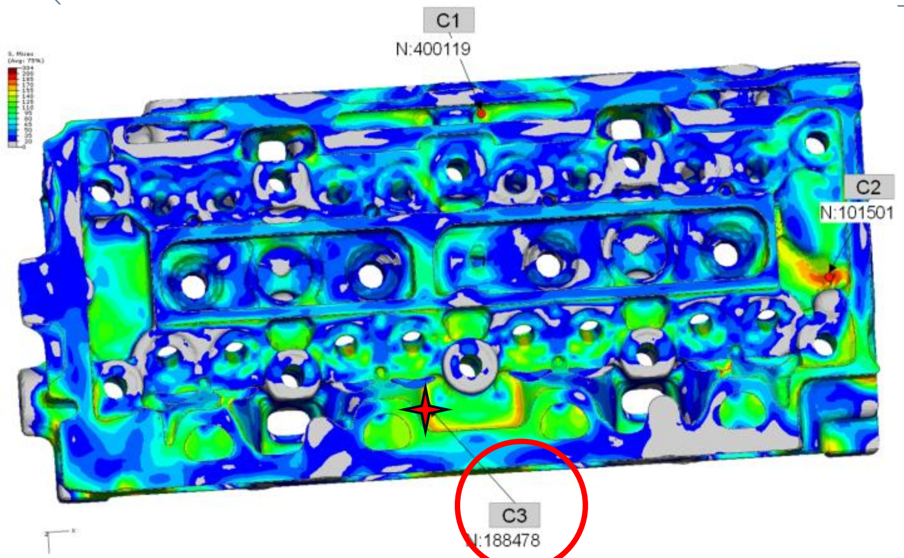
Orientation effect - deformation



Temperature and deformation

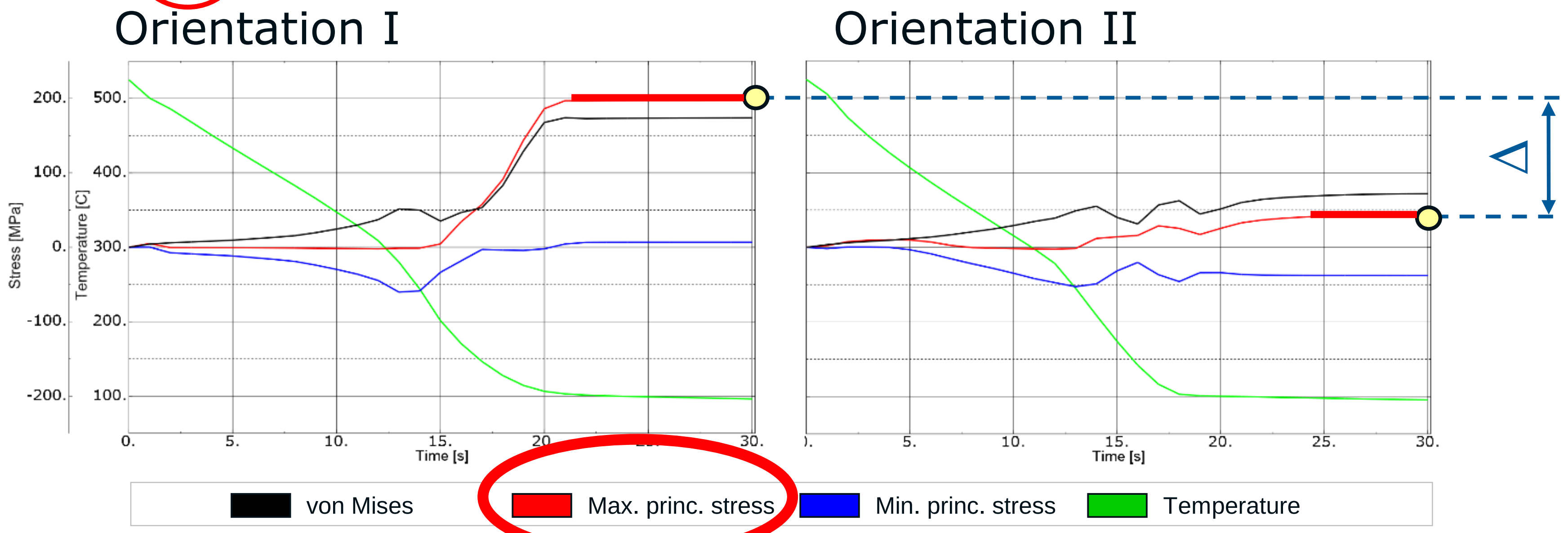
- GUI based mapping CFD → FEM

Orientation effect - stresses

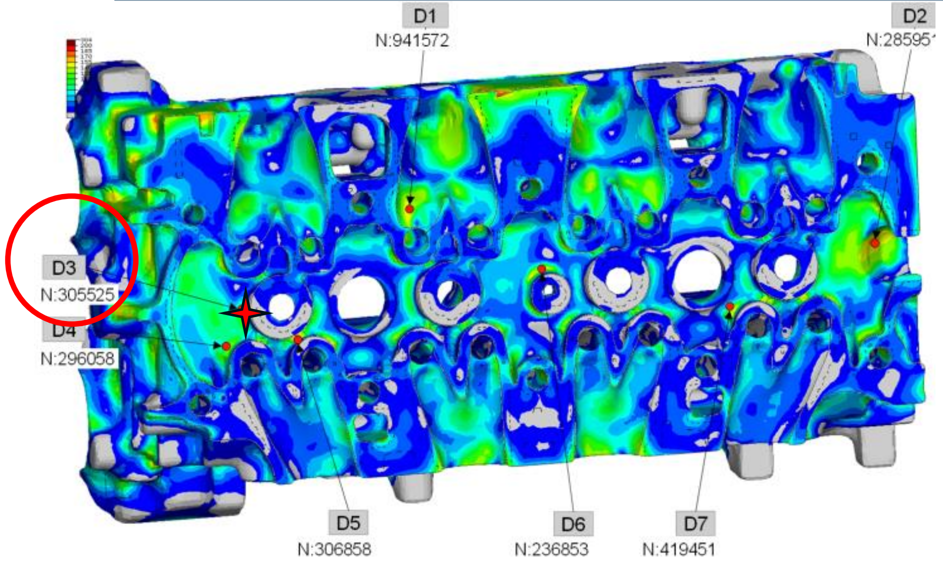


Evaluation point C3

- Tensile stress dominant
- Orientation I > Orientation II

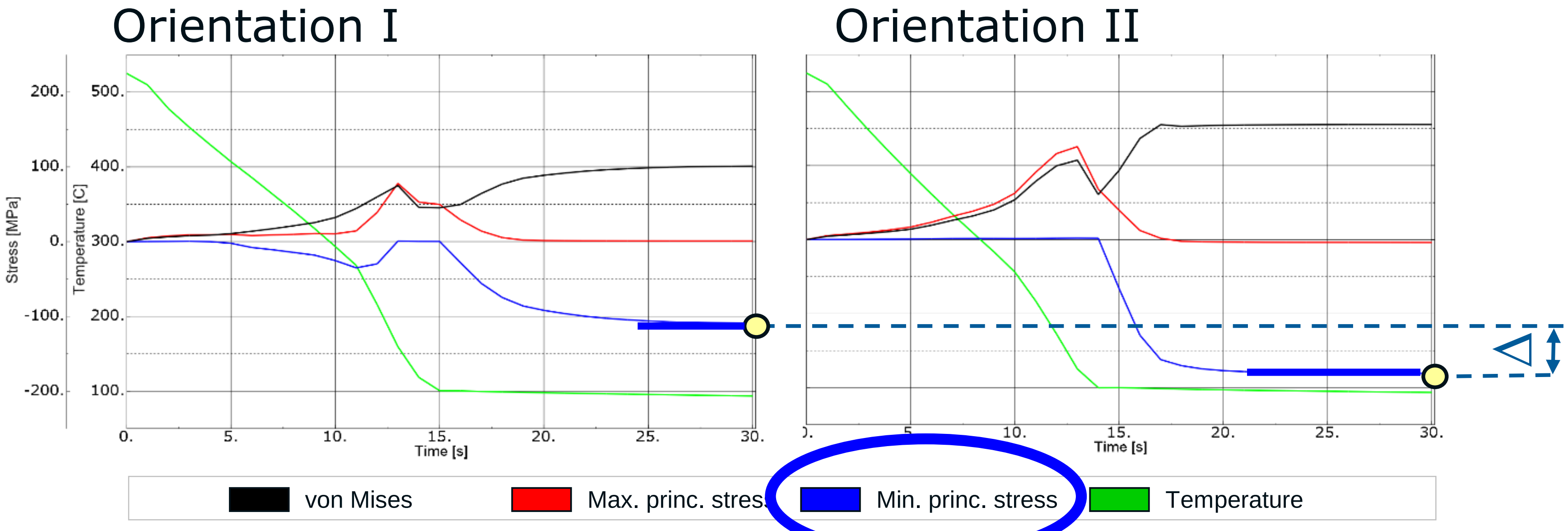


Orientation effect - stresses



Evaluation point D3

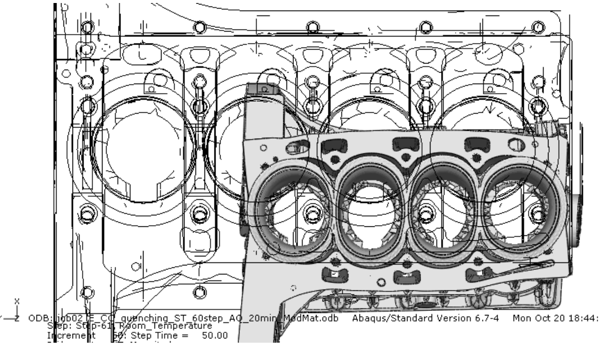
- Compressive stress dominant
- Orientation I < Orientation II



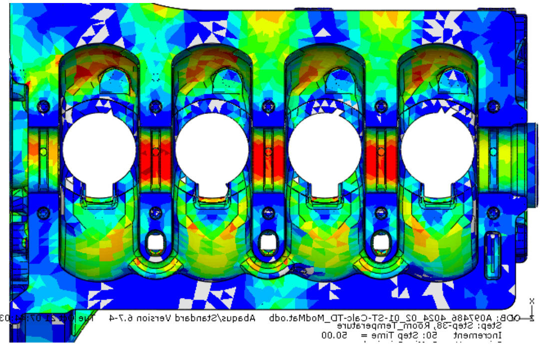
Air and immersion quenching

Air Quenching

Deformation (scale x 30)

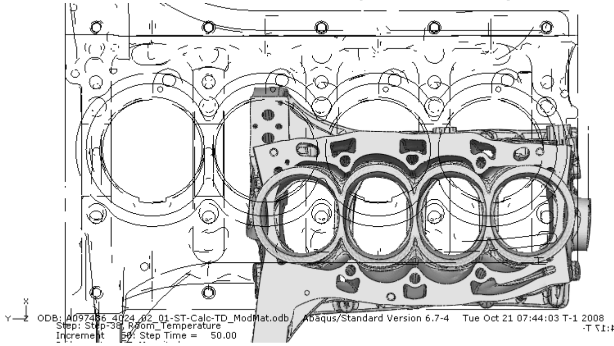


Minimum principle stress

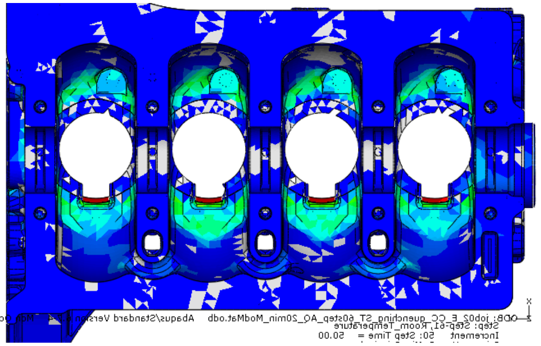


Water Quench – top down

Deformation (scale x 30)

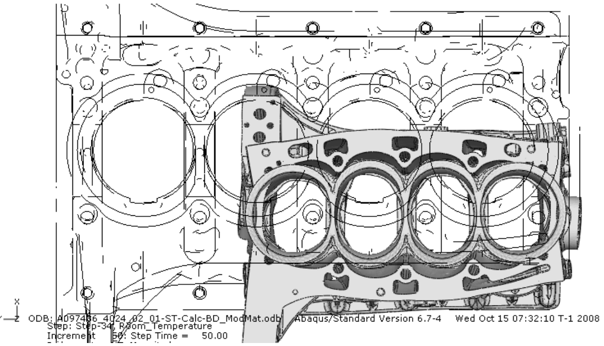


Minimum principle stress

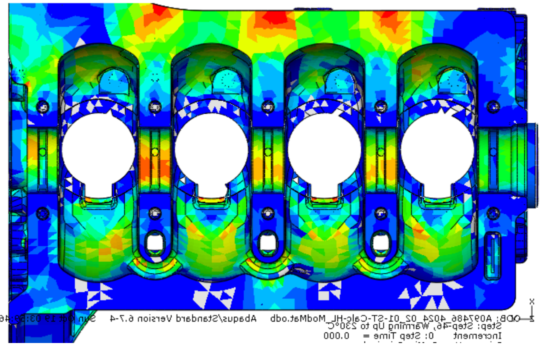


Water Quench – water down

Deformation (scale x 30)

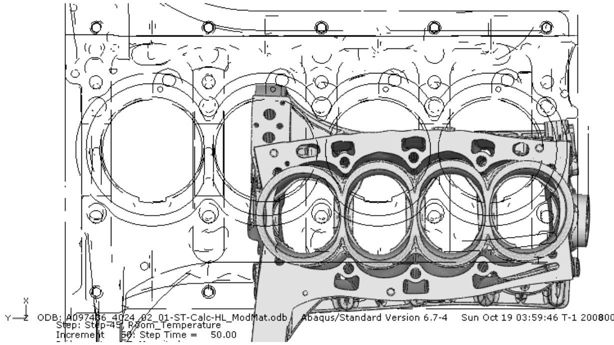


Minimum principle stress

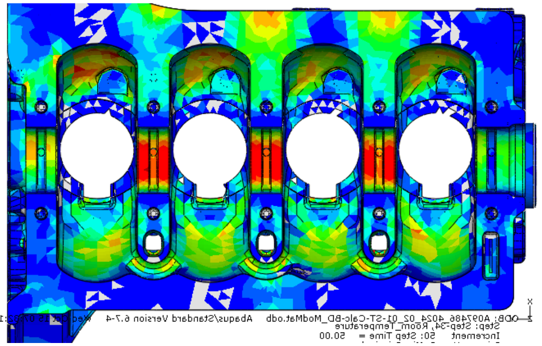


Water Quench – horizontal liner

Deformation (scale x 30)



Minimum principle stress

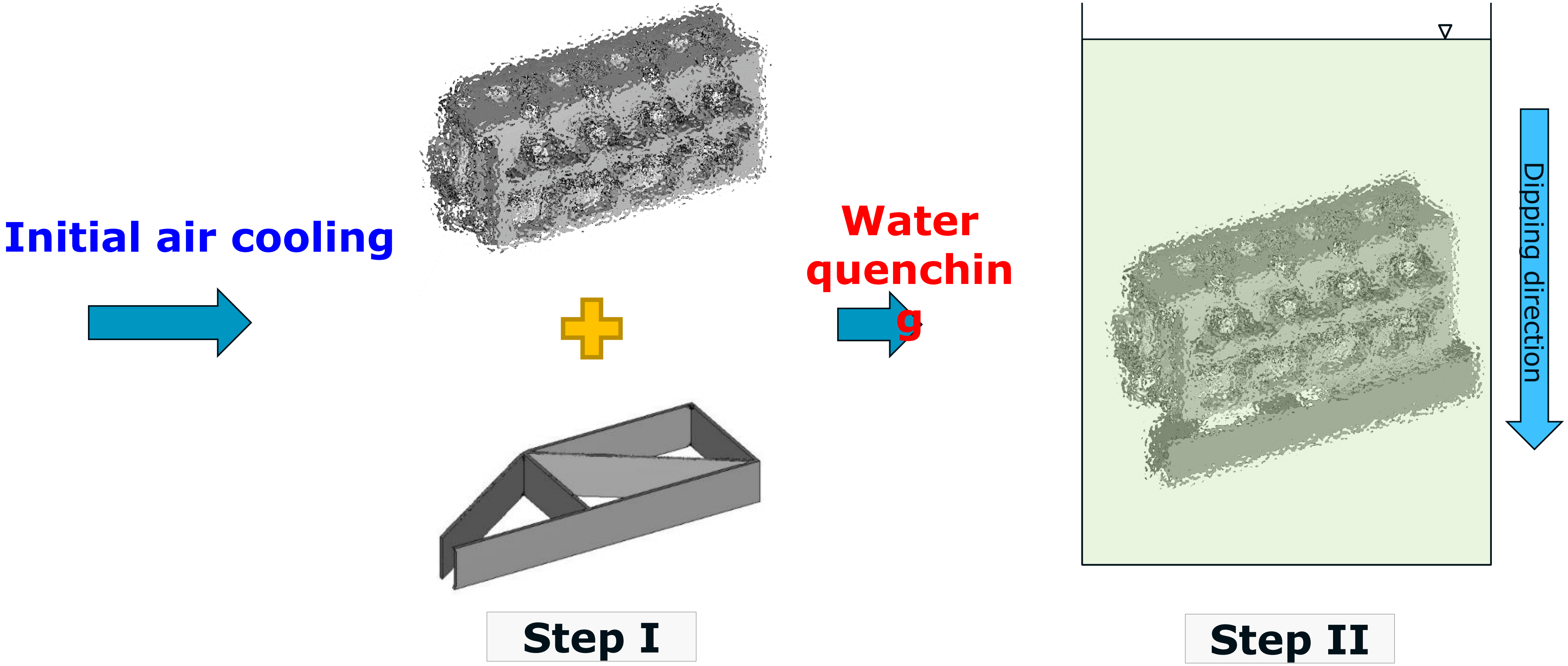


Real life conditions

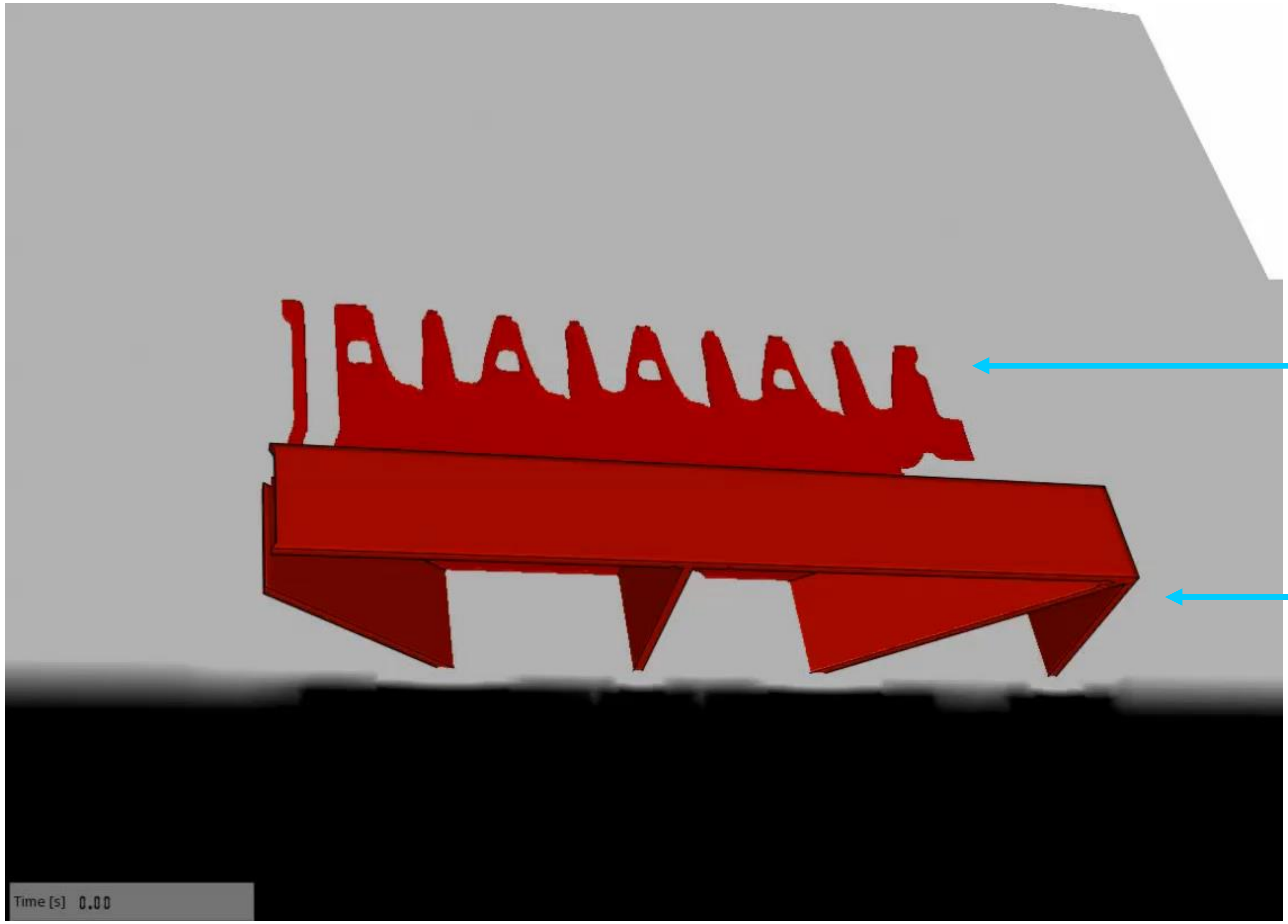
- Rack consideration
- Clustering of several solids

Rack effect

- Step I: **Initial air cooling** (for more accurate initial condition)
- Step II: **Water quenching**



Rack effect



Aluminum head

on

a steel rack

Temperature

low high

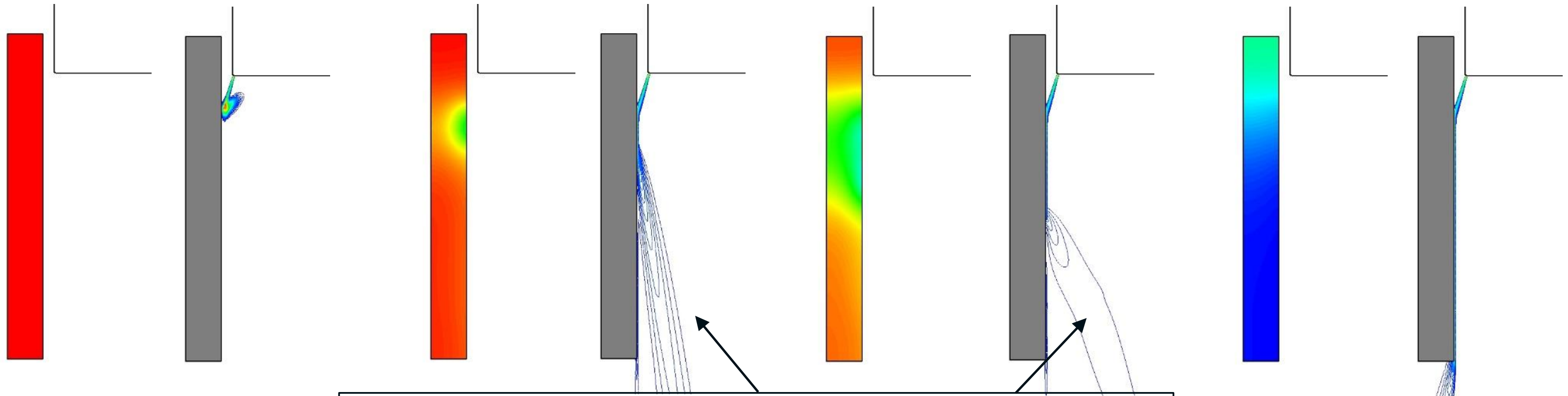
Volume fraction

0 0.5 1

IMPINGEMENT JET - QUENCHING

Water jet impingement cooling process, also known as continuous chill casting process

Time: 0.1 [sec] Time: 5 [sec] Time: 10 [sec] Time: 50 [sec]



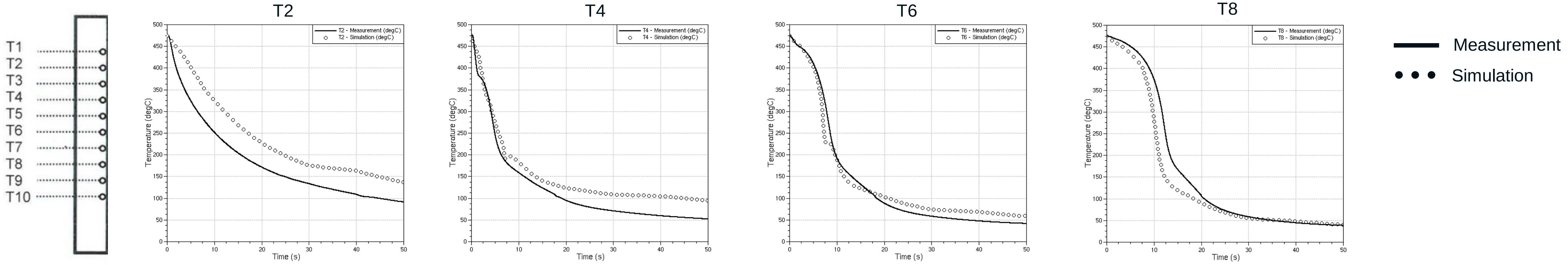
Temperature [°C]

20 475

Comment:
Additional levitational force was implemented in order to simulate rebounding effect from the heated surface

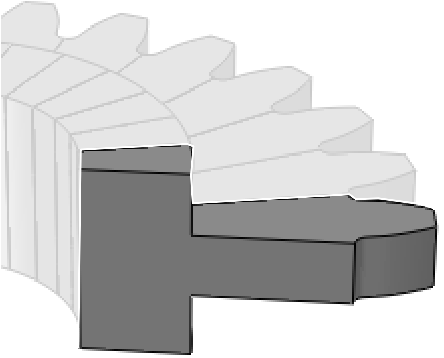
Volume fraction [/]

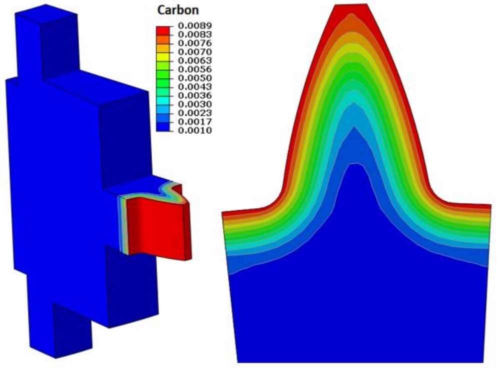
0 1



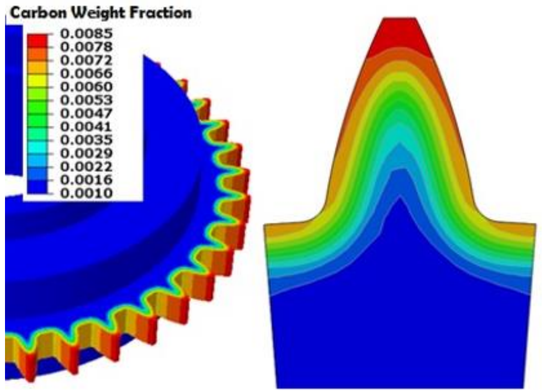
IMMERSION QUENCHING

Carbon distribution has a significant effect on the phase transformation during the hardening process which will affect the hardness and phase distributions, as well as distortion and residual stresses.



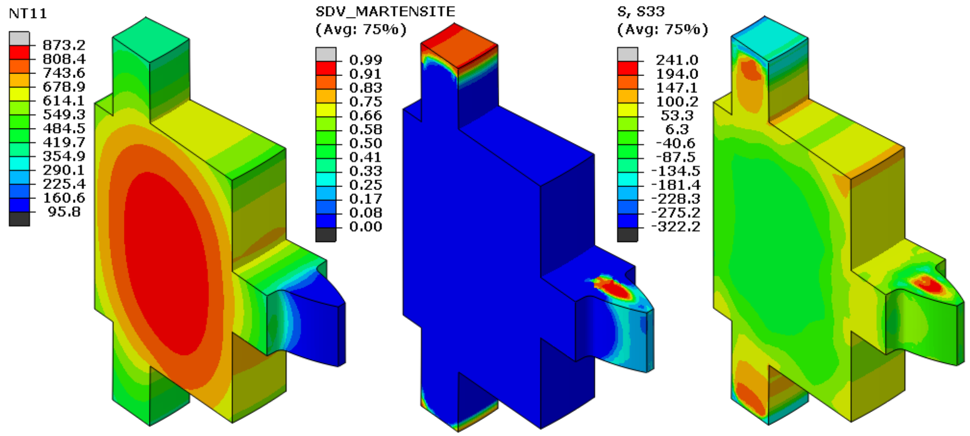


After carburization

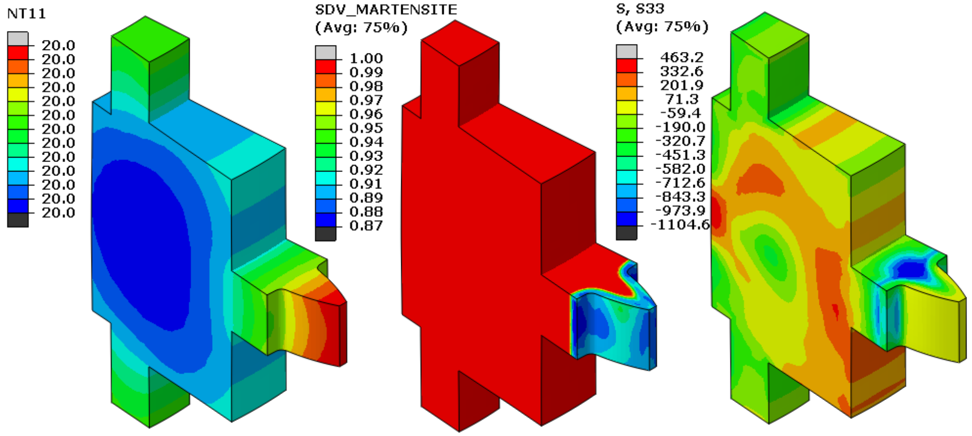


After re-austenitization

Time: 3 [sec] - during the quenching process

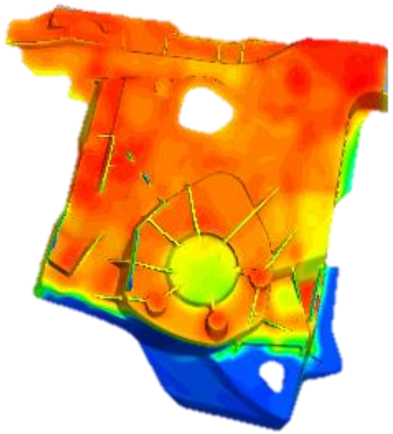


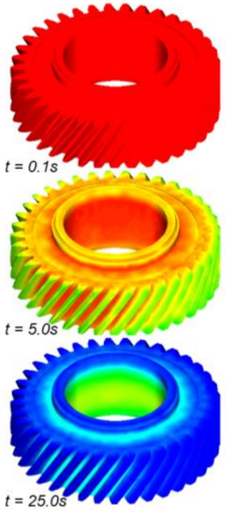
Time: 60 [sec] - at the end of quenching process

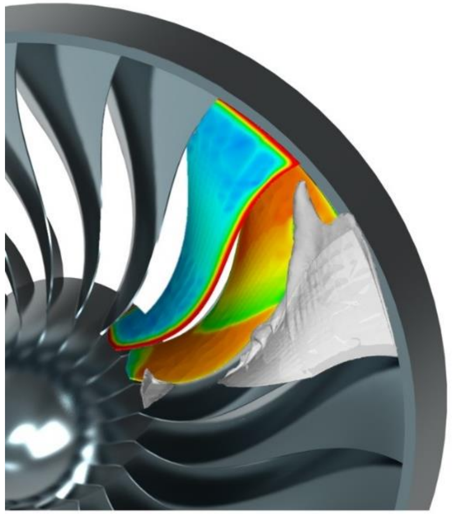


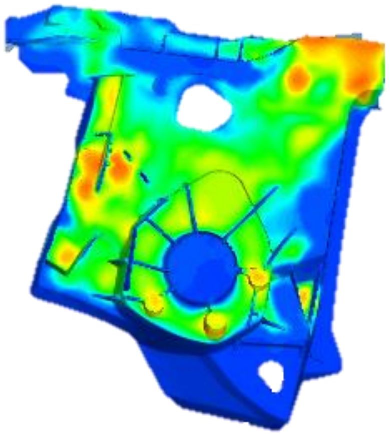
Li Z.C., Ferguson B.L., Greif D., Kovacic Z., Urbas S., Kopun R. Coupling CFD and Oil Quench Hardening Analysis of Gear Component. 28th ASM Heat Treating Society Conference, October 2015, Detroit, Michigan, USA.

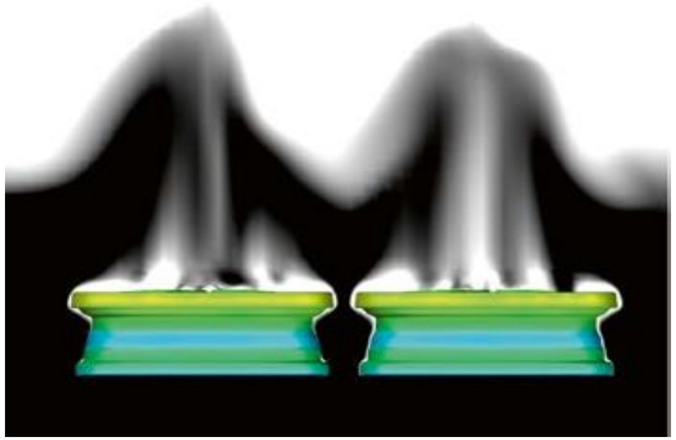
IMMERSION QUENCHING
Applicabilitions











Applicability

Cylinder heads and blocks

Chassis parts

E-motors and components

Gears

Wheels

Turbine blades,...

Materials

Aluminum alloys, Steel, Chrome - Nickel,…

Cooling media

Water, air, oil, polymer,…

Thank You

www.avl.com