Der Einfluss thermophysikalischer Daten auf die numerische Simulation von Gießprozessen

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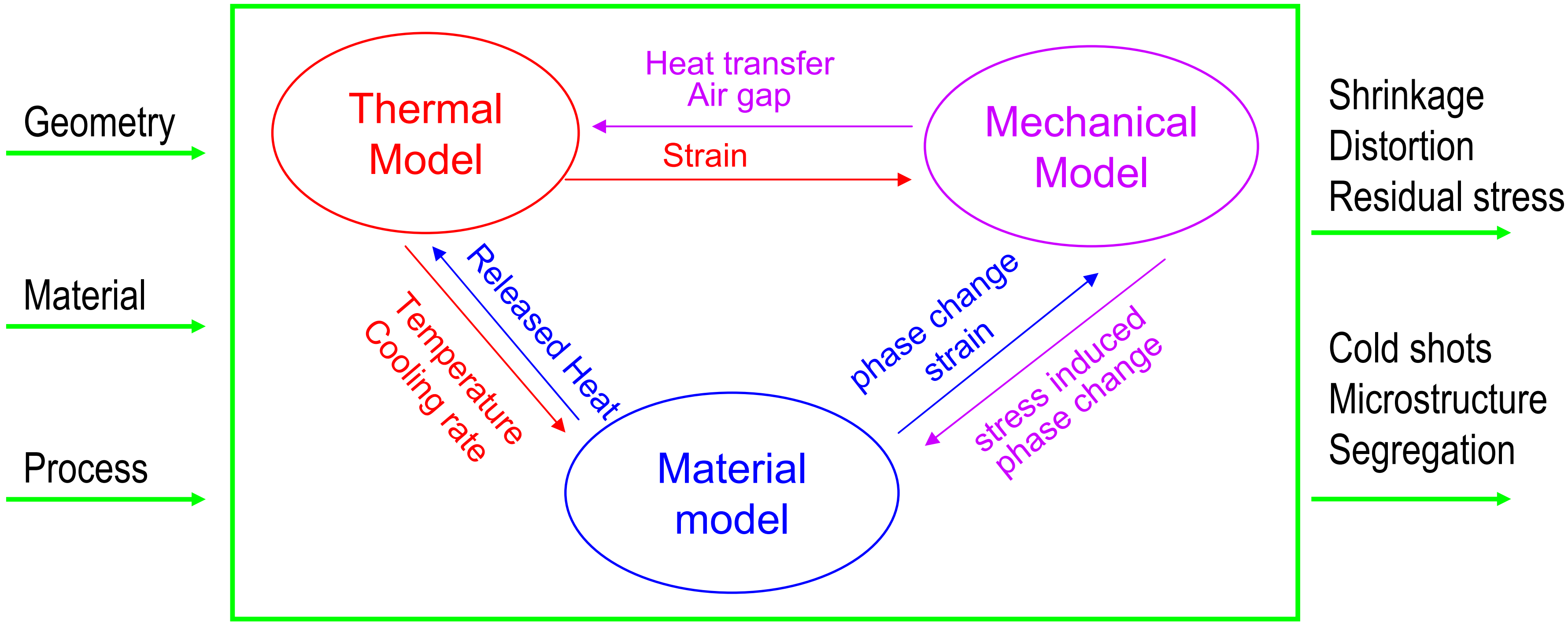
Numerical simulation in metal part production:

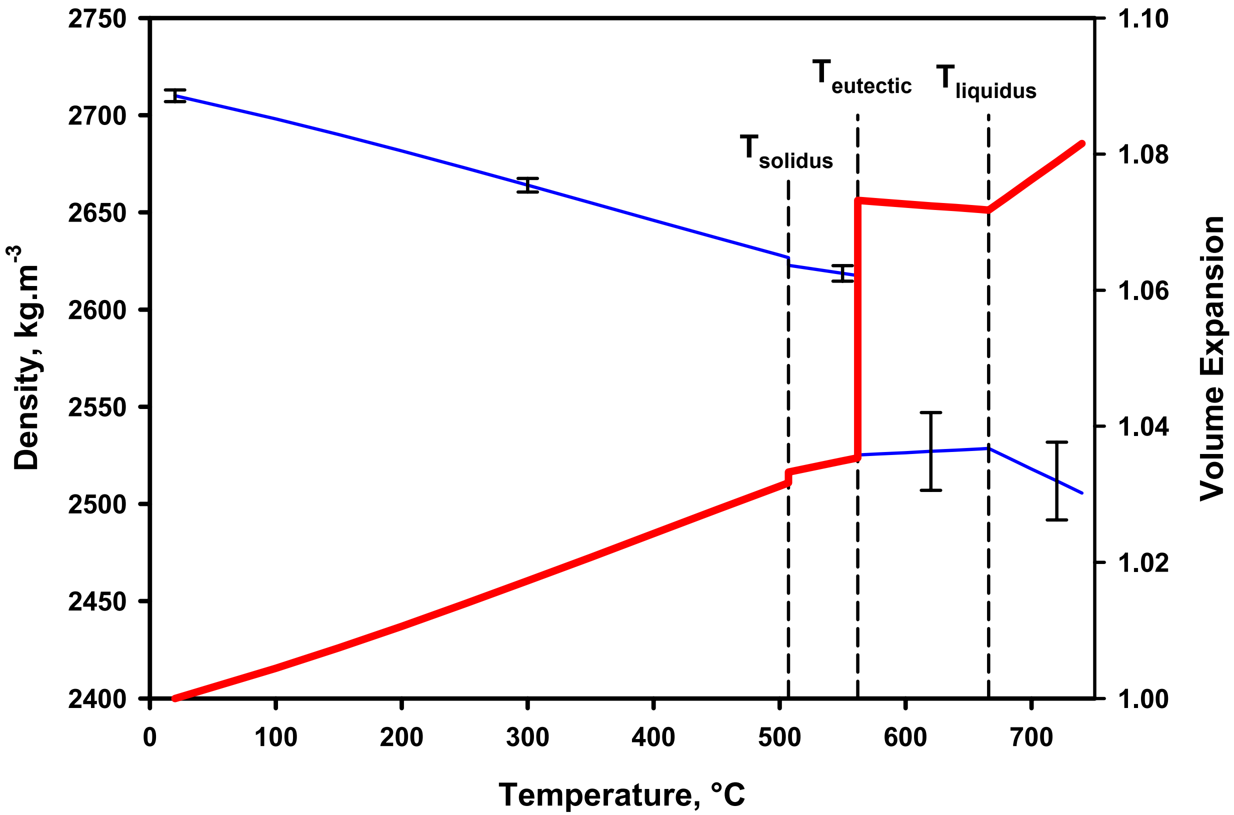
- Differential equations describing the physical phenomena are usually highly non-linear and coupled
- Analytical solutions are not obtainable
- Numerical approximations by means of Finite Methods (e.g. Finite Elements, Finite Differences, ...)
- Need of high computing power (computing times hours, days, weeks), parallelization of processes
- Simulated processes: casting, welding, forging, heat treatment, rolling, cutting …
- Accurate thermo-physical and -mechanical properties are urgently needed

Einfluss thermophysikalischer Daten auf die Simulation



Thermal model: fluid flow, heat transfer, diffusion
Material model: macro-, meso- micro-model
Mechanical model: elasto-, plasto-, visco-model
And Combinations

Density and volume expansion of Al-17Si-4Cu:



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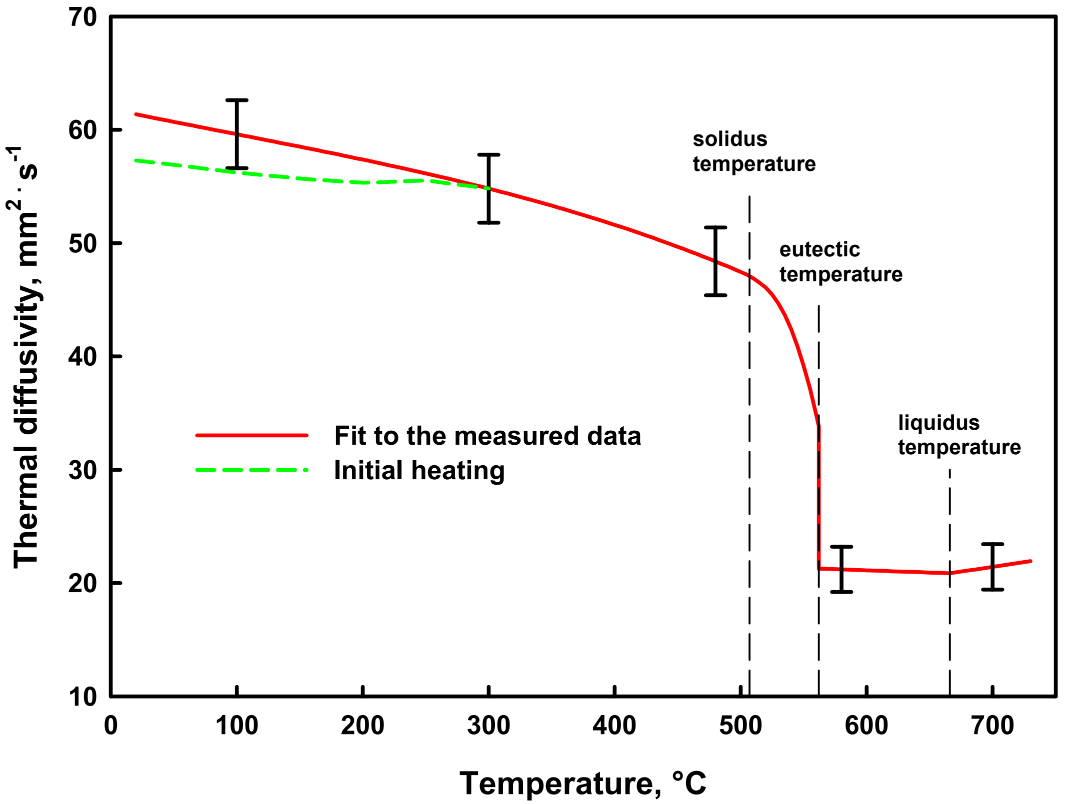
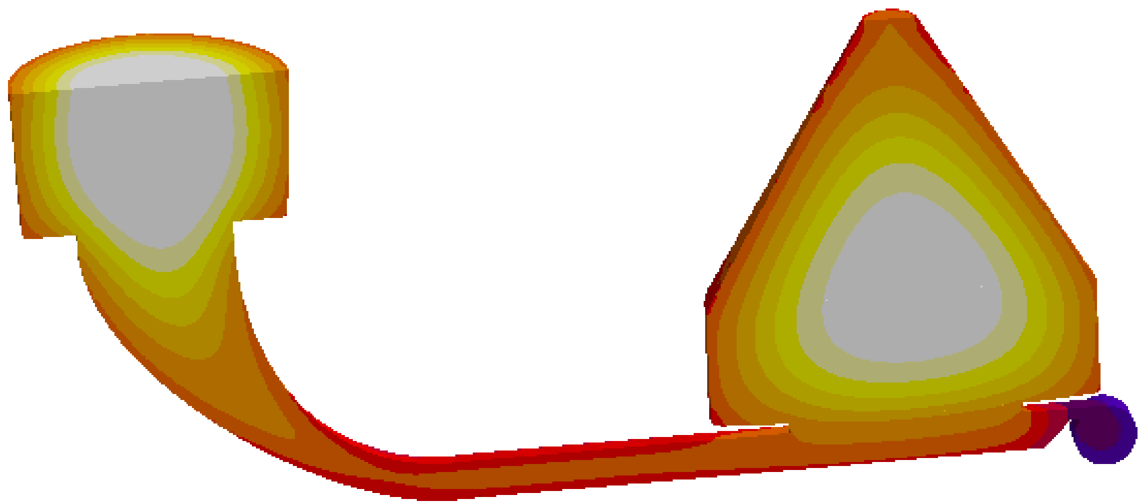
Thermal diffusivity of Al-17Si-4Cu:



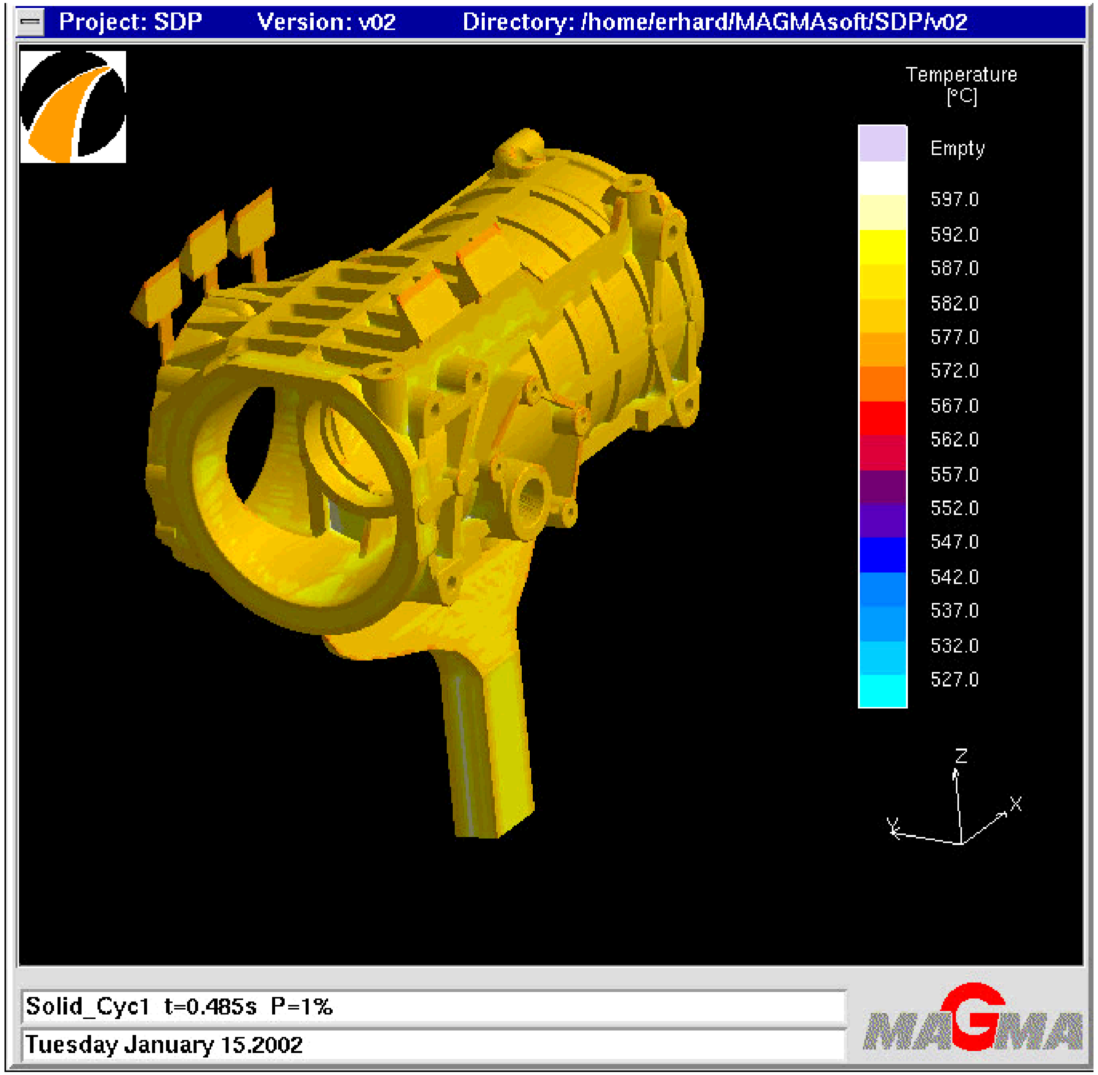
Influence of volume thermal expansion data on feeding of castings:

- Alloys are (usually) contracting during solidification (up to several percent)
- Shrinkage has to be compensated in order to get a sound casting
- Additional material is provided from an extra reservoir by hydrostatic or external pressure (feeding)
- If feeding is disturbed, shrinkage cavities or porosity will be found in the final casting – leading to scrap
- feeding channels must not been frozen until solidification of casting (directional solidification towards the feeders)
- Precise volume expansion (contraction) data in the vicinity of the solidification region must be known

Example: Liquid and solidification shrinkage due to density change during cooling – porosity and shrinkage cavity



Example: Solidification of a gear housing



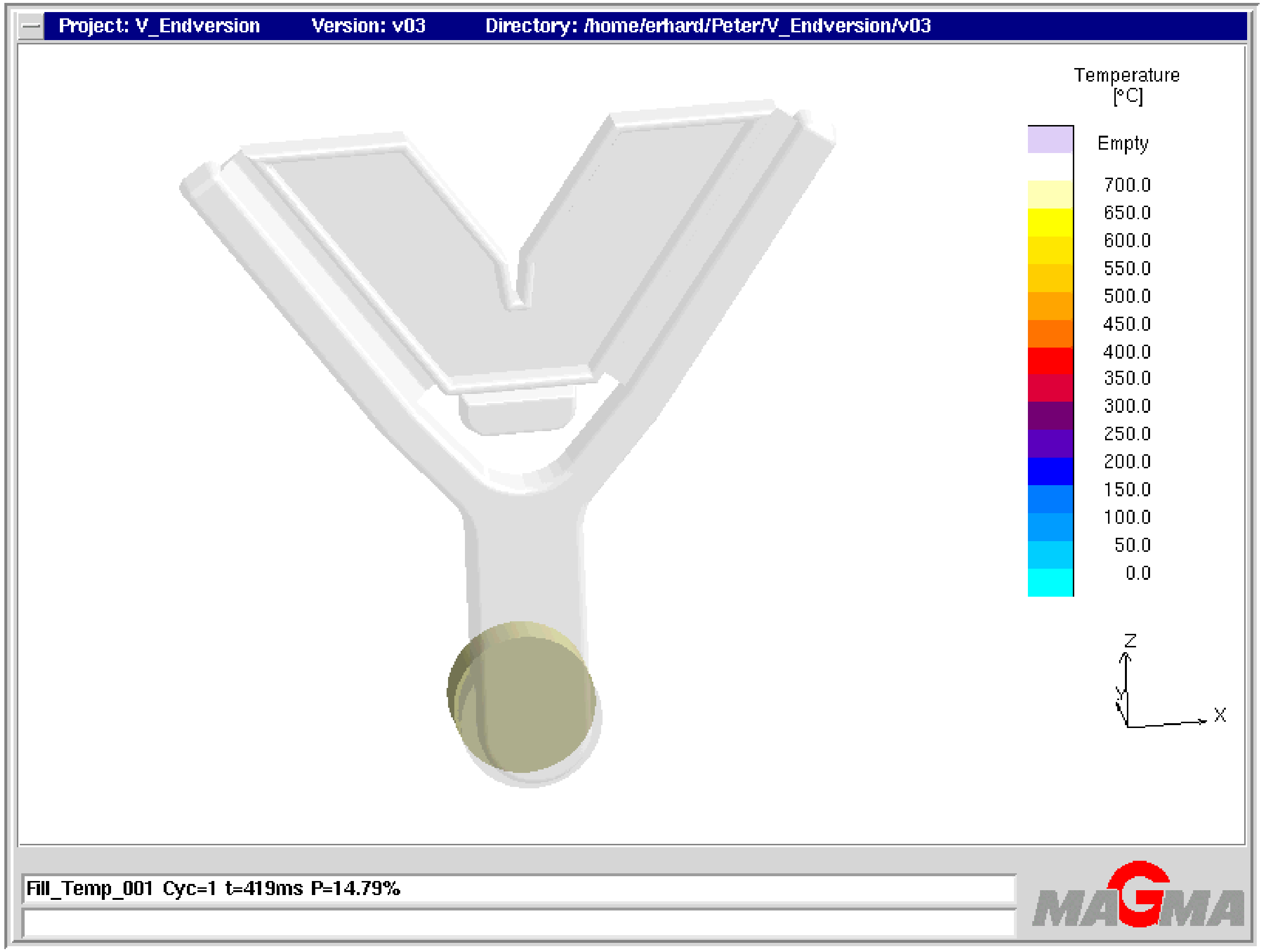
Volume thermal expansion (contraction) depends also on:

- **Exact chemical composition – an alloy designation has (wide) composition ranges for each element**
- **Solidification speed – competition between thermal and mass diffusion (lever rule, Scheil, back diffusion models)**
- **Global vs. local equilibrium at solidification front – development of different phases**
- **Melt treatment (inoculation, grain refinement, modification, degassing**

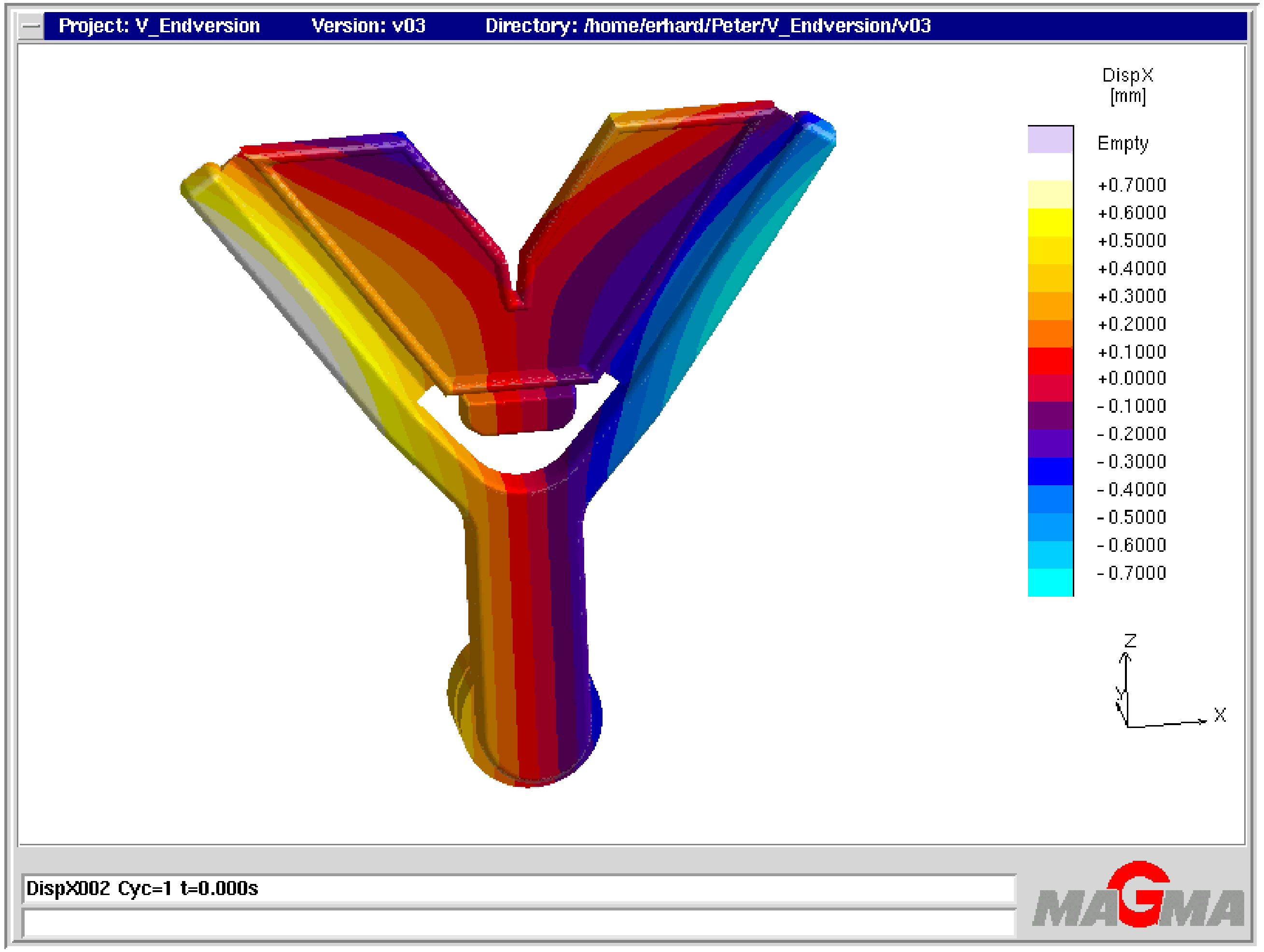
Influence of linear thermal expansion data on distortion of castings:

- When solidified, the casting shrinks from its high temperature dimensions to room temperature
- In the mold, the (relatively soft) casting is more or less constrained and follows the dimensions of the (stiff) mold (plastically deformed at high temperature)
- When the casting is shaked out of mold, it can shrink freely
- Different regions of the casting are at different temperatures at shake-out – shrinkage is locally different
- The local shrinkage (elastic part) equals to thermal expansion x local temperature difference to room temperature
- Each region has an individual shrinkage – that can lead to distortion (plastic contributions ease the stress but increase distortion)

Example: V-shaped high-pressure die-casting – temperature distribution until shake-out



Example: V-shaped high-pressure die-casting – distortion in x-direction during free cooling

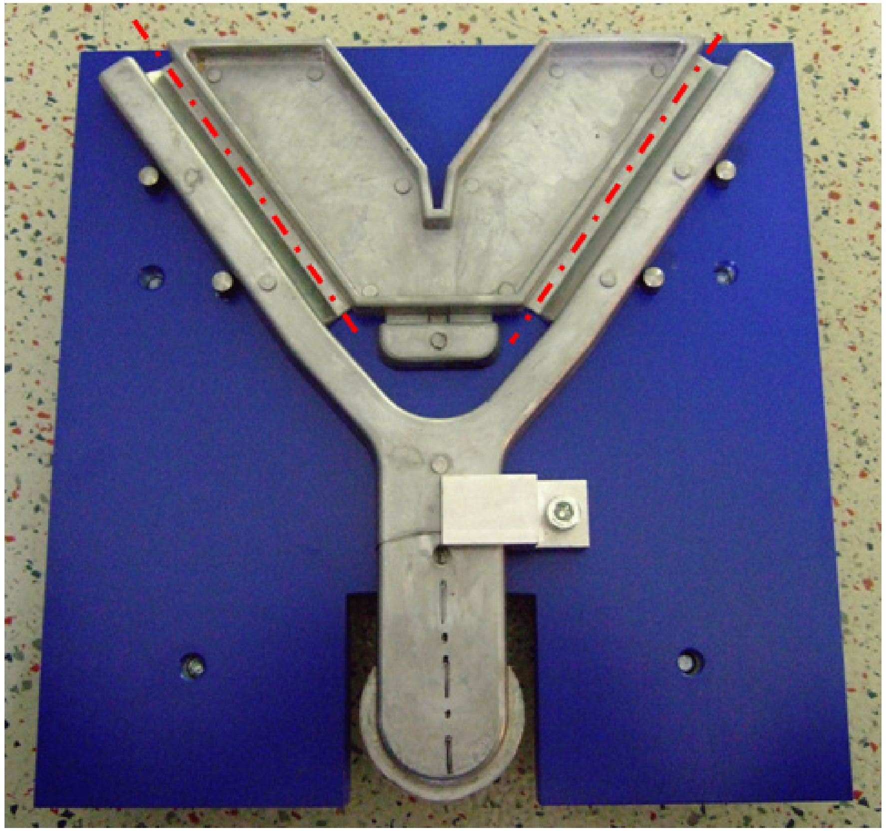


V-shaped high-pressure die-castings are produced at ÖGI

V-shaped specimens

High-pressure die-casting machine

Dimensions of the V-shaped specimens are measured and compared to simulation



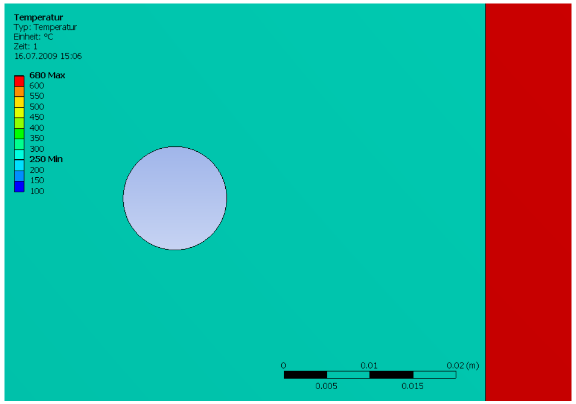
Influence of linear thermal expansion data on distortion of castings:

- Different regions of the casting are at different temperatures at shake-out – shrinkage is locally different (plastic strain can also happen in the die – some stress is already present at shake-out)
- The local shrinkage leads to distortion
- After machining, the stress distribution changes – also the distortion
- Similar problems arise at heat treatment of metal parts

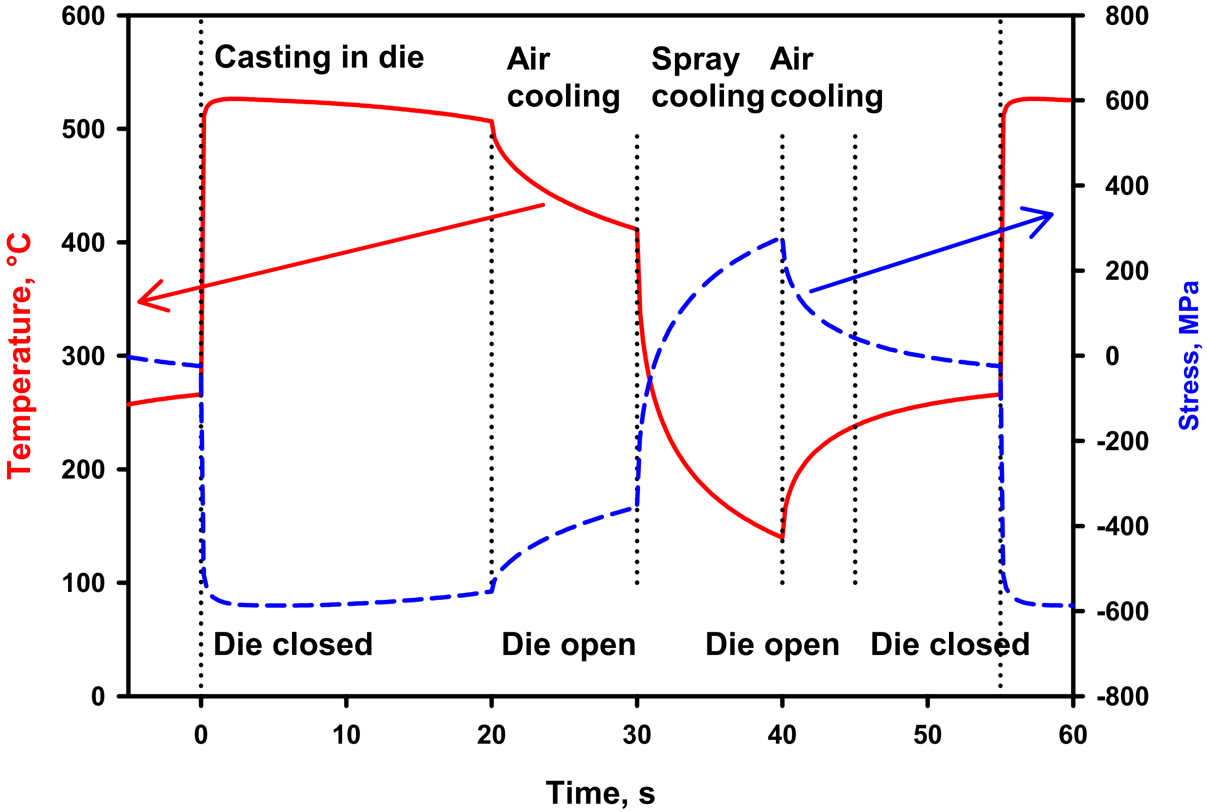
Influence of linear thermal expansion and thermal conductivity data on die life expectance (high-pressure die-casting):

- After filling of the cavity the hot melt is in direct contact with the cooler tool steel
- The steel surface is heated rapidly, the material expands in the vicinity of the surface
- The surface layer gets under heavy compressive stress – can be beyond the yield stress
- This leads to plastic deformation of the surface layer
- After removing of the casting, a lubricant-water mixture is sprayed at the surface – rapid cooling
- The cooled surface layer gets under tension stress – the material is now "too short" – cracking of the surface under tension stress

Temperatures at a tool-steel die-surface in high-pressure die-casting:



Cut of a fraction of die and melt



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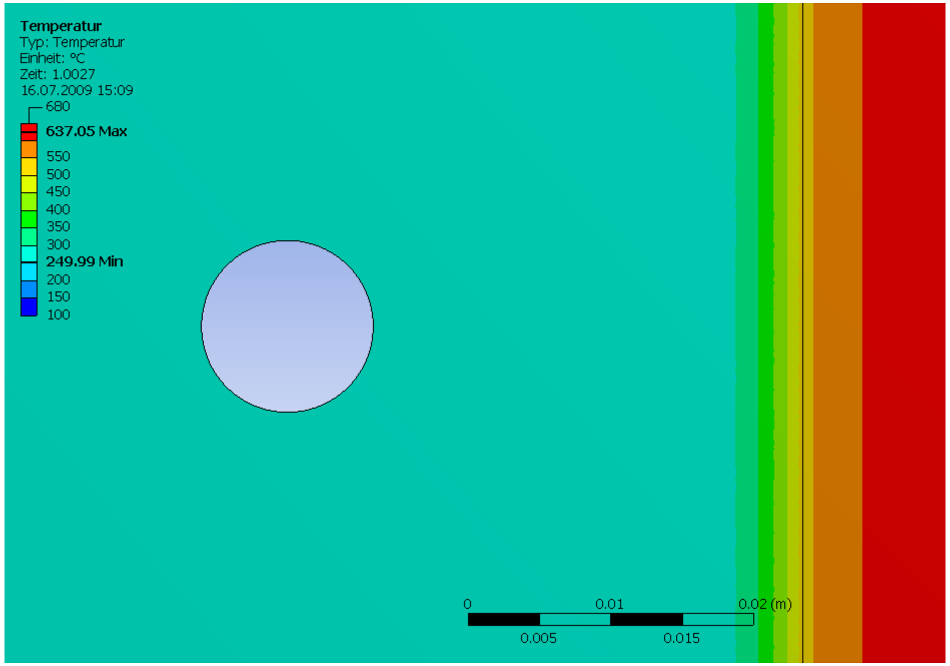
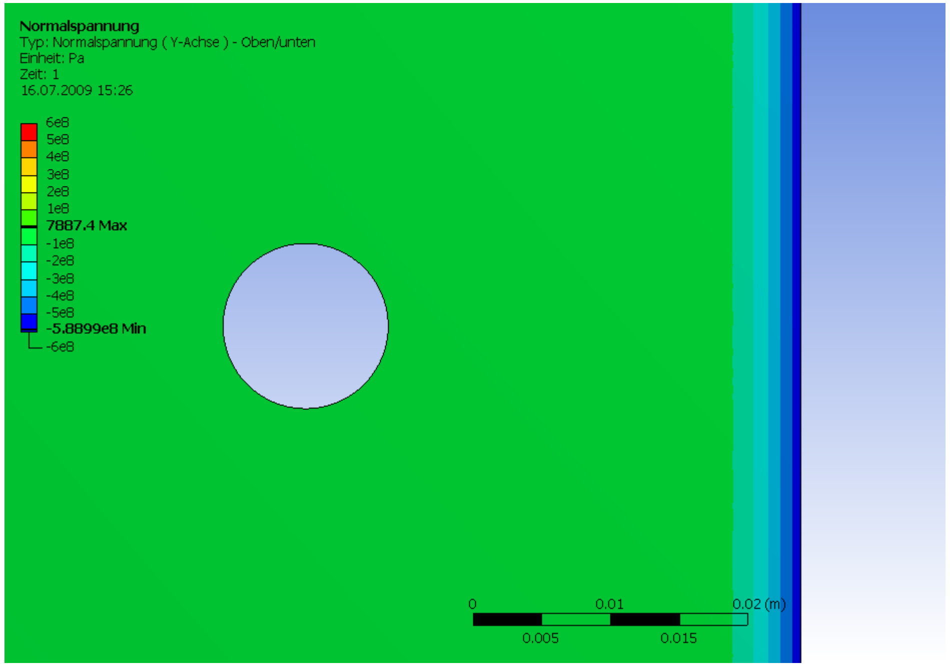
Tool-steel die in high-pressure die-casting during solidification: After 1 second

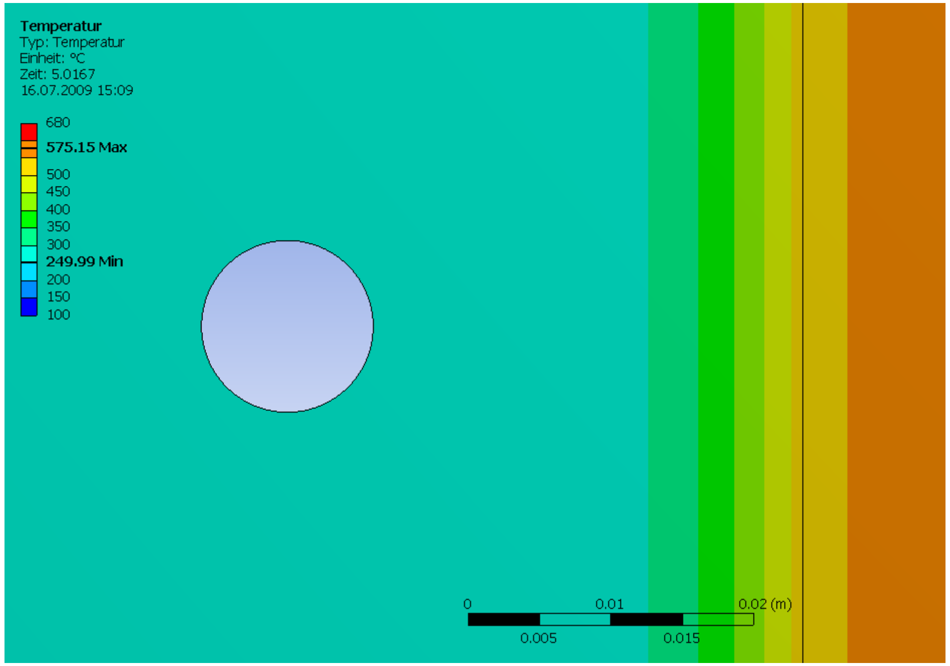


Temperature

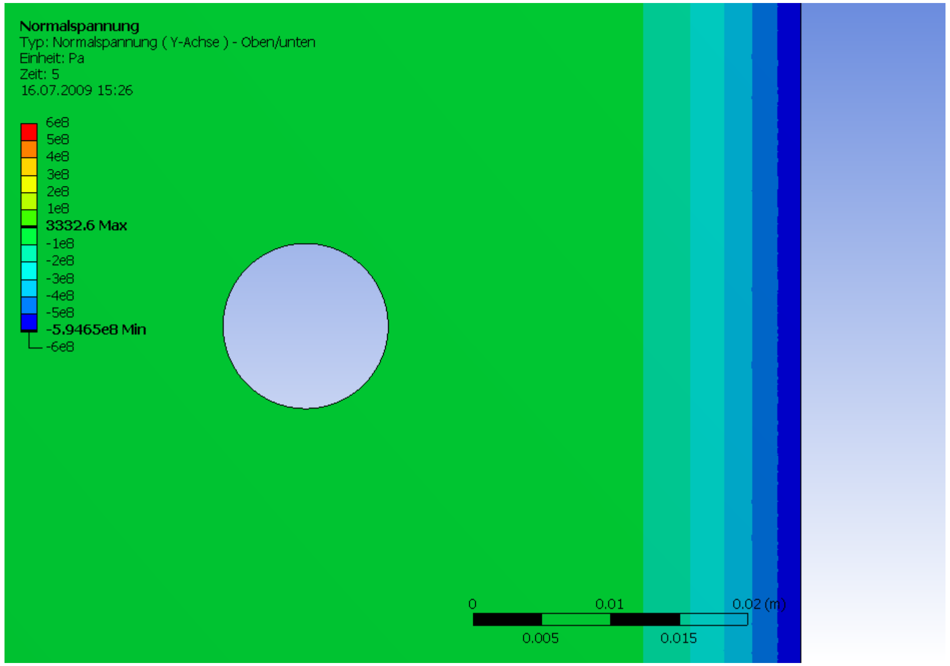


Normal stress in vertical direction

Tool-steel die in high-pressure die-casting during solidification: After 5 seconds



Temperature



Normal stress in vertical direction

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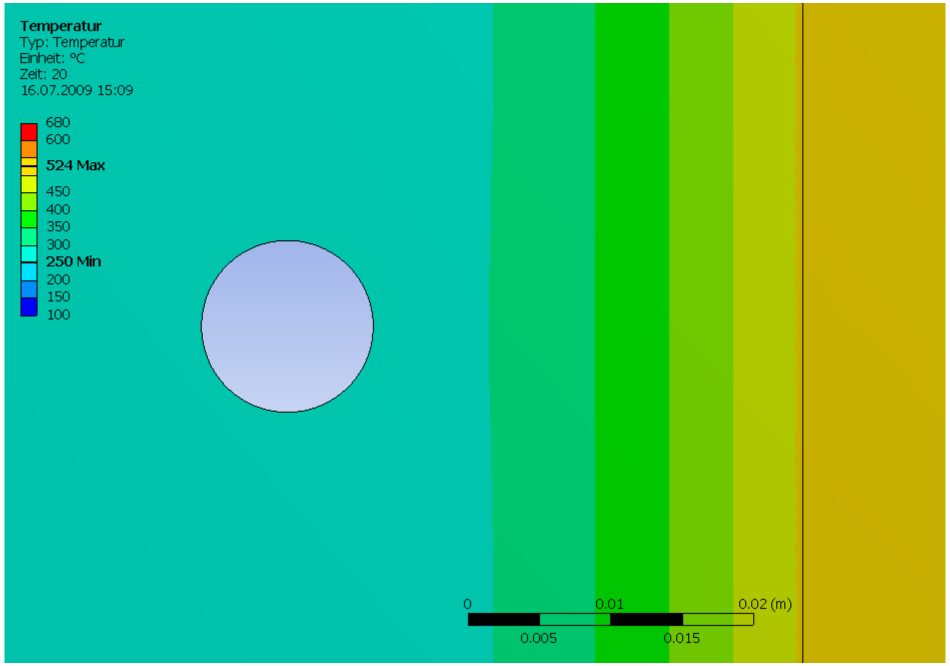
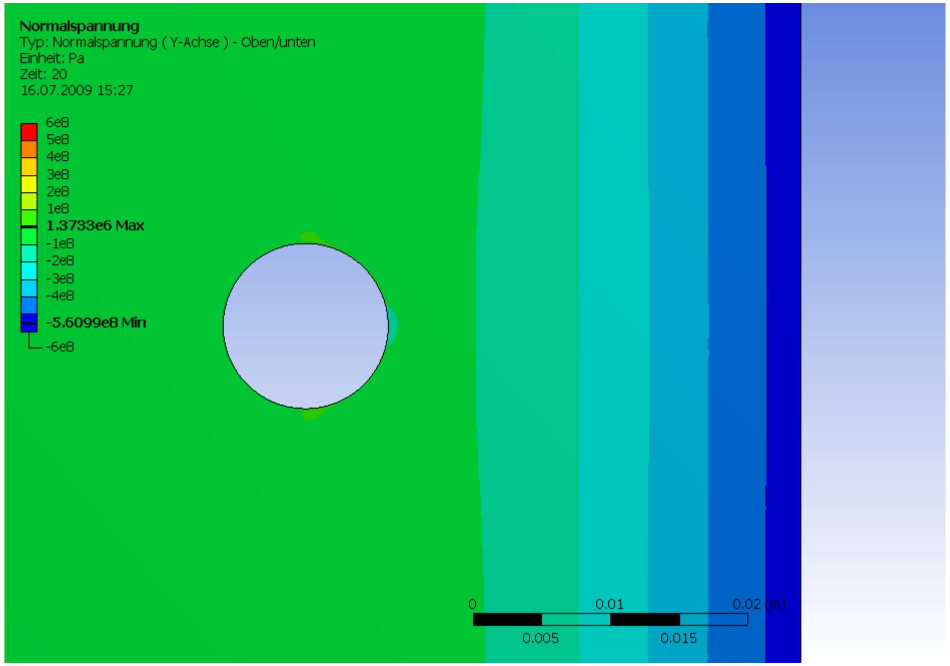
Tool-steel die in high-pressure die-casting during solidification: After 20 seconds



Temperature



Normal stress in vertical direction

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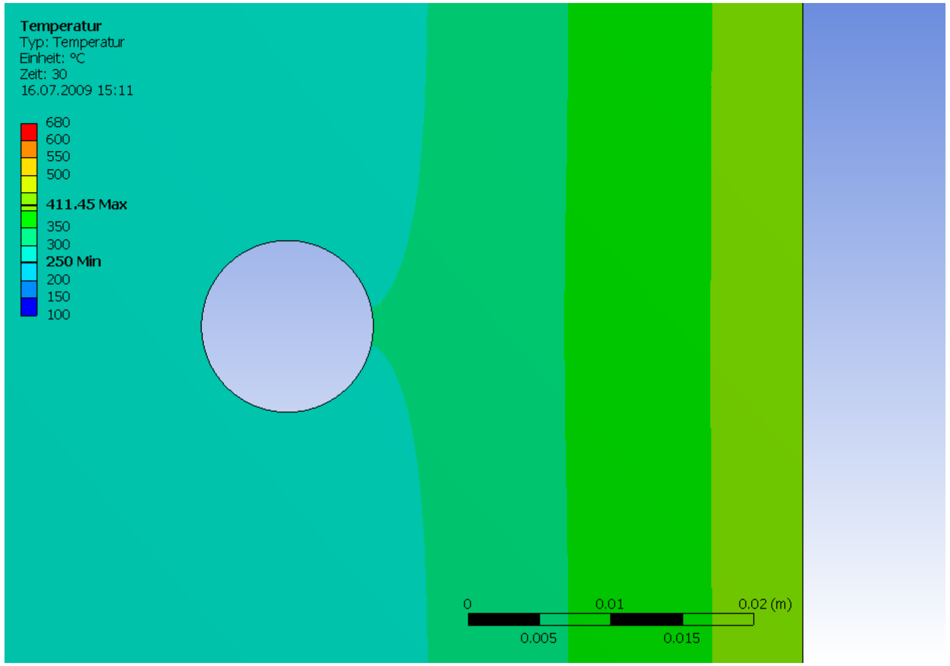
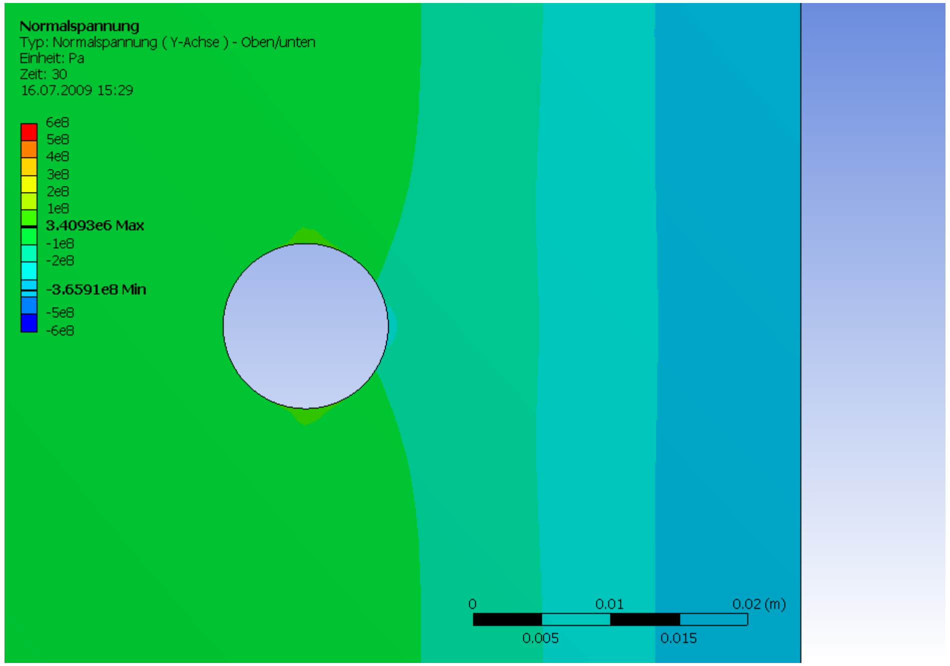
Tool-steel die in high-pressure die-casting at open die:
After 30 seconds

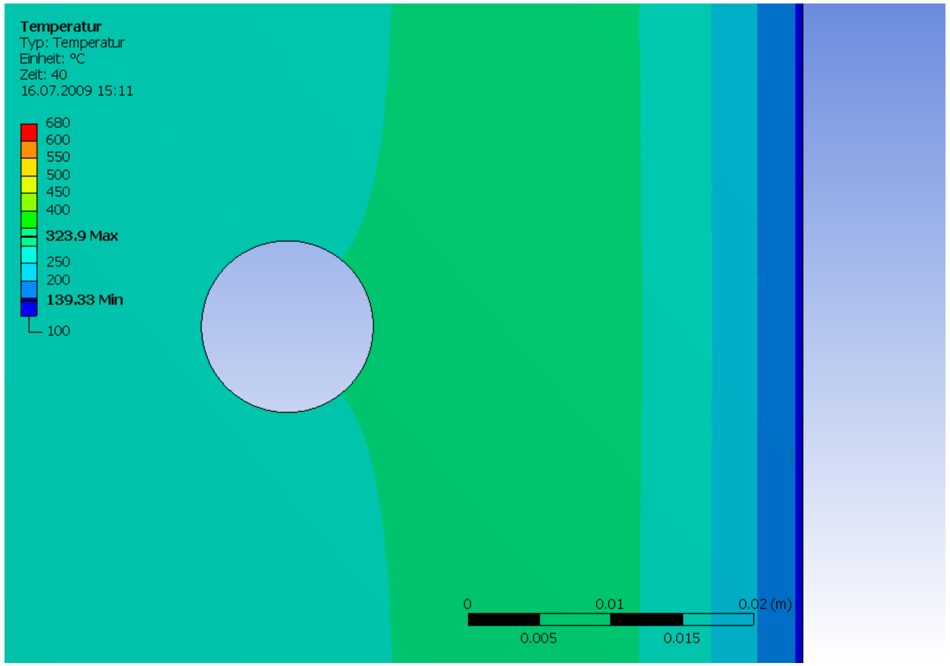


Temperature

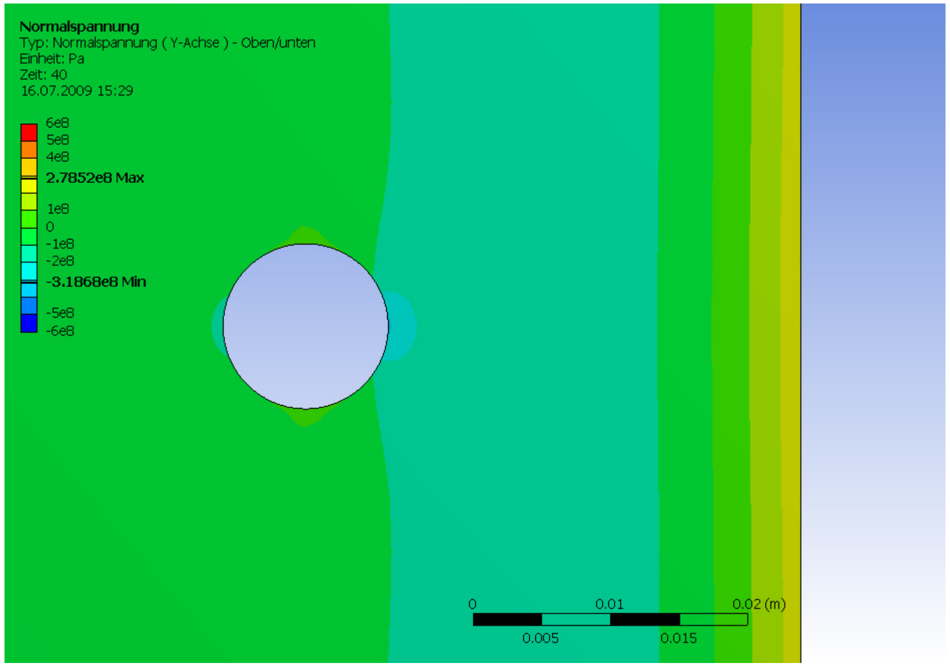


Normal stress in vertical direction

Tool-steel die in high-pressure die-casting during spraying:
After 40 seconds

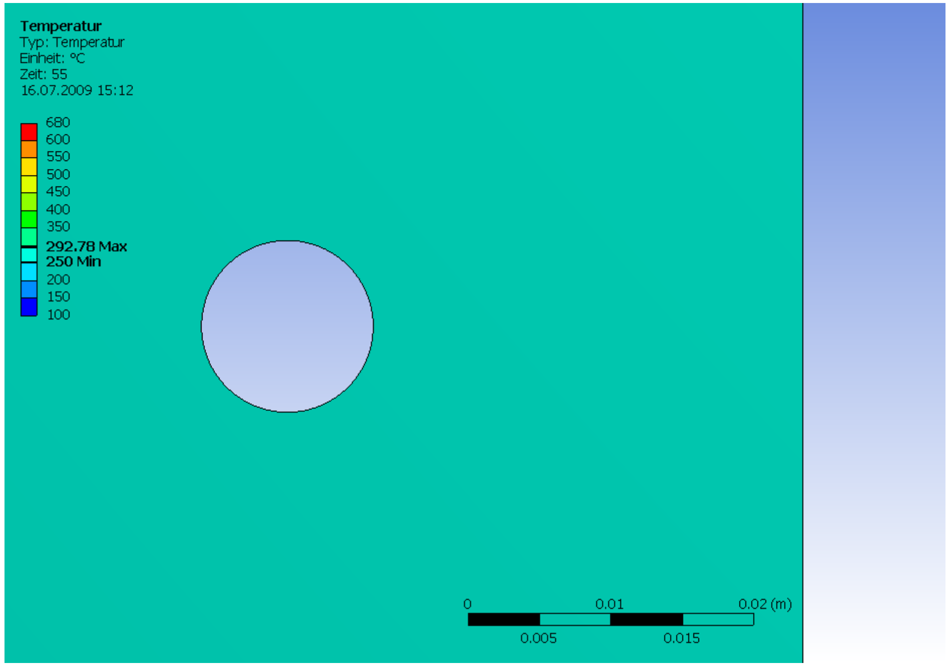


Temperature

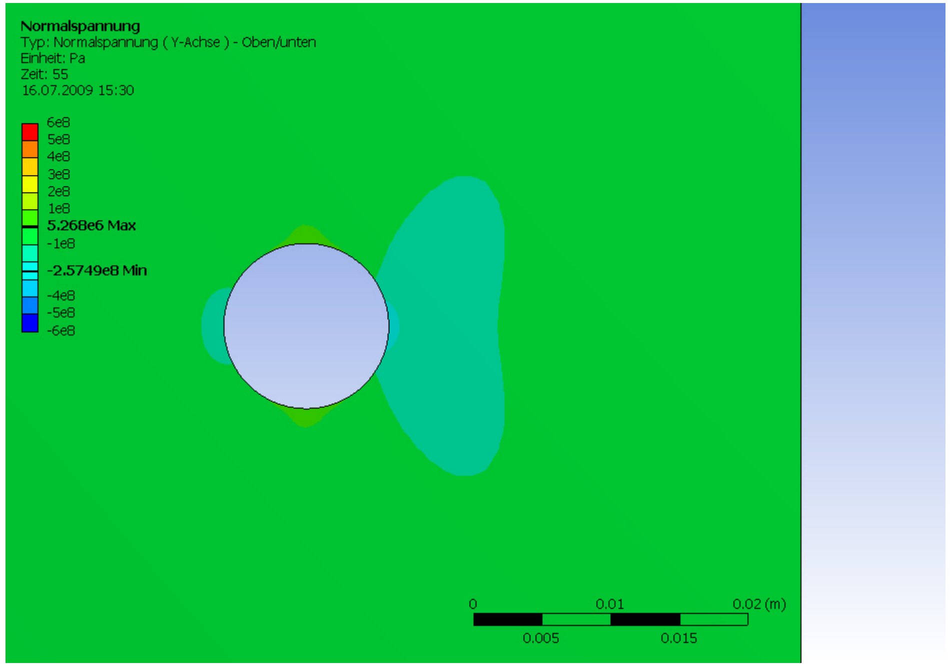


Normal stress in vertical direction

Tool-steel die in high-pressure die-casting at the end of cycle:
After 55 seconds



Temperature

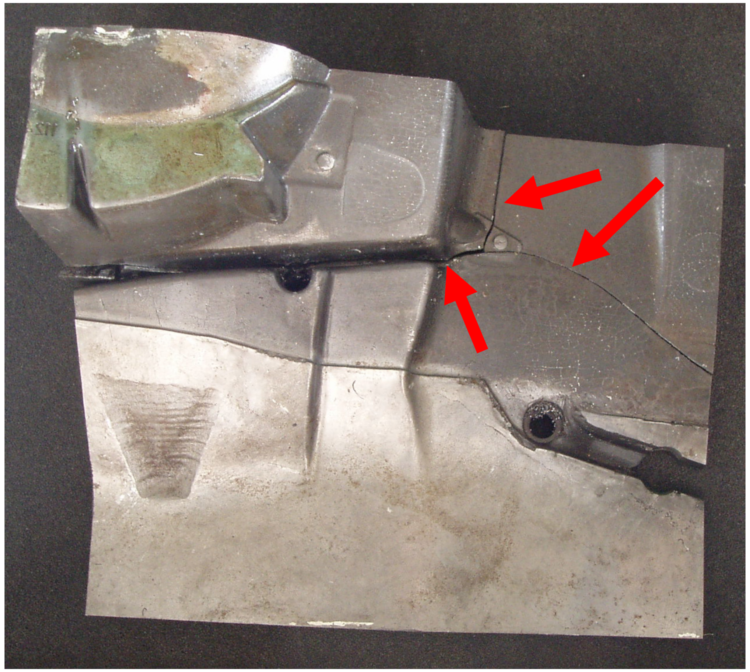


Normal stress in vertical direction

Examples of die damage:

Thermal fatigue cracks

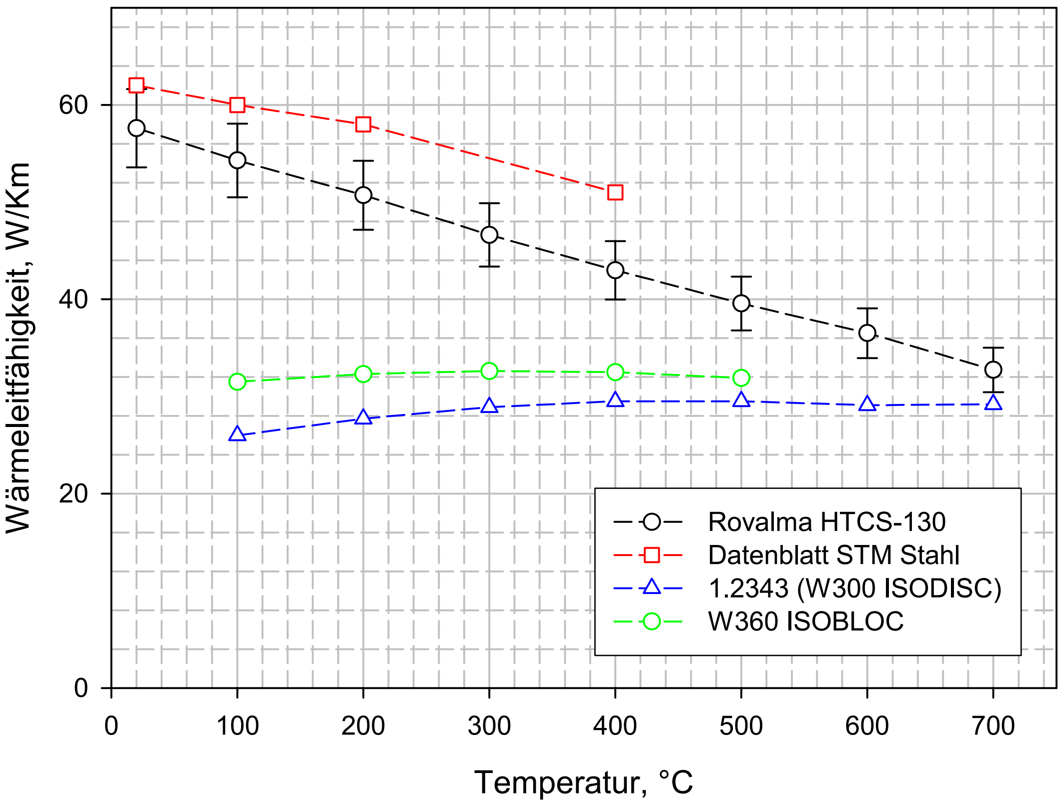
Fracture of the entire die



Influence of linear thermal expansion and thermal conductivity data on die life expectance simulation (high-pressure die-casting):

- Plastic deformation at heating leads to cracking during rapid cooling
- Smaller linear thermal expansion lowers thermal stress
- Higher thermal conductivity removes heat faster – smaller temperature gradients – lower thermal stress
- just a few percent change in thermal conductivity of the tool steel changes peak temperature at the surface for several degrees – that can have a tremendous influence in die life expectance (up to a factor of 10)
- Search for a tools steel with higher thermal conductivity is ongoing

Warmarbeitsstahl von Rovalma HTCS-130:

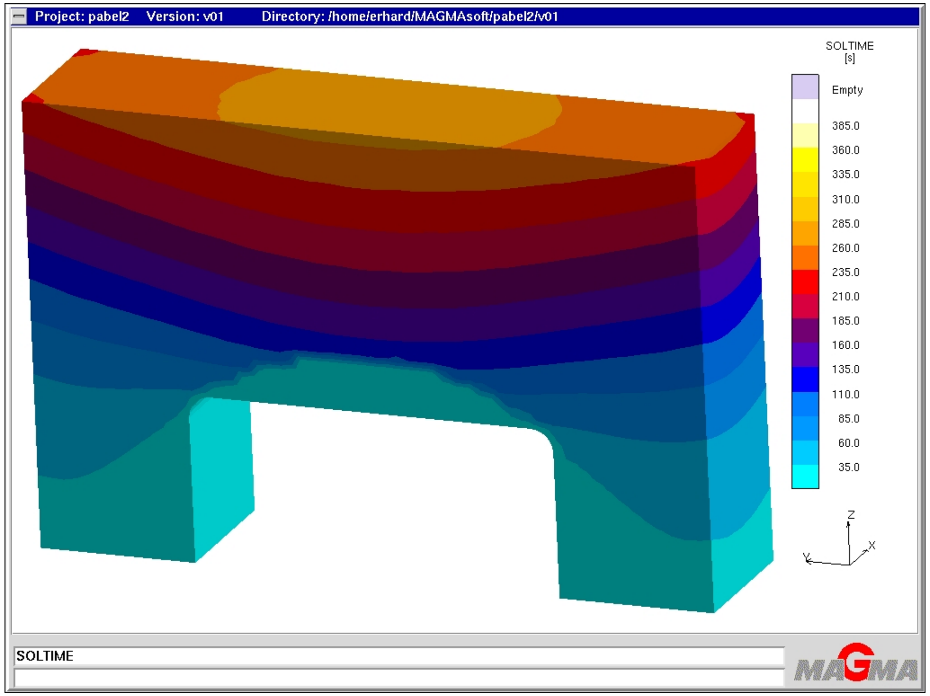


Influence of thermal conductivity on microstructure simulation of castings:

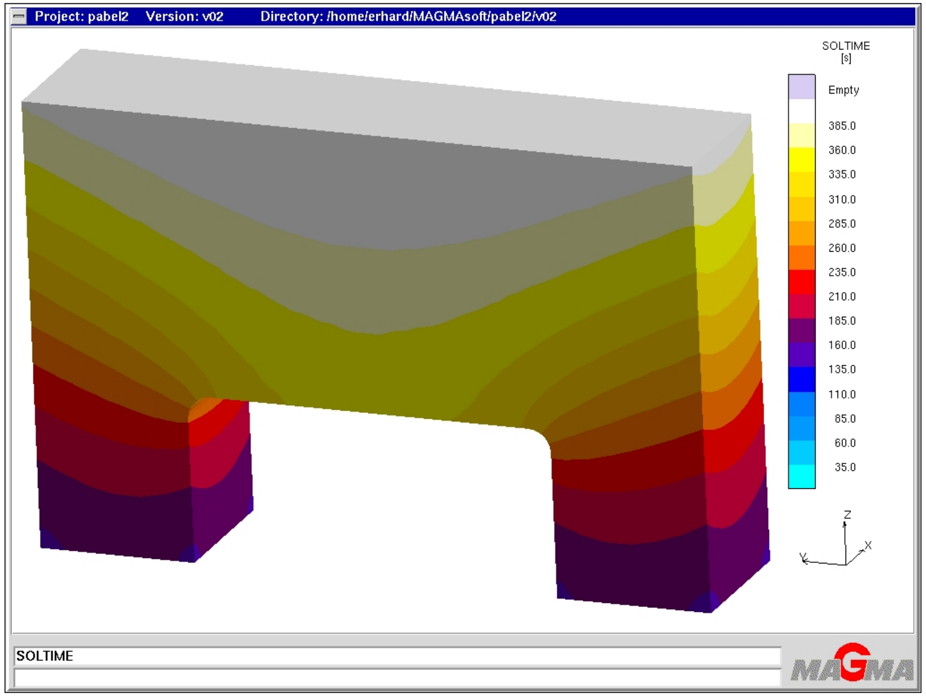
- Mechanical properties (aluminum, magnesium) depend on
  - Melt cleaning, degassing, grain refinement, modification
  - Correct fluid flow, feeding technique
  - Solidification speed (thermal conductivity of the mold)
- Rapid solidification leads to fine grain and small secondary dendrite arms in the microstructure – superior mechanical properties
- Local cooling of crucial regions of a casting

Simulation of the cooling time:

Casting with grey iron core

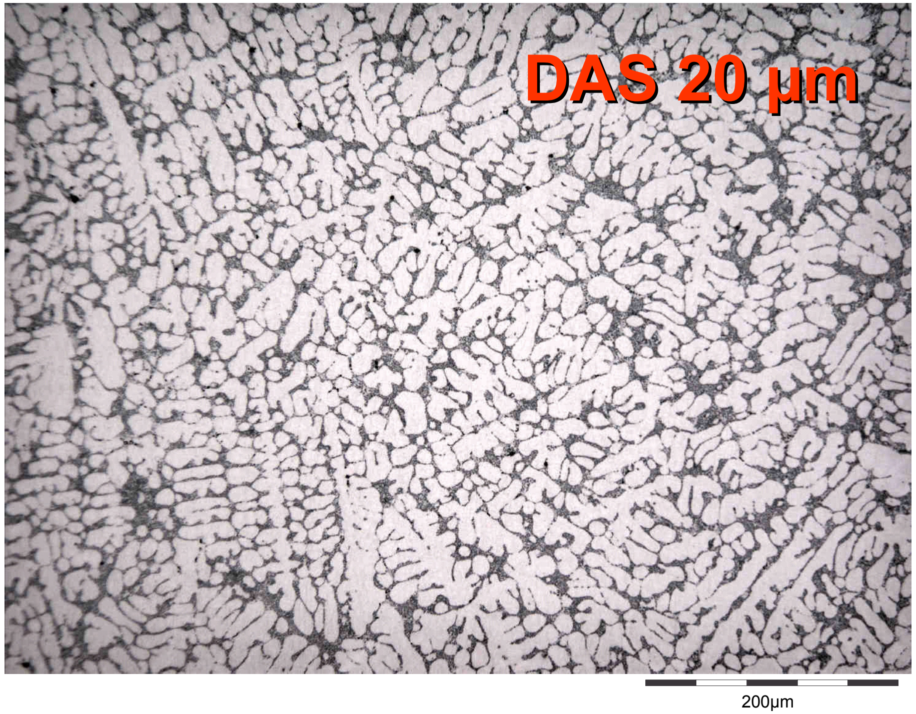


Casting with quartz sand core

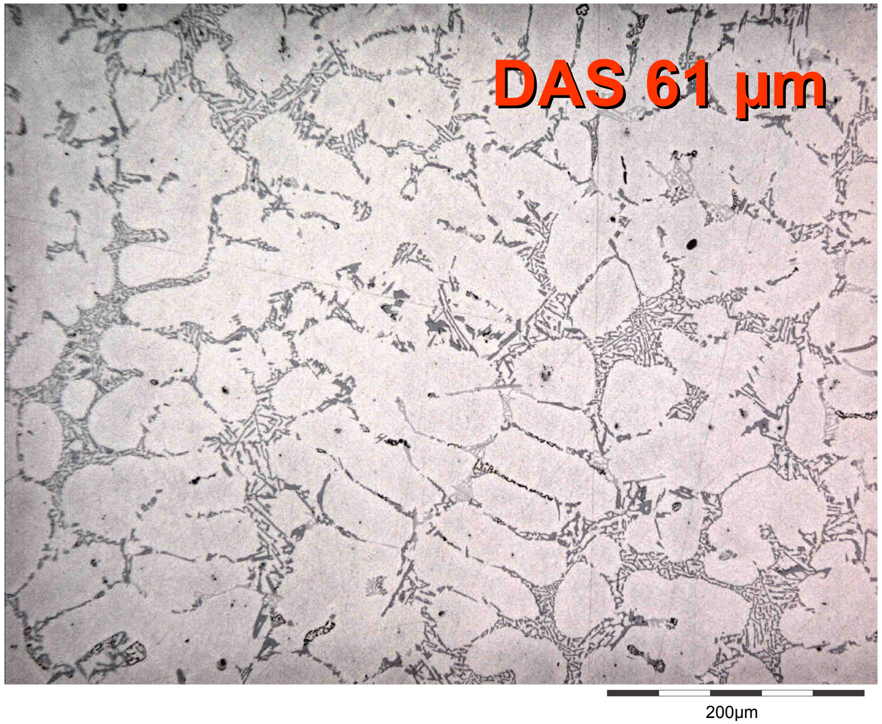


Microstructure (position 7 mm from surface):

Casting with grey iron core



Casting with quartz sand core



Conclusions: How in(accurate) thermal conductivity and thermal expansion data influences the quality of casting simulations

- Volume thermal expansion of the solidifying melt can lead to shrinkage porosity – with inaccurate data cavities can be predicted when casting is sound and vice versa
- Linear thermal expansion is responsible for thermal strain – with inaccurate data the final distortion of the casting and residual stresses are not correctly predicted
- Thermal conductivity of the mold determines the heat removal from the solidifying casting – with inaccurate data the microstructure will develop different in simulation and reality
- Thermal conductivity and linear thermal expansion of a die are responsible for the amount of (cycling) compression and tension stress – inaccurate data lead to a completely wrong prediction of cracking (lifetime)

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