## GTT-Technologies' 10th Annual Workshop, Herzogenrath, Germany, June 4-6, 2008

# The need for thermochemical and thermophysical property data in the modelling of casting processes

(Christoph Honsel, Konrad Weiß)

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www.rwp-simtec.de

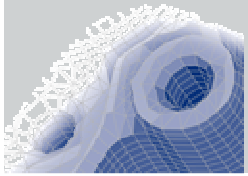
- founded 1984 as spinn-off of the “Giesserei-Institutes der RWTH Aachen“

- Development and distribution of the FEM-program SIMTEC / WinCast
  (mainly for calculation of solidification processes)

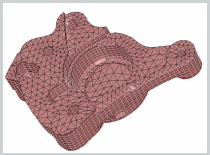
- Activities: Distribution of licenses, Support and training
  consulting works
- Since 1997 Own Building in Roetgen, near Aachen

- Employees: 6 (in Roetgen)

Christoph Honsel: responsible for software development

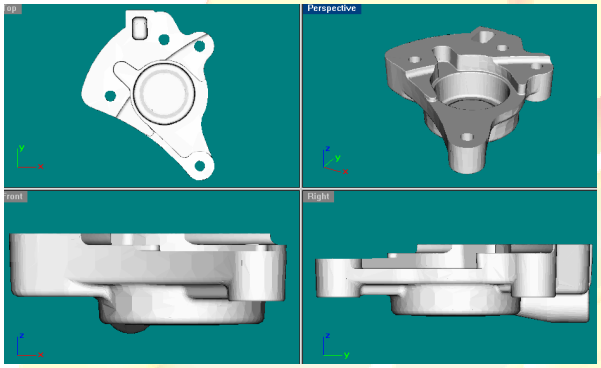


# Example:
# Shimano disk brake

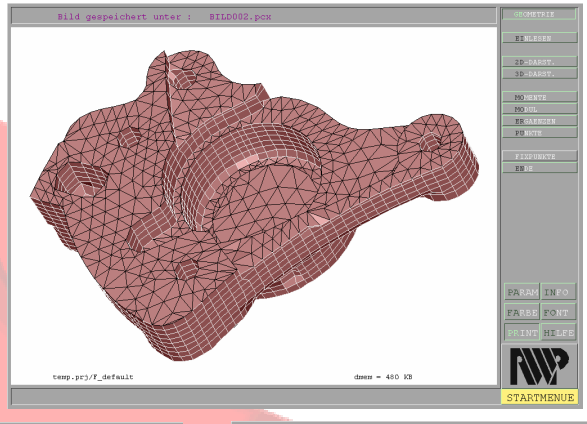


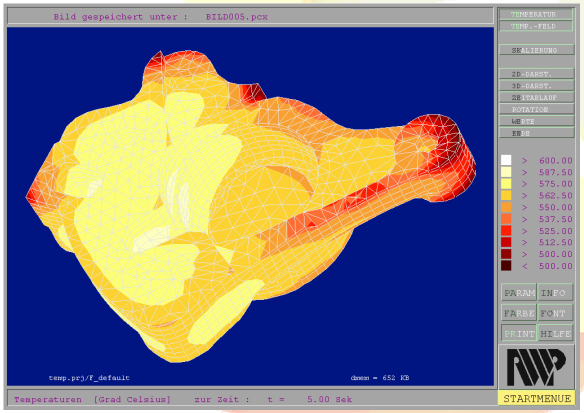


## CAD

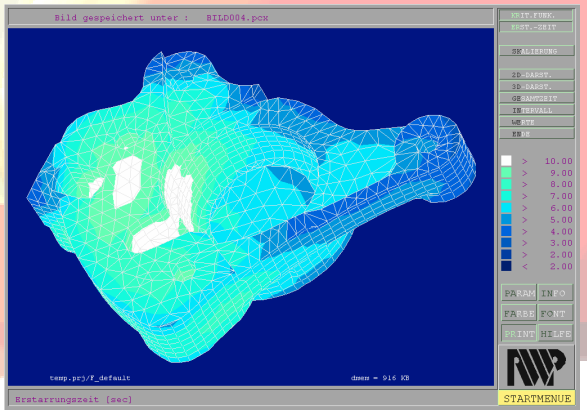



## FEM

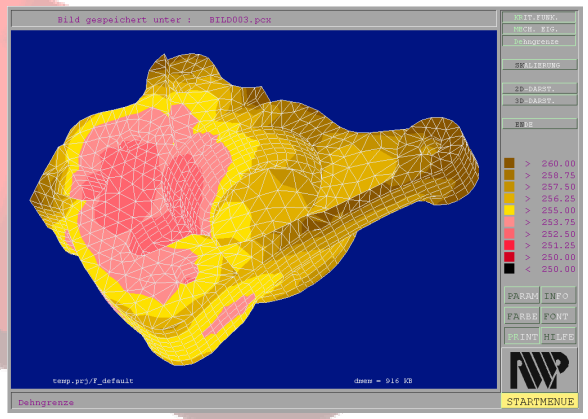


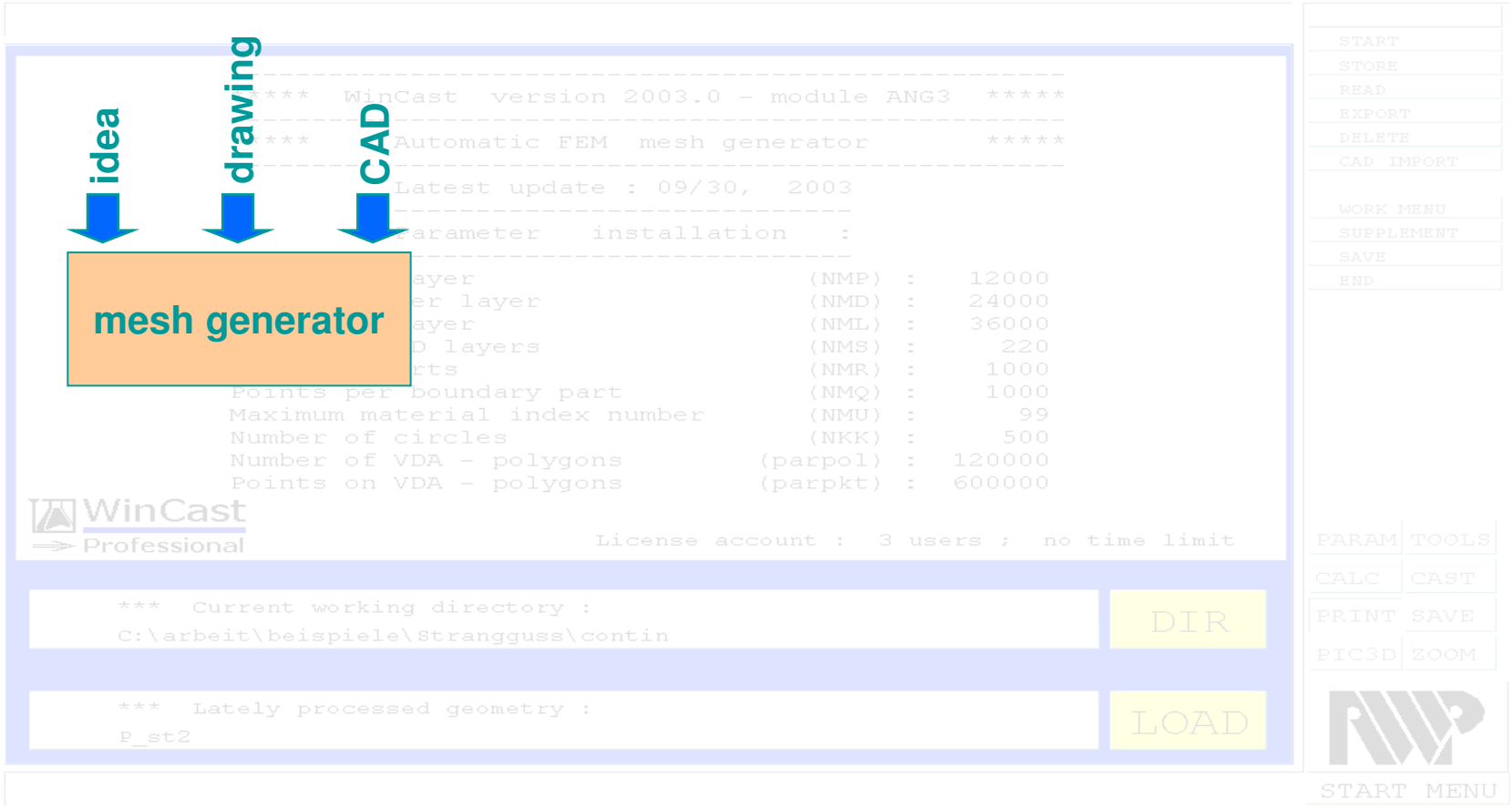

temperature



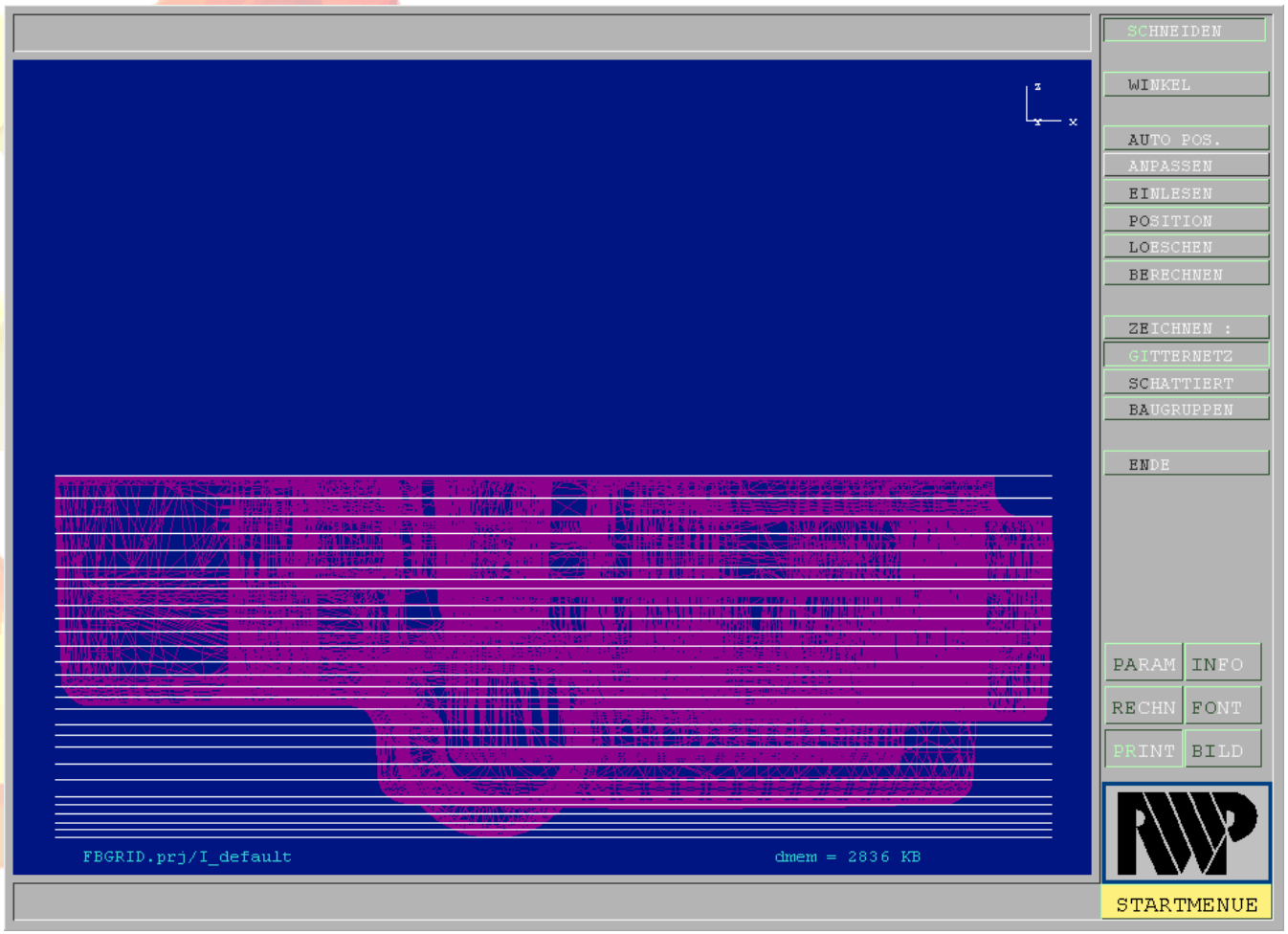

solidification time

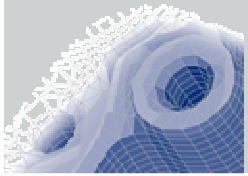



mechanical properties


idea
drawing
CAD
mesh generator
*** WinCast version 2003.0 - module ANG3 *****
*** Automatic FEM mesh generator *****
Latest update : 09/30, 2003
Parameter installation :
(NMP) : 12000
(NMD) : 24000
(NML) : 36000
(NMS) : 220
(NMR) : 1000
Points per boundary part (NMQ) : 1000
Maximum material index number (NMU) : 99
Number of circles (NKK) : 500
Number of VDA - polygons (parpol) : 120000
Points on VDA - polygons (parpkt) : 600000
WinCast Professional
License account : 3 users ; no time limit
*** Current working directory :
C:\arbeit\beispiele\Strangguss\contin
DIR
*** Lately processed geometry :
P_st2
LOAD
START
STORE
READ
EXPORT
DELETE
CAD IMPORT
WORK MENU
SUPPLEMENT
SAVE
END
PARAM TOOLS
CALC CAST
PRINT SAVE
PIC3D ZOOM
START MENU

## Definition of parallel layers:





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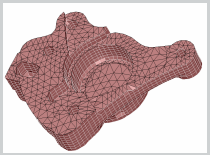
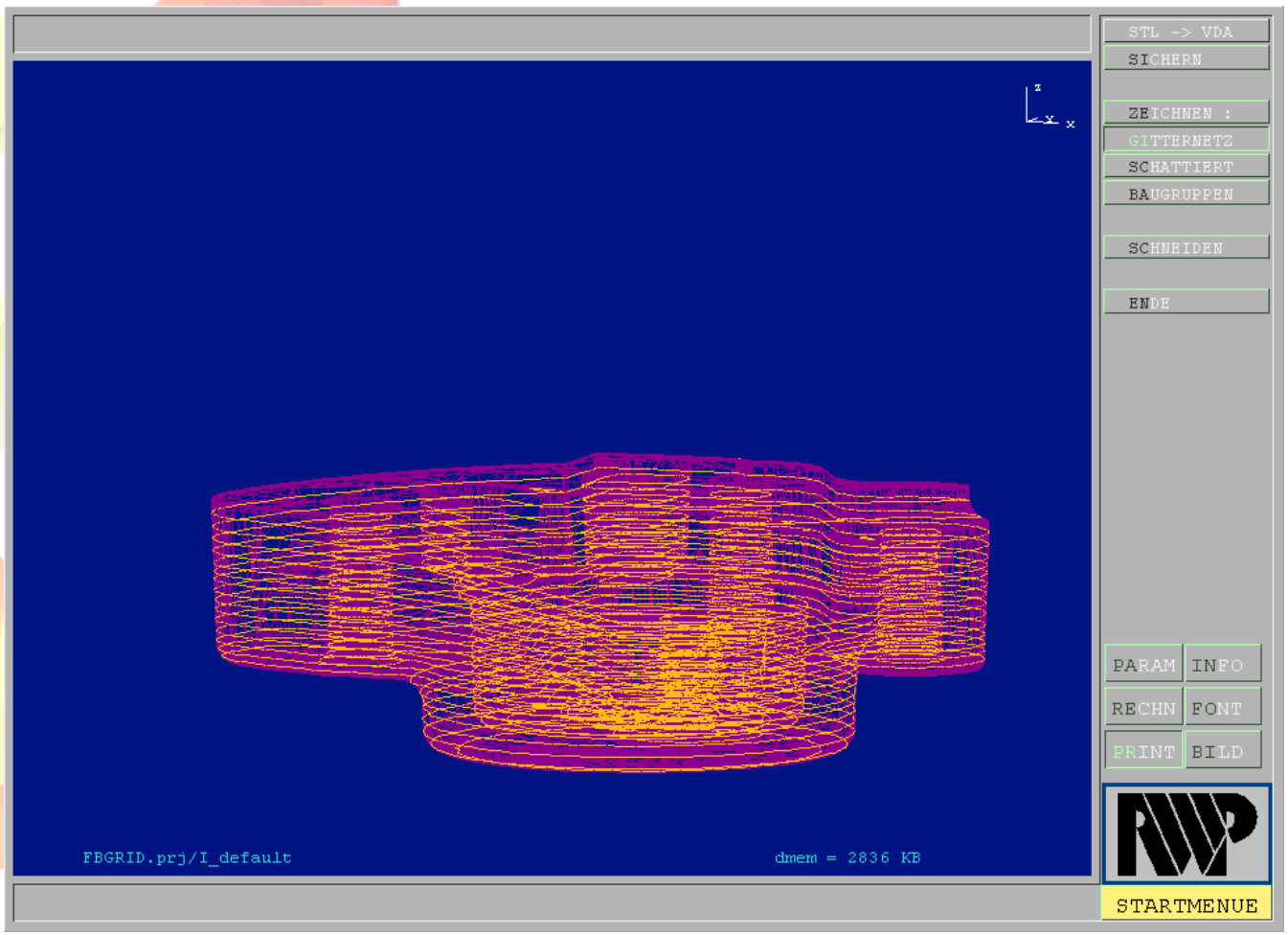
# Shimano disk brake

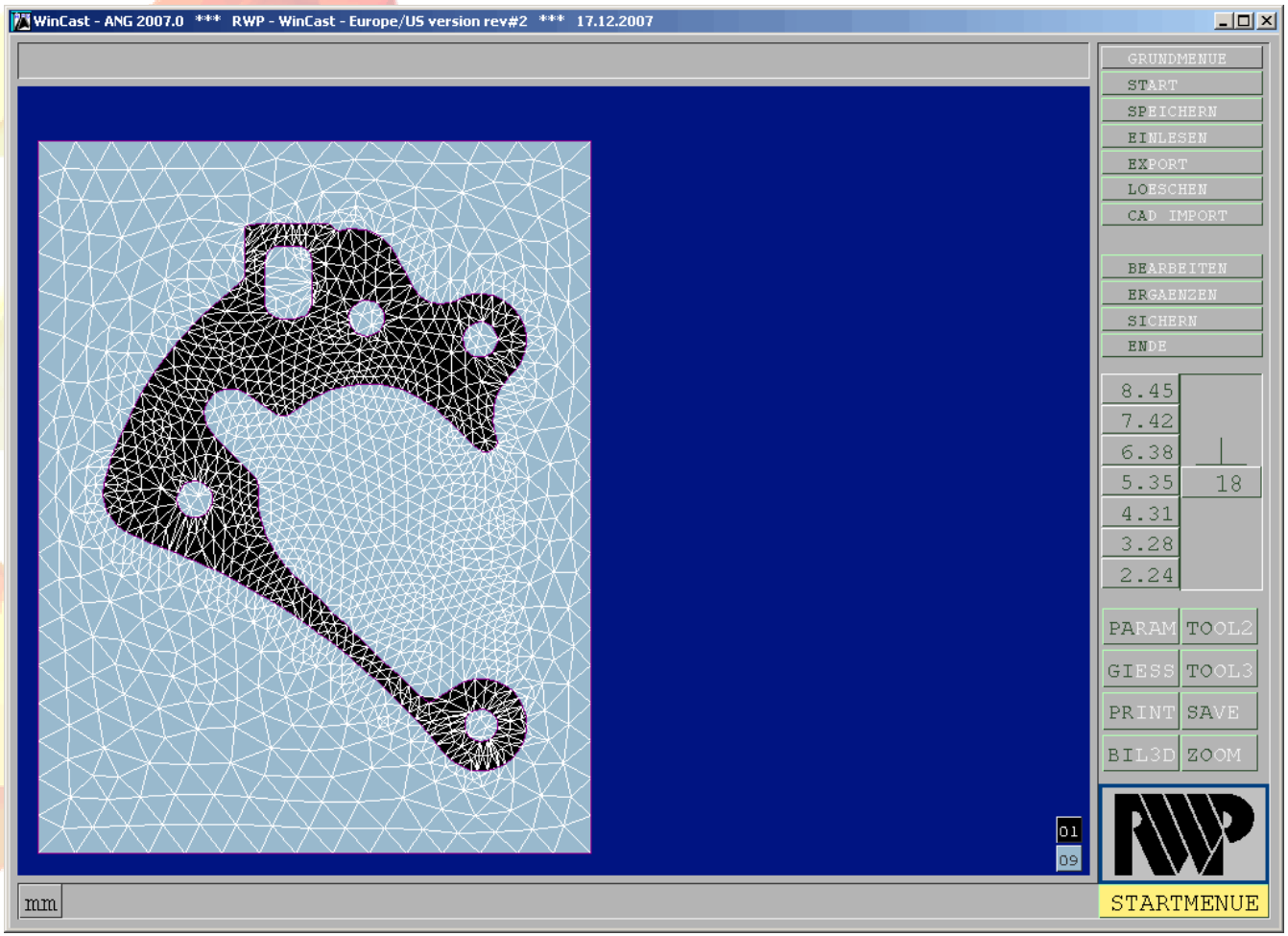




## Calculation of section planes:

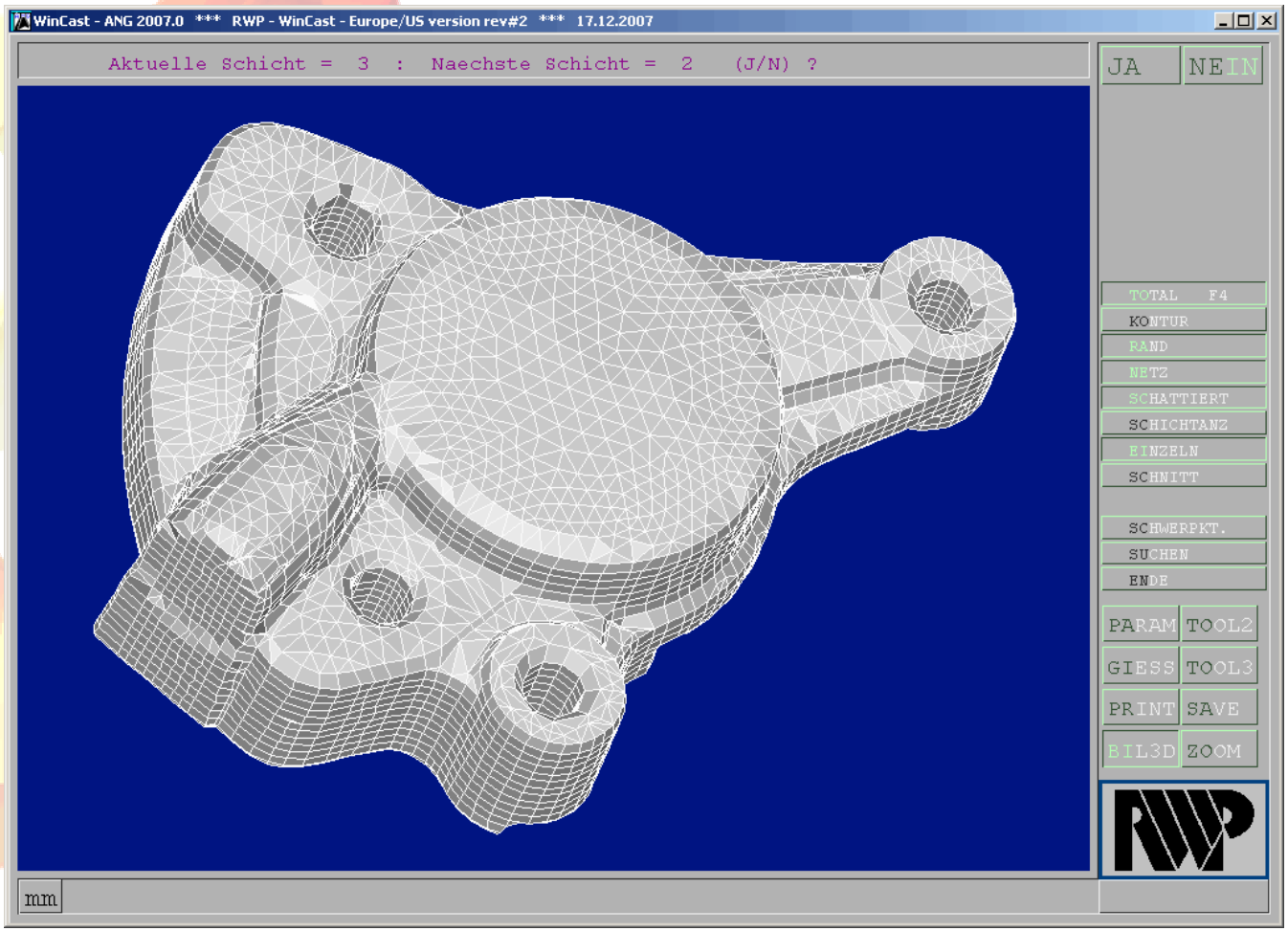


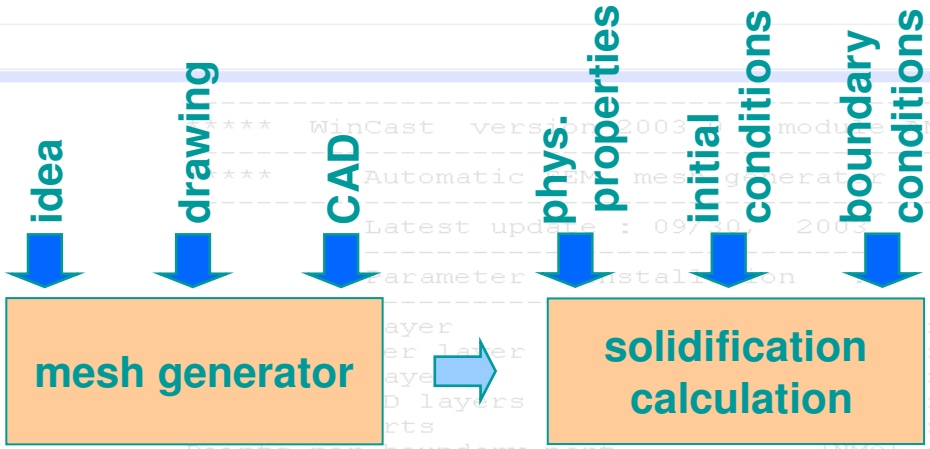
## Enmeshment of a 2d section with triangles:



## Layer by layer :

## 3d enmeshment



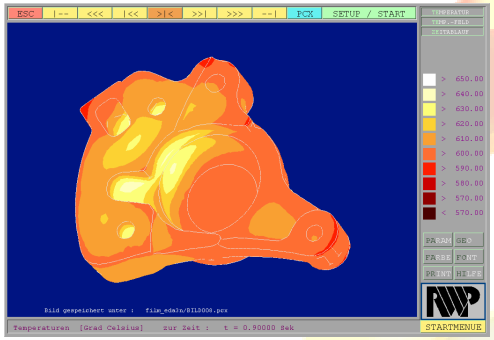


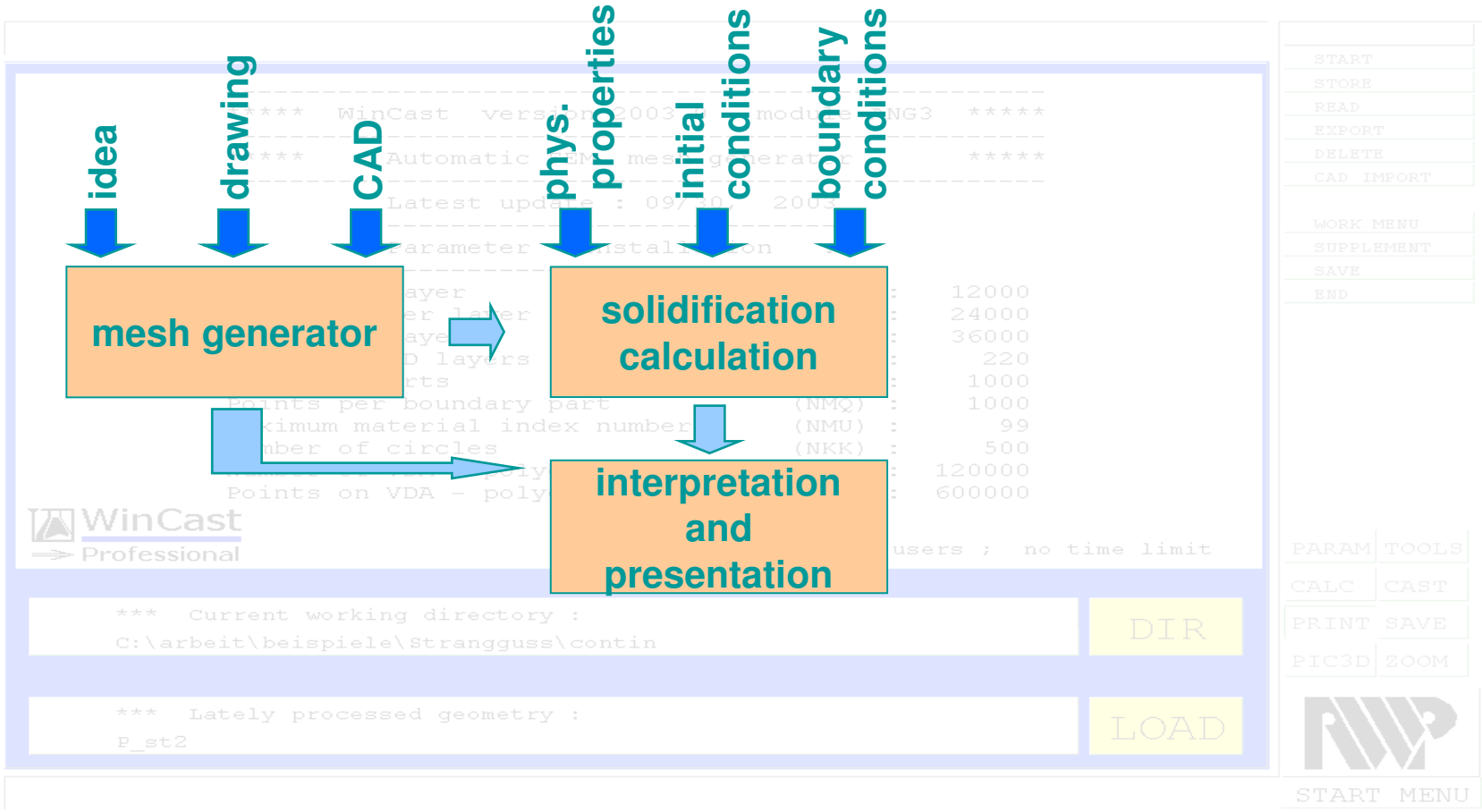

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + \dot{Q}$$

| | | |
|---|---|---|
| T | = | temperature |
| t | = | time |
| x,y,z | = | coordinates |
| $\rho c_p$ | = | density * spec. heat |
| $\lambda$ | = | conductivity |
| $\dot{Q}$ | = | heat source/sink (latent heat) |

# Example: Shimano disk brake

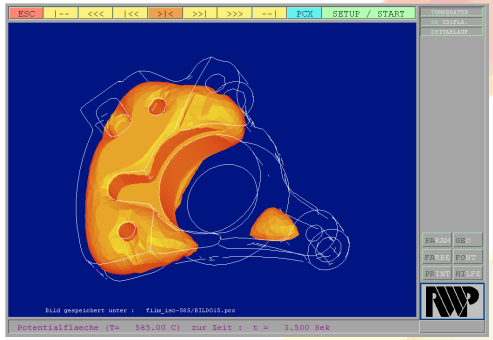
## Calculation of solidification

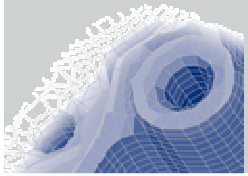



idea
drawing
CAD
phys. properties
initial conditions
boundary conditions
mesh generator
solidification calculation
interpretation and presentation
WinCast
Professional

## Interpretation:

## 3d isotherms





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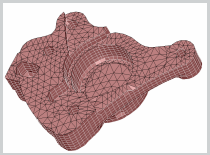
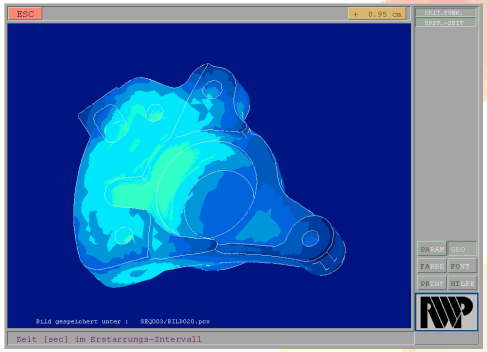
# Shimano disk brake

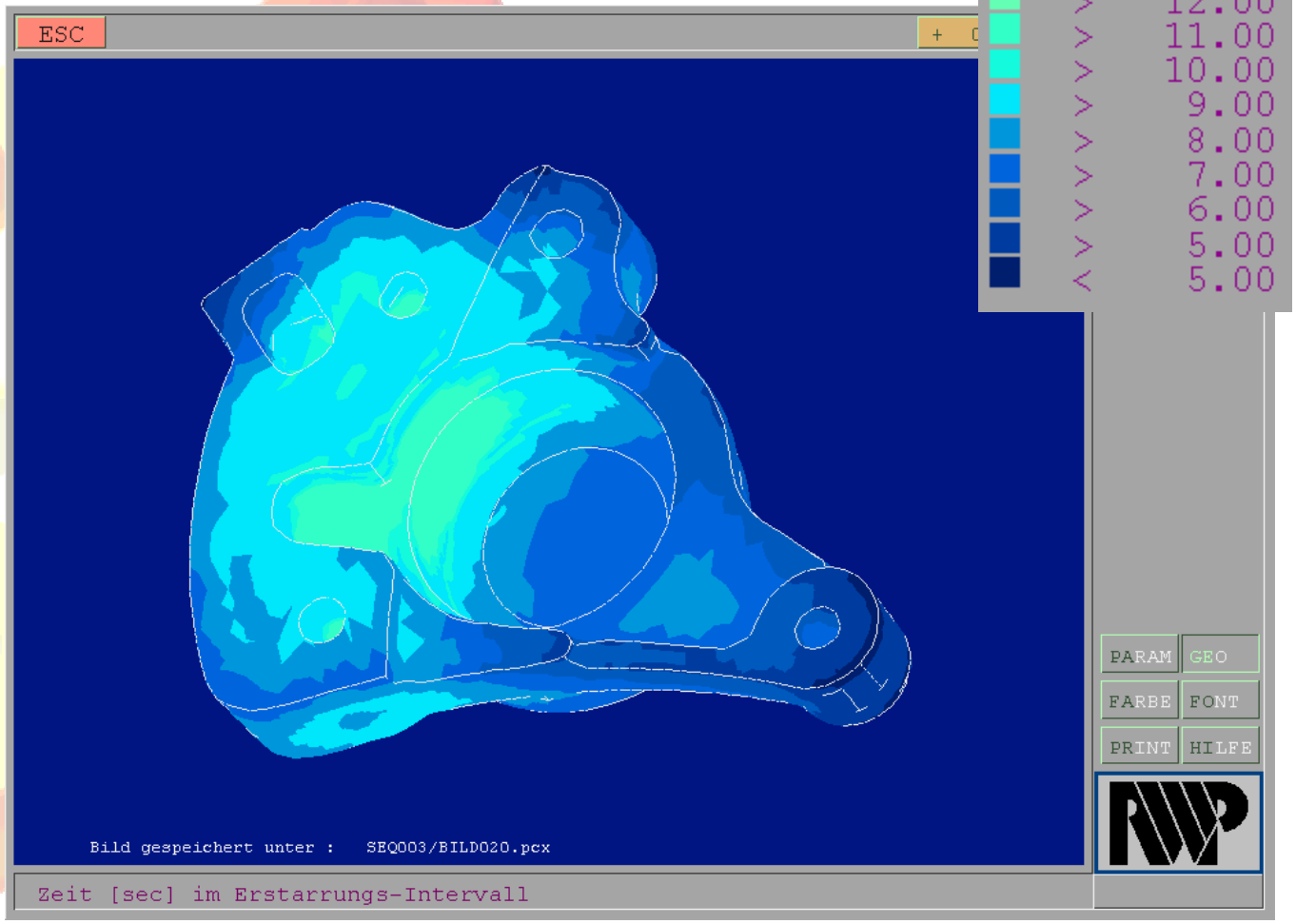


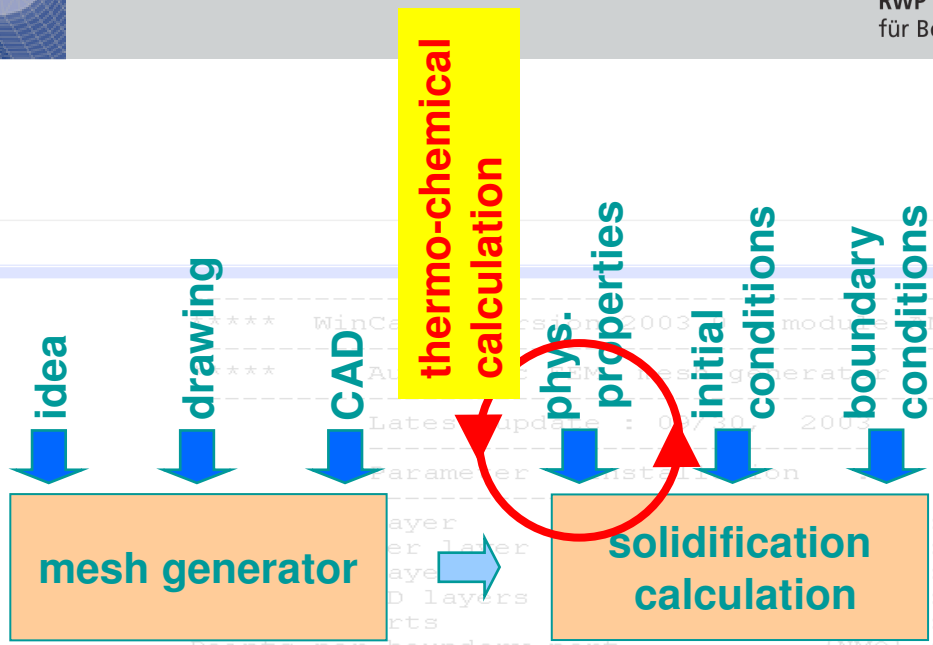


## interpretation:

## local solidification time



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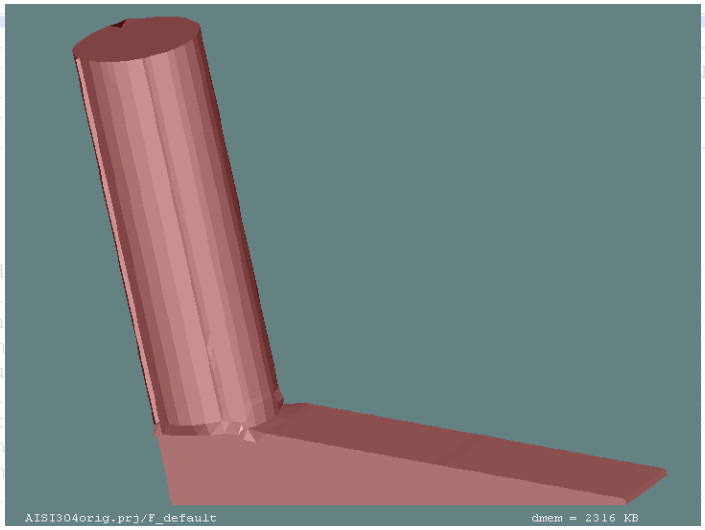
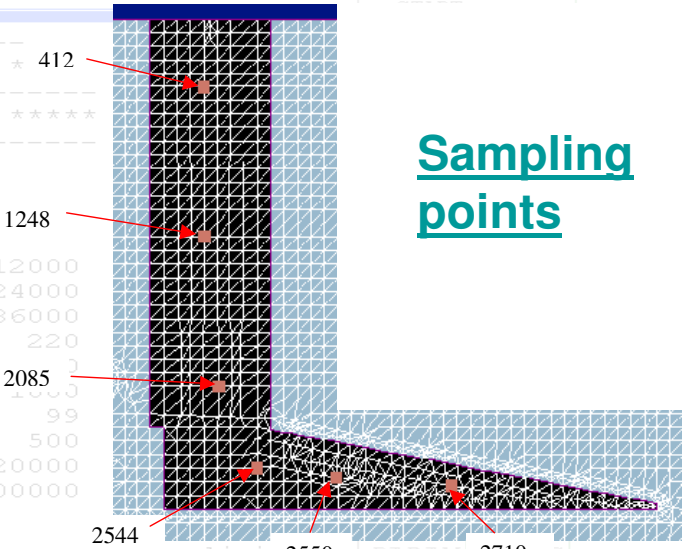
| x,y,z | = | coordinates |
| $\rho c_p$ | = | density * spec. heat |
| $\lambda$ | = | conductivity |
| $\dot{Q}$ | = | heat source/sink (latent heat) |

# Sensitivity analysis

## Geometry standard wedge




## Sampling points

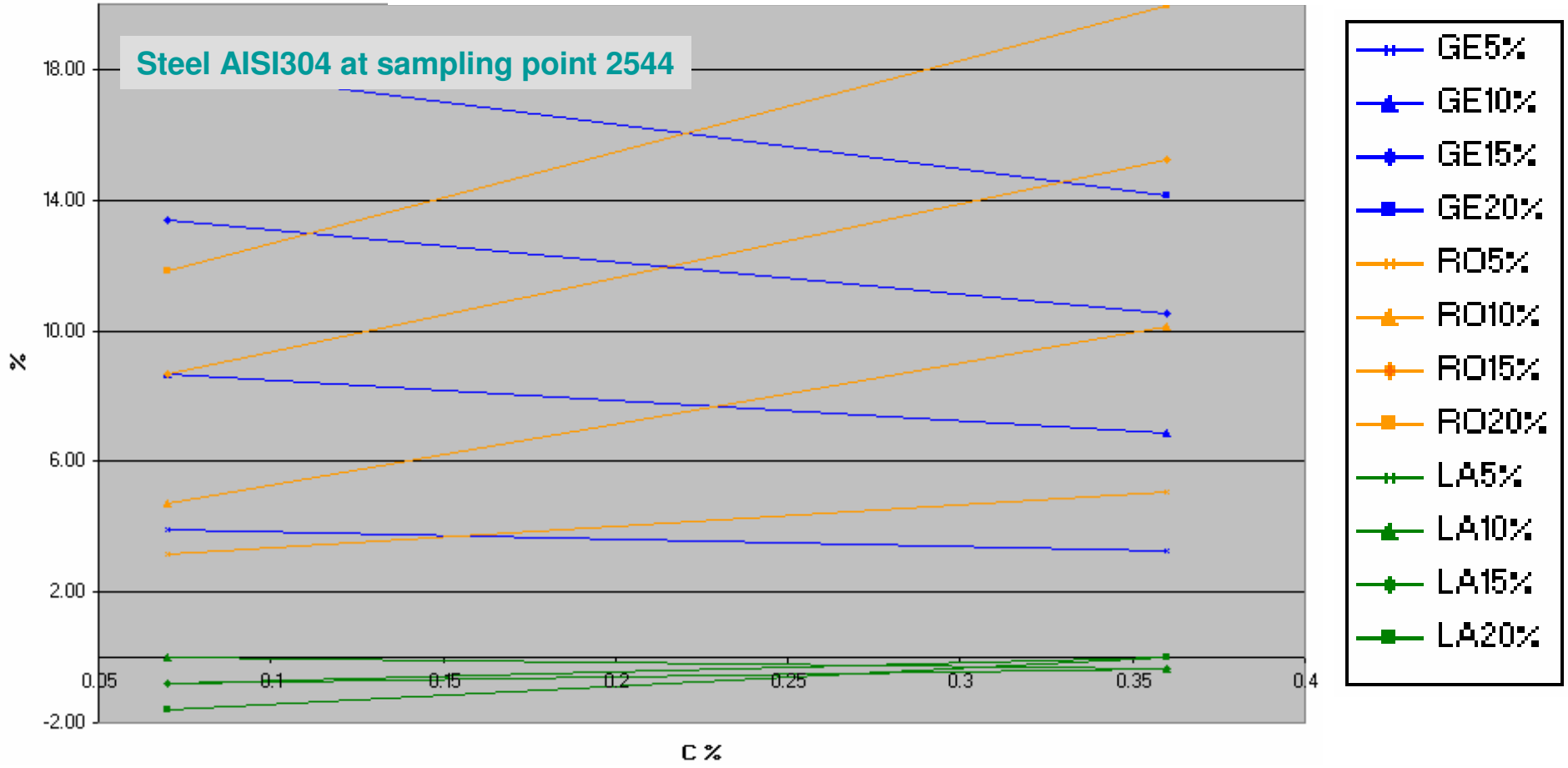



## Steels investigated

- 1.1201
- 1.6740
- AISI430
- AISI304
- Microalloyed steel
- DP500

## Integration

GE: the latent heat function, i.e. the fraction energy released
RO: the product of density and specific heat (ρ*Cp)
LA: the heat conductivity



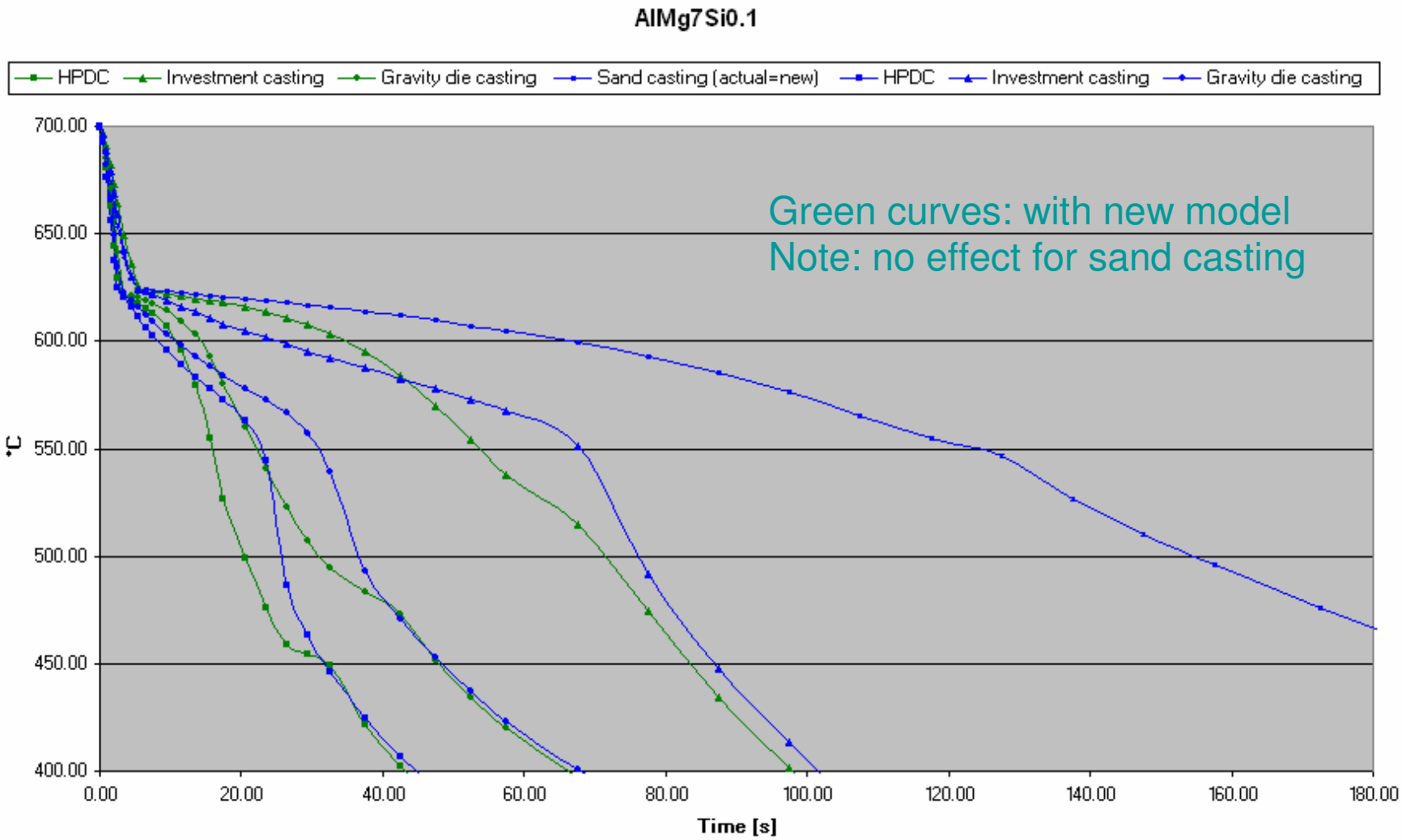
A Software/data link has been established between ChemApp and WinCast

- Calculated thermophysical properties are provided for use in WinCast calculations.

- Calculation accuracy improved since four different latent heat release (GE) and density*Cp (RO) modes can be computed.

**ChemApp provides full phase equilibria, i.e. solid and liquid fractions, phase names, phase composition, specific heat capacities or liquidus and solidus temperatures.**
**The Scheil mode provides appropriate information for rapid cooling.**

**→ Interpolation between the results (Equilibrium and Scheil) permits the influence of cooling velocity to be investigated in the WinCast calculations.**




HPDC new solidification temperature interval 100% greater than actual.

**interpretation:**

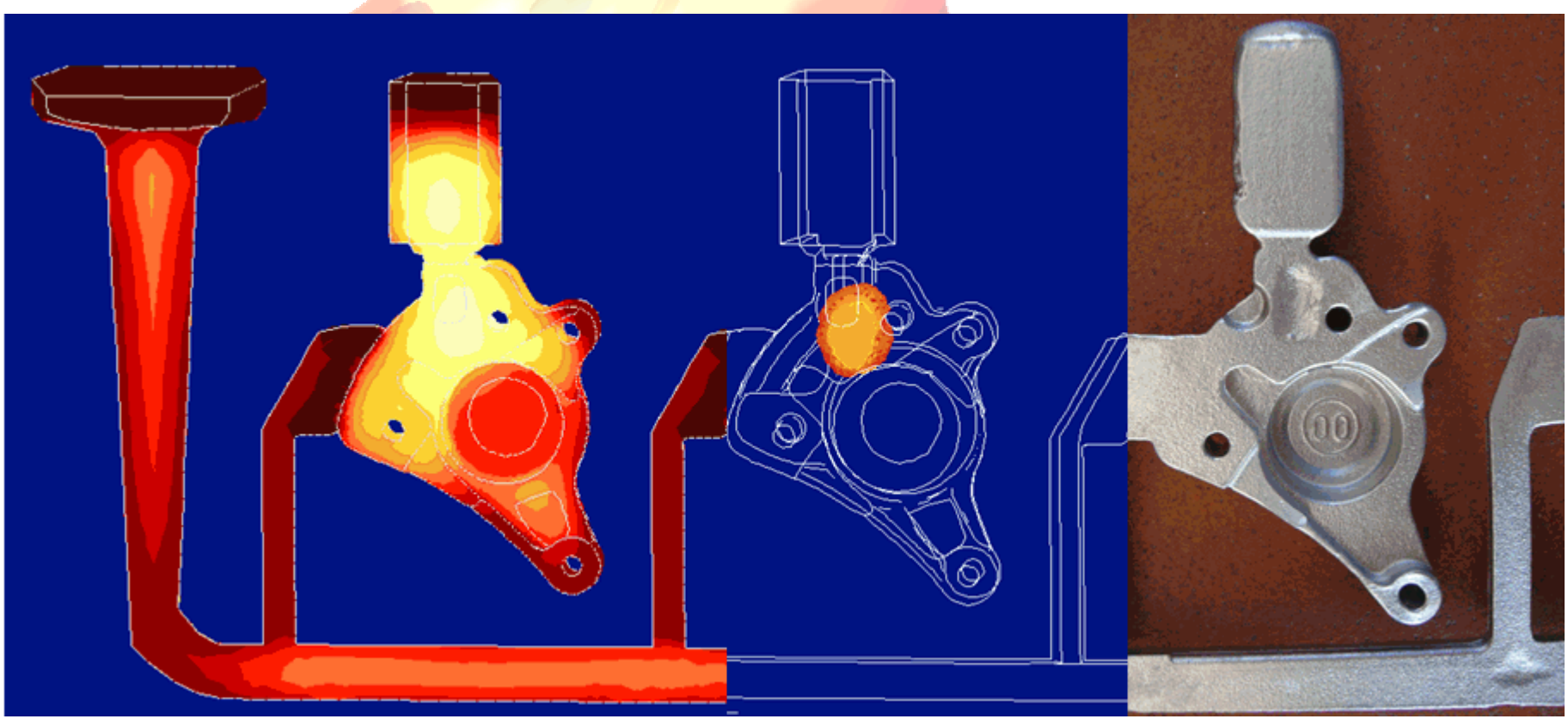
**local porosity**

**Al:**

**hotspot = defect!**

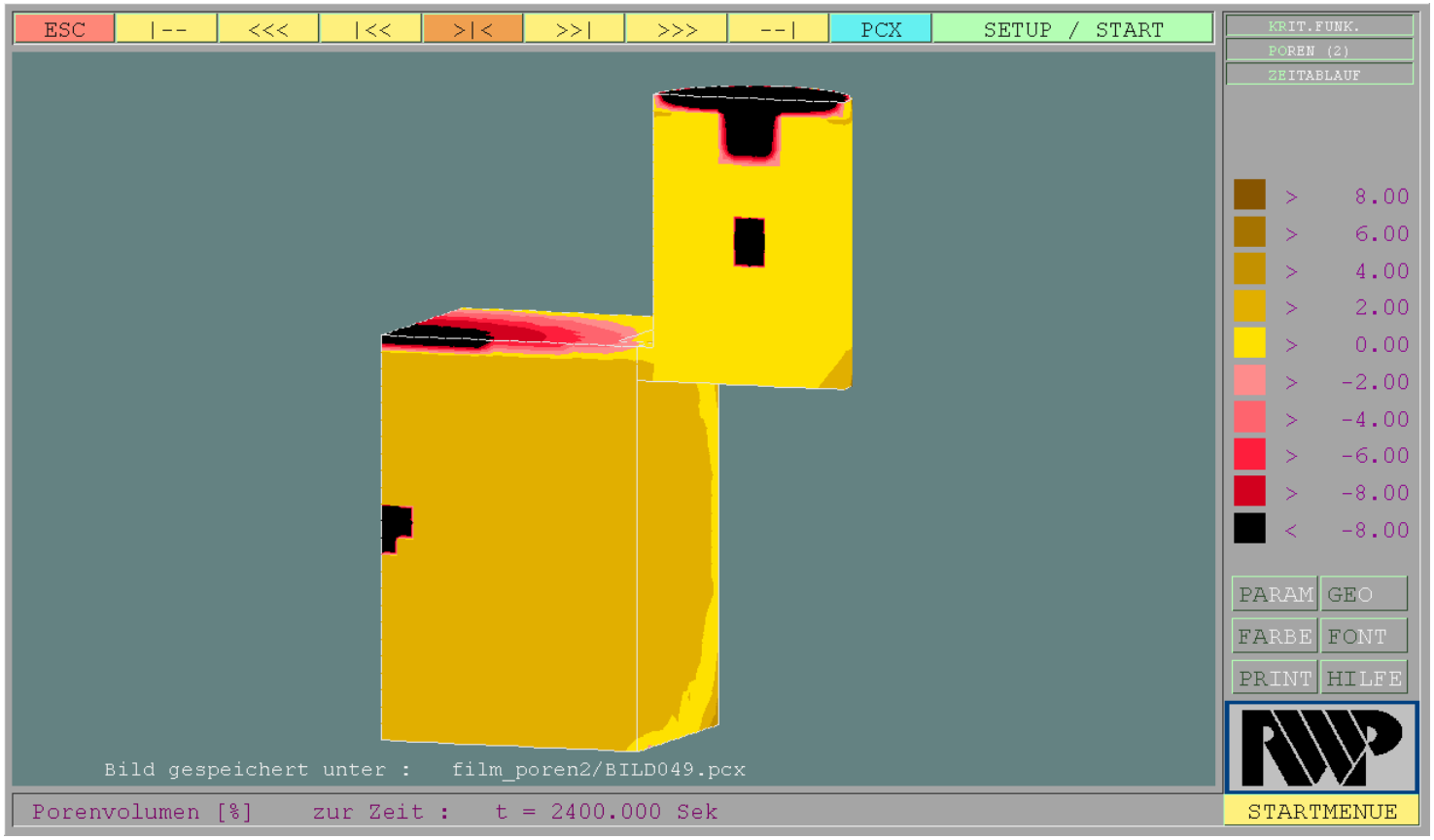
**Cast Iron:**

**hotspot = defect ?**



## Cast Iron:

## hotspot = defect ?



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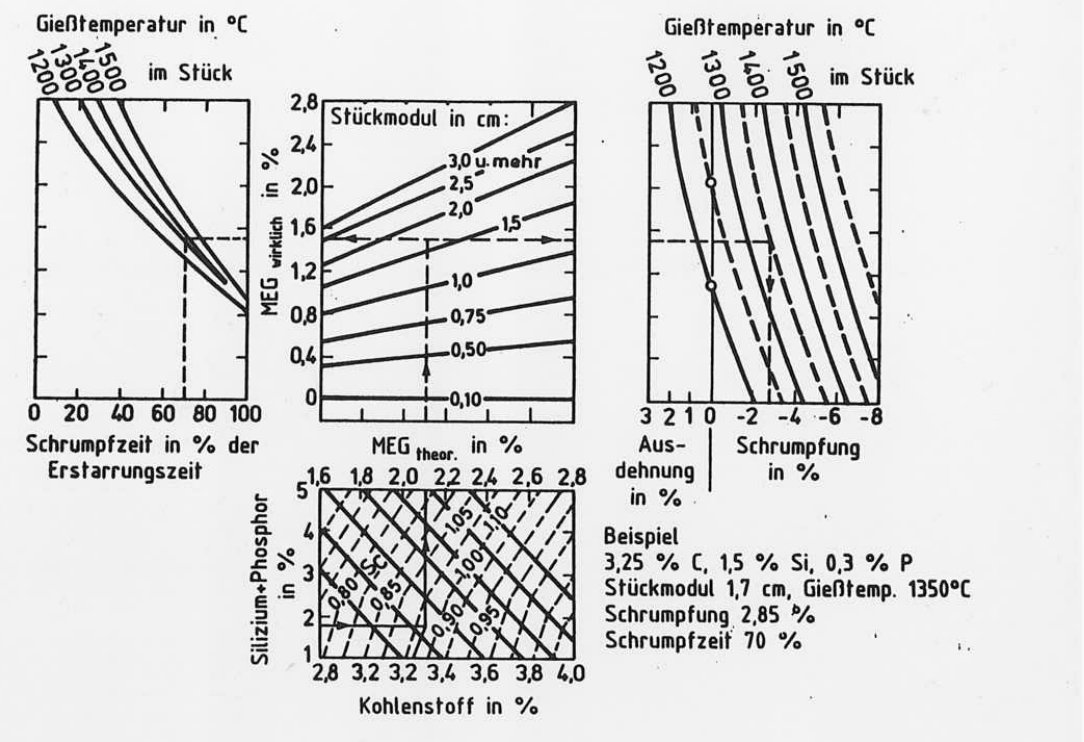
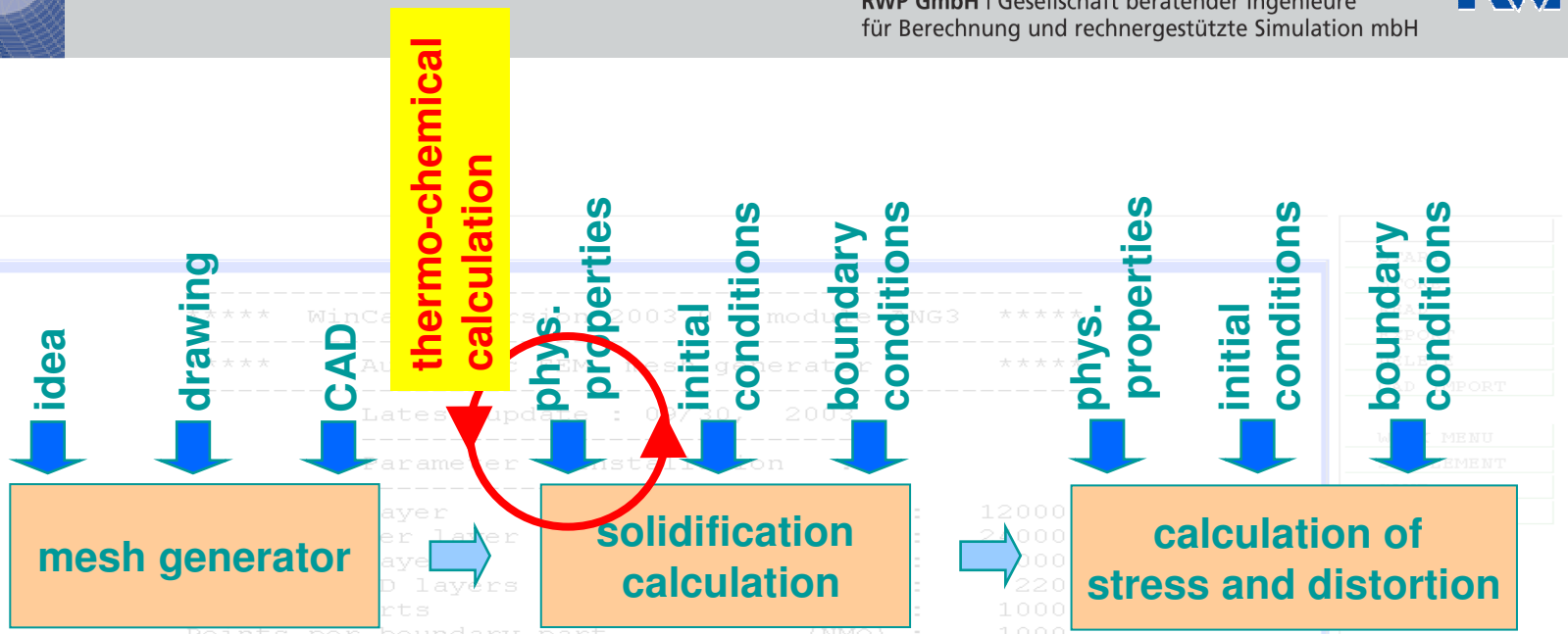
## hotspot = defect ?




**expansion depends on**

- **Components of alloy**
- **T,**
- **time**
- **…**

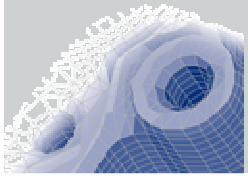
**[F. Krützner]**




**Equilibrium of forces :**

$$F_l = \int_V B_{kl} E_{ki} (B_{ij} u_j - (\varepsilon_i)_\Theta) dV$$

| | | |
|---|---|---|
| $B_{ij}$ | = | geometrical factors |
| $E_{ij}$ | = | Youngs modulus |
| $u_i$ | = | distortion vector |
| $(\varepsilon_i)_\Theta$ | = | thermal expansion |



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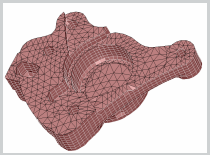
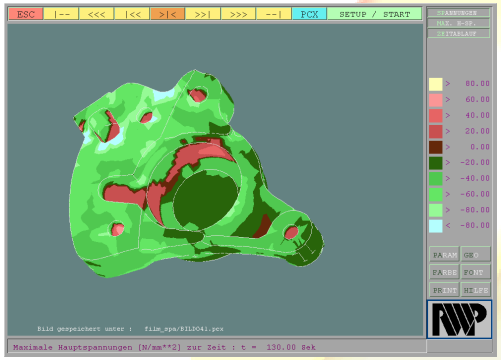




## residual stress and ditortion




## Aluminium A356:

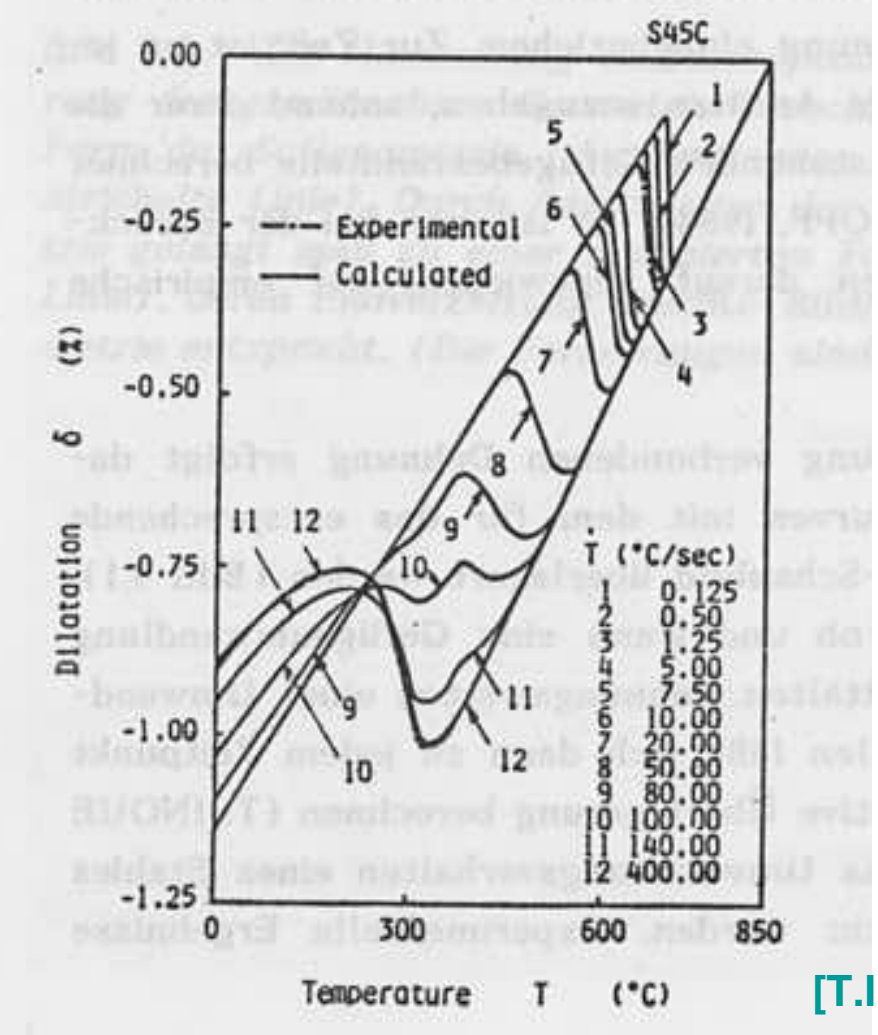
## no phase change after solidification

## e.g. steel:

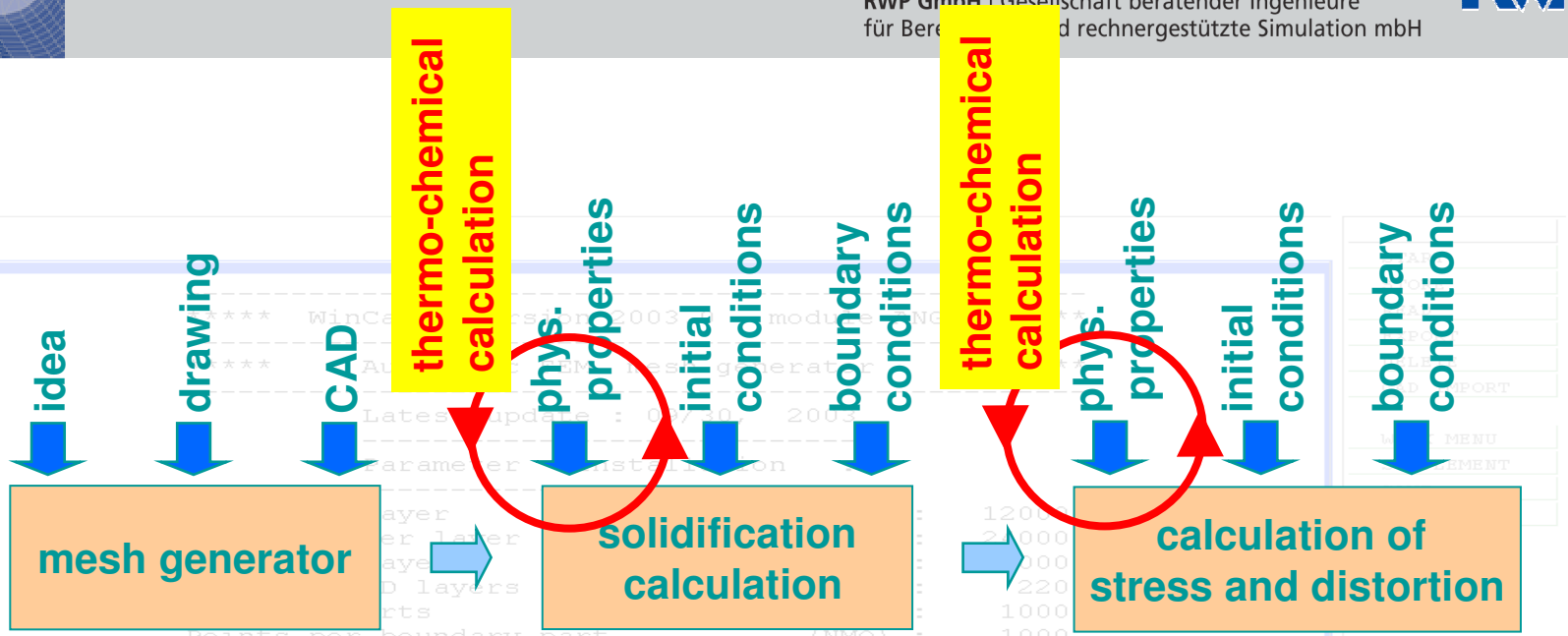
## expansion due to a phase change after solidification

**e.g. steel:**

**expansion due to a phase change after solidification**




[T.Inoue et al., 1981]

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| $u_i$ | = | distortion vector |
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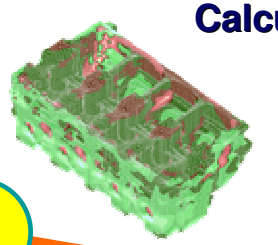
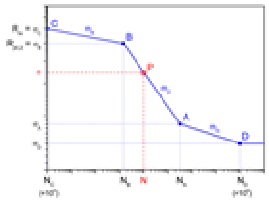
# Virtual product development

*Calculation of life cycle*



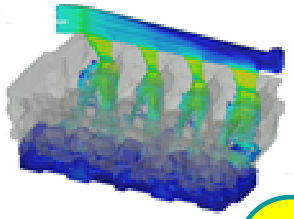
**Calculation of load stress**

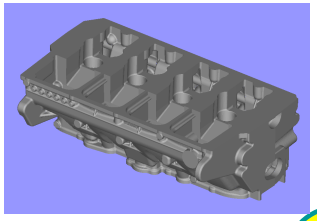
**prototype**

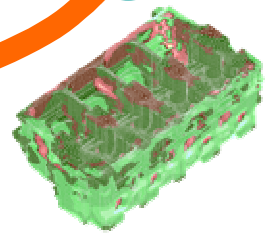


**Calculation of stress and distortion**

- cast process
- heat treatment
- machining





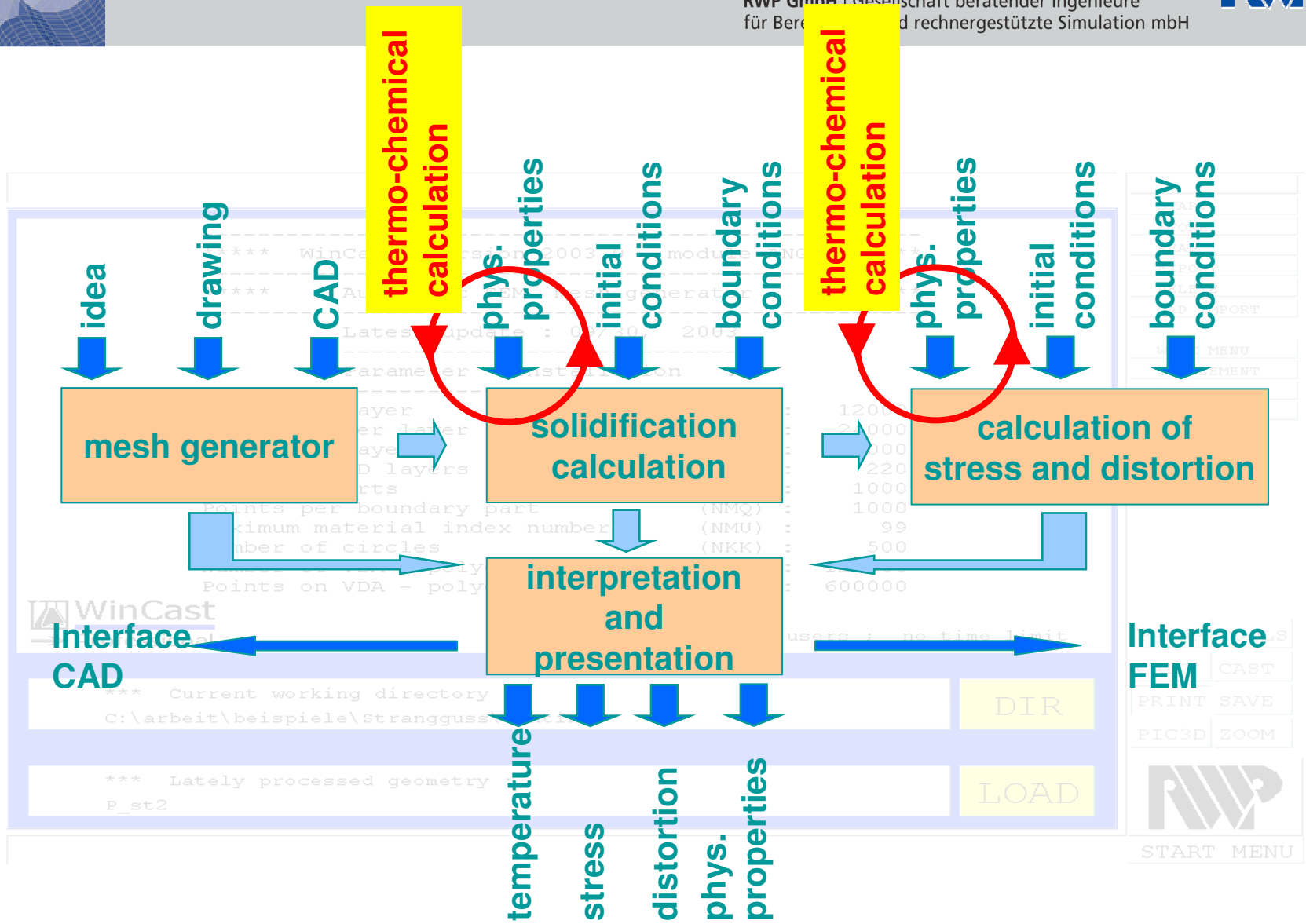


**CAD-Construction**

- shape optimisation

**Calculation of filling and solidification**

***Calculation of mechanical properties***

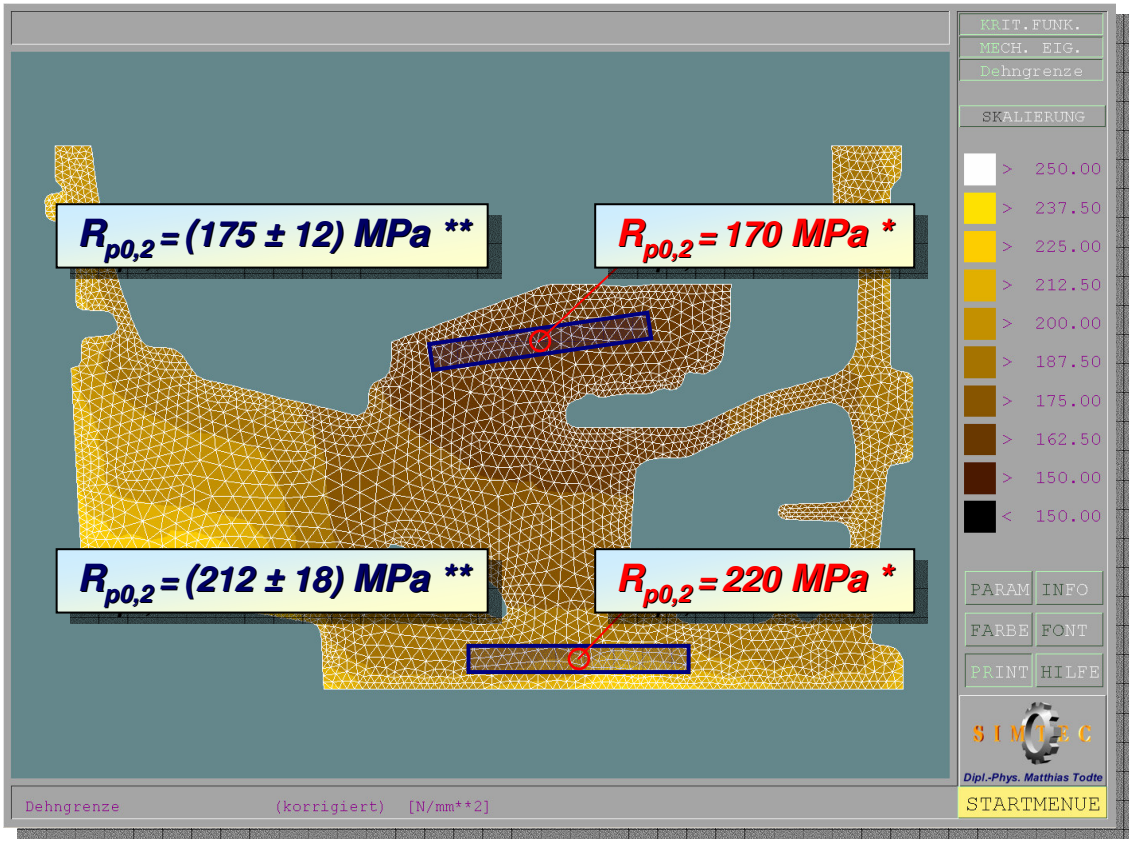

idea
drawing
CAD
thermo-chemical calculation
phys. properties
initial conditions
boundary conditions
thermo-chemical calculation
phys. properties
initial conditions
boundary conditions
mesh generator
solidification calculation
calculation of stress and distortion
interpretation and presentation
Interface CAD
Interface FEM
temperature
stress
distortion
phys. properties

## Al-Si alloy
## Mg alloy

## Comparison between experiment and calculation

- ⇨ *DAS = f ($t_s$)*
- ⇨ *Hall Petch:*

  *Yield strength = f (DAS)*



# One more example:

# austempered ductile iron (ADI)

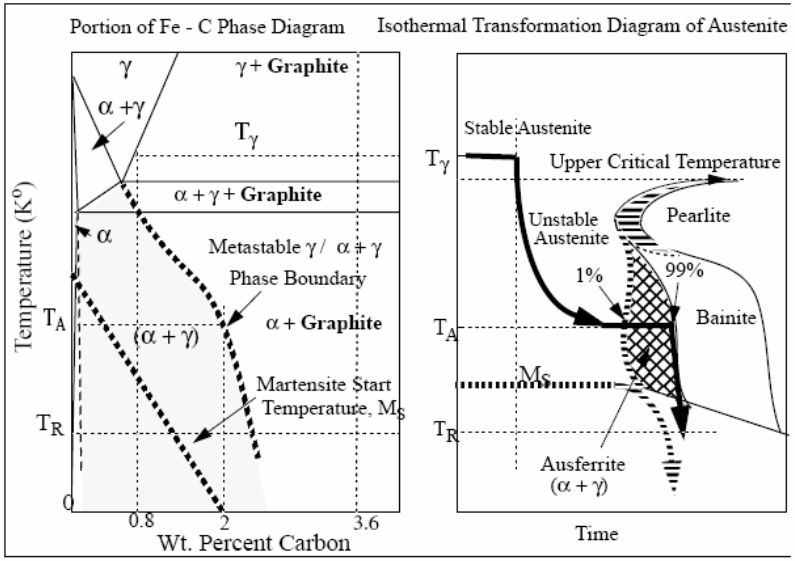



Fig. 1 Schematic phase and isothermal transformation diagrams illustrating the $M_S$ temperature, its change with austempering time and the metastable $\alpha + \gamma$ region.

Rapid cooling to Ta : $\gamma \rightarrow \alpha + \gamma_{HC}$ ; Due to C enrichment Ms decreases
Before Bainite formation the process ceases.