Calculation of Temperature Fields, Problems and Solutions

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

The differential equation of Fourier describing heat conduction. (1)

$$I(T) := \iiint_V \left\{ \frac{\lambda}{2}\left[\left(\frac{\partial T}{\partial x}\right)^{(2)} + \left(\frac{\partial T}{\partial y}\right)^{(2)} + \left(\frac{\partial T}{\partial z}\right)^{(2)}\right] + \rho c_p T \frac{\partial T}{\partial t} - \dot{Q}T \right\} dxdydz$$

$$+ \iint_R \left\{ \frac{1}{2} a(u,v) T^2 - g(u,v) T \right\} dudv \overset{!}{=} \min imal$$

The differential equation will be solved by solving an equivalent variation problem (2)

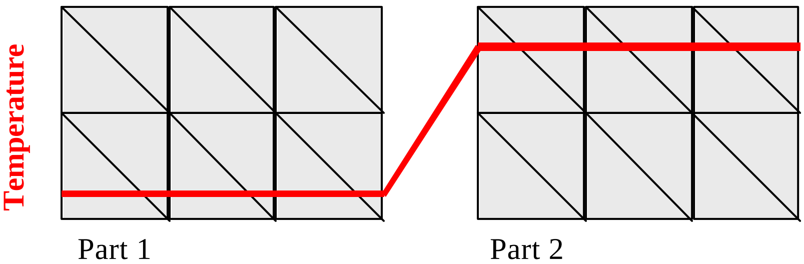


Figure 1:
The heat transfer between melt and mold plays an important role on the solidification

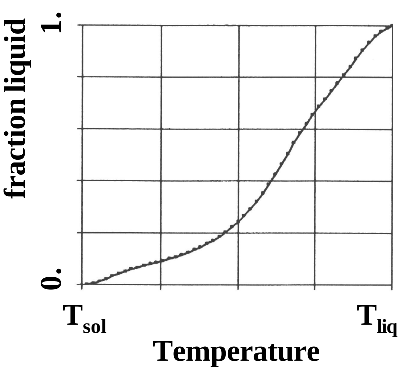


Figure 2:
Dependent on the alloy there is a special distribution of latent heat between liquidus and solidus

The basis of all solidification simulations is the heat equation of Fourier (1). Using the finite element method (FEM) this differential equation will be solved by solving an equivalent variation problem. The geometry is divided into small elements, but while the FDM/FVM needs a rectangular grid, FEM can handle nearly all basic elements. The variation problem will be solved by assuming a certain function of the temperature within such an element. For example the assumption may be a linear or quadratic function. Using this function the variation problem can be integrated and solved for one element. By fitting all elements a set of equations is generated and has to be solved. For every node there is one equation and one unknown value. To get an unique solution we need additionally an initial condition

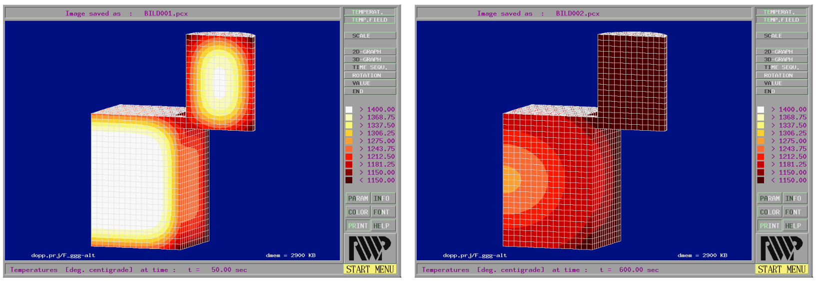
$$T(x,y,z,t=0) = f(x,y,z)$$

and boundary conditions.

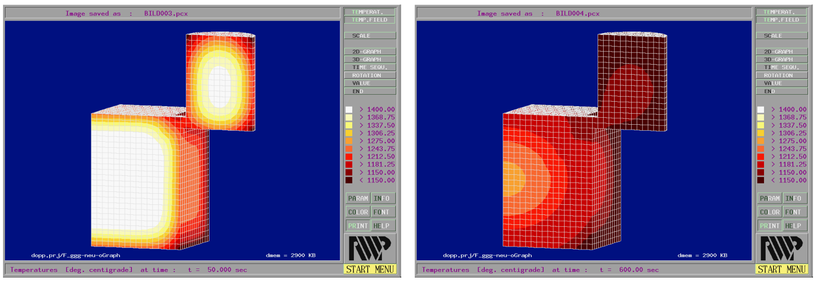
$$T(u,v,t) = g(u,v,t)$$

$$\lambda(u,v)\frac{\partial T}{\partial n} + a(u,v)\left(T - T^0\right) = g(u,v,t)$$

<u>Solving the Heat Transfer Problem:</u>
The heat transfer through phase boundaries has an important influence on the cooling behavior of castings. Whereas Stafford et al. [1987] suggested the usage of contact elements of the thickness 0 to calculate the heat transfer between different materials, within SIMTEC/WinCast® software, "virtual" elements are inserted and the heat transfer problem is transformed to a heat conduction problem. The numerical stability can be proven in comparison to analytical solutions.



without liquid – solid shrinkage



with liquid – solid shrinkage

Figure 3:
Depending on the liquid – solid shrinkage the the temperature in the area of the gating changes and the gating remains open for a longer time

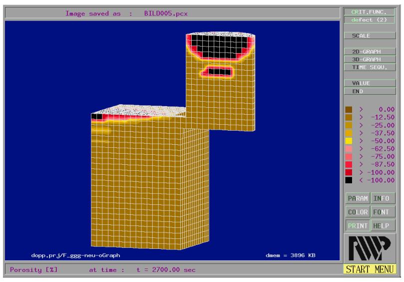


Figure 4:
The defects are located on the top of the hot spots

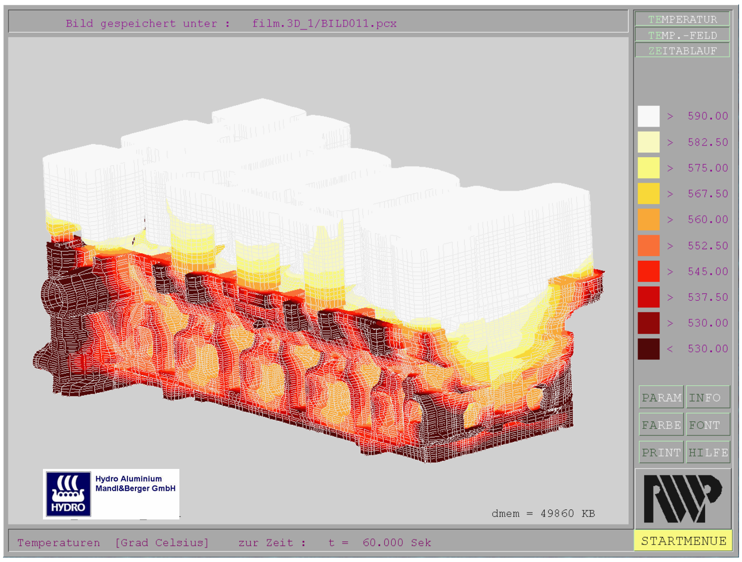


Figure 5:
With finite elements it is possible to get fast and precise answers to various technical questions

<u>Solving the Latent Heat Problem:</u>
Up to 30% of the entire energy is based on the latent heat. Depending on the alloy components the amount of energy between liquidus and solidus temperature differs considerably from a linear function. (fig.: 2). With SIMTEC/WinCast the user can edit a simple ASCII-file and define not only the function between liquidus and solidus, but also for phase transformation below solidus. For example, this transformation can be calculated with the help of time-temperature-transformation diagrams. If such a function is not known for the specific material, a default distribution will be taken.

<u>Solving the Shrinkage Problem:</u>
The shrinkage of the liquid metal leads to a convective flow, which changes the temperature distribution particularly in the riser and gating areas. This is why it is sometimes difficult to predict defects located there. Figure 3 shows different details that are dependent upon this effect. Very soon after poring, there is an air gap formation on top of the riser. This causes the heat transfer in the mold to decrease. Due to the liquid flow through the gating it remains open longer. Together with this calculation an exact location of the defects is possible.

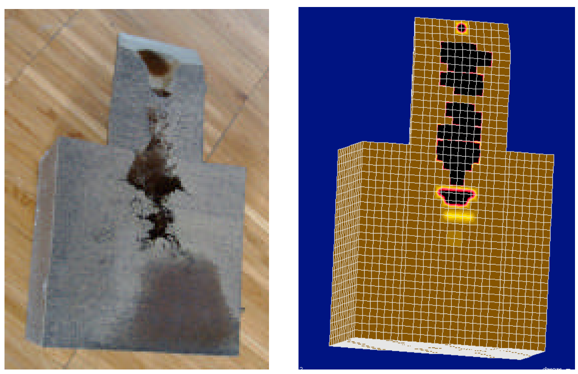


Figure 6:
Location of defects, numerical and experimental results