The Challenge of Simulating Casting and Heat Treatment

Foundries that have implemented casting simulation to shorten development time, further wish to use simulation in order to reduce the cost of subsequent processing steps. This often requires the simulation of heat treatment.

Cast components are often heat treated in order to relieve residual stresses and to control the microstructure, in particular for alloys that exhibit solid state phase transformations. In some cases, heat treatment is associated with isostatic pressing in order to reduce the level of internal porosity and cracks.

Heat treatment is an expensive process. If possible, the casting process should be designed in order to skip this stage. In case heat treatment is necessary, then the questions are at which temperatures it should be realized, for how long and how many parts can be heat treated simultaneously.

By chaining casting and heat treatment simulation, the processing steps can be optimized and thereby compromises during the casting stage might be accepted because they improve the heat treatment one. Such a chain typically requires the prediction of:

- *Deformation and residual stresses during solidification and subsequent cooling*
- *Knock-out and separation of the gating and risering systems*
- *Stress relief during heat treatment*
- *Microstructure evolution*
- *Uniformity of the heat treatment*

Deformation and Residual Stresses during Solidification and Subsequent Cooling

It is common to use casting simulation in order to design the gating system to provide quiescent filling and to design the risers to reduce shrinkage porosity. With advanced packages, these simulations can be fully coupled with thermomechanical calculations. In such a way, the gating system, for instance, can also be designed in order to reduce the level of residual stresses in the casting.

Knock-Out and Separation of the Gating and Risering Systems

The mould expands and shrinks differently from the casting, as they are usually composed of different materials. The gating system and the risers, which should be designed to solidify last in order to cope with the solidification shrinkage, have a different cooling kinetic to the casting. Both phenomena contribute to the fact that the casting is constrained during cooling and elastic stresses thereby build up, potentially associated with viscoplastic deformation. In order to predict the true residual stresses in the casting, the elastic spring-back resulting from the knock-out and the separation of the gating system must also be simulated.

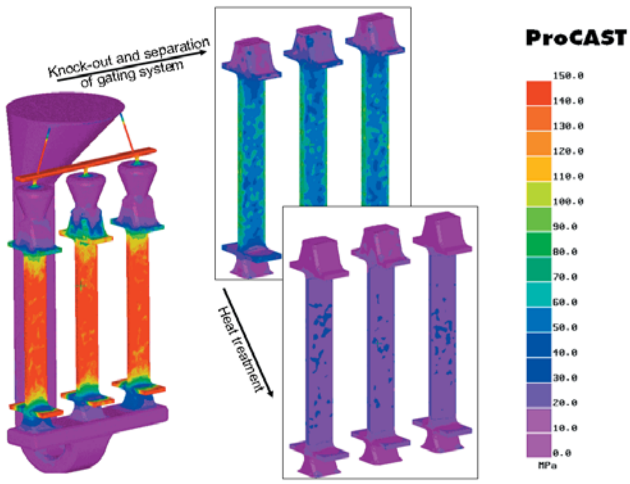

Figure 1: Calculated effective stresses (von Mises) after solidification of the complete casting cluster (simplified turbine blade prototypes, tilt casting, intermetallic alloy); stress evolution after knock-out and separation of the gating system and final residual stresses after heat treatment. This figure shows the relief of stresses at the different stages.

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Stress Relief during Heat Treatment

One purpose of the heat treatment is to relieve all residual stresses that result from the casting process. In order to simulate this, and therefore to be able to understand and optimize this expensive step, special material models are implemented in order to simulate the viscoplastic behavior. These models are currently mostly adapted to cooling rates typical to the casting process. To some extent, they can also model the material flow during a temperature hold or the cooling/heating rates typical of heat treatments.

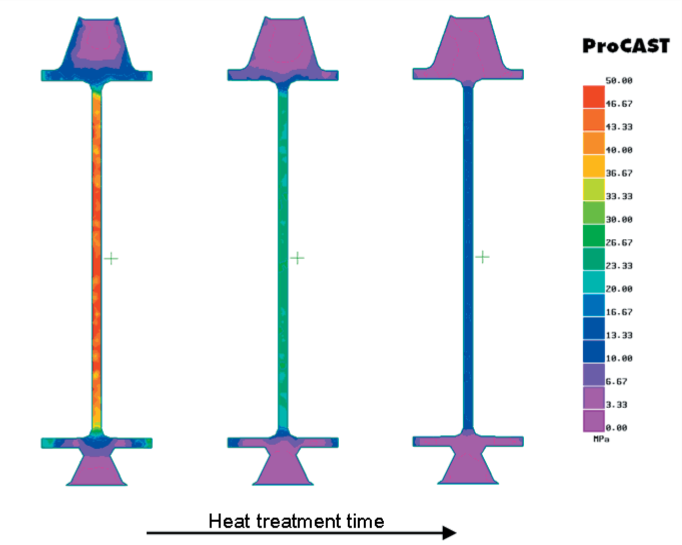

Figure 2: Evolution of the level of residual stresses during the heat treatment, at different time steps.

Microstructure Evolution

For most alloys, in particular steels, cast irons and selected aluminum alloys (to name just the most popular ones), solid state phase transformations take place. In parallel to the phase changes, recrystallization may also occur. These phenomena influence the thermomechanical properties, in particular the yield stress that strongly depends on the grain size and presence of hard phases and precipitates. A comprehensive model for heat treatment simulation requests therefore a coupling between the microstructure evolution and the stress relief predictions. Such modeling capacities are for instance aimed in the frame of IMPRESS (see below) for selected high performance alloys.

Uniformity of the Heat Treatment

A key issue in reducing the cost of the heat treatment is to maximize the number of parts per charge. The uniformity of the temperature in the furnace (depending on the number of parts and their location) can be predicted with CFD software. The difference in cooling conditions of adjacent parts must also be addressed from a thermal point of view. A dedicated simulation package for casting and heat treatment can then be used to verify whether the identified variations in pro- cessing conditions are acceptable for a sound cast- ing at lowest cost.

Conclusions

Through process modeling, from casting to heat treatment, requires advanced thermomechanical models coupled with microstructure prediction. Some of them are readily available for the casting process and may also be applied for modeling the heat treatment. More sophisticated approaches are however under development, such as for instance in the frame of the IMPRESS project or in other projects under preparation.

About IMPRESS

IMPRESS is an Integrated Project in the 6th Framework Programme of the European Commission, coordinated by the European Space Agency. The goal of this 5 year project, in which 41 European institutes and companies are participating, is to understand the critical link between material processing, material structure and material properties of novel high-performance multi-functional intermetallic alloys and to transfer this new knowledge into breakthrough prototypes tailored for extreme applications, such as turbine blades and fuel cells. Calcom ESI contributes to this ambitious project with the simulation software ProCAST and SYSWELD, by concentrating its efforts on (i) coupled casting and heat treatment simulation, (ii) pre- diction of material properties and (iii) assessment of the solid state phase transformations during heat treatment.