SFB 1120

Annual report 2018

Subproject B9

Title
Thermomechanical multiphase simulation with local calculation of material properties to predict and minimize distortion of cast components

Project management/-processing
Bührig-Polaczek, Andreas, Prof. Dr.-Ing.
Gießerei-Institut – Project management

Vossel, Thomas M.Sc.
Gießerei-Institut – Project processing management

Task definition

- Physical modelling of the heat transfer
  - Implementation of a physical HTC mode
  - Verification by inverse simulation and model comparison

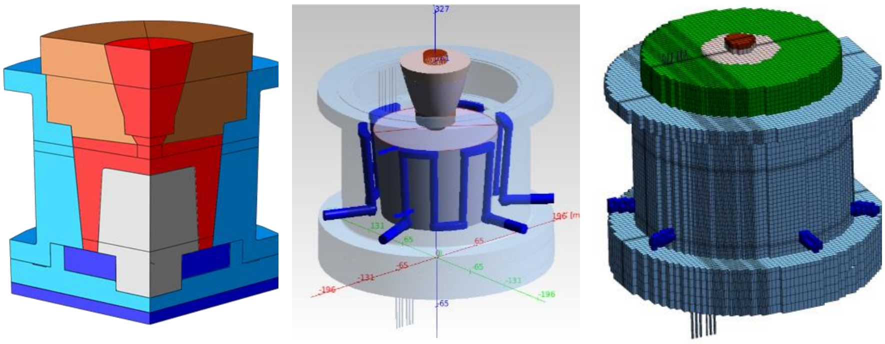
Procedure

- Implementation of a physical HTC model

Although an inverse or empirical HTC model can provide values for heat transfer that, when applied, provide a good representation of the prevailing conditions, they are limited to the availability of experimental measurement data or the determination of empirical model parameters and cannot be applied as a general solution that can be applied to any structure. A consideration of the physical conditions, such as heat transfer across an air gap or improved heat transfer due to increasing contact pressure, makes it possible to set up a purely physical model in order to obtain a generally valid model - assuming a knowledge of the physical data of the materials involved. For this purpose, with regard to casting processes a distinction would be made between three basic phenomena: 1) The solid-liquid contact between liquid melt and solid mould walls. 2.) The transition via a gas gap 3) The contact under increasing contact pressure.
The resulting model was implemented as a routine in Abaqus.

- Inverse simulation of HTC development

In addition to the use of HTC models based on physical or empirical model assumptions, heat transfer modelling, which is purely temperature-dependent and based on the measurement data obtained in the experiment, will also be carried out. For this purpose, the experimentally used setup is simulated in the simulation software Magmasoft and the cooling curves of the thermocouples used in the experiment are fed in as input data (cf. Figure 1). Since the experiment involves shrinking a cylindrical cup onto an inner core, the heat transfer on the outside is characterized by an air gap created by the volume shrinkage, while on the inside of the cup an increasing contact pressure between cup and inner core occurs. Since these two cases have different HTC curves, separate HTC curves are determined for the two regions. For this purpose, a parameterized function is used whose parameters can be used to adapt the function in such a way that the resulting HTC(T) curves lead to a good agreement between experimentally measured cooling curves and corresponding curves taken from the simulation results.



Figgure 1: Left: Schematic diagram of the experimental setup (casting red, moulds light blue/grey, insulation dark blue, sand brown)

Middle: Simulation setup in Magmasoft

Right: Networking

- The modelling of the HTC in the numerical simulation of the solidification of melts is an essential variable to describe the heat balance. For this reason, thermomechanical solidification simulations with Abaqus have been carried out, in which an inverse HTC model, which provides purely temperature-based values for heat transfer, is contrasted with an empirical HTC model, which uses the results of the thermomechanical simulation such as gap width and pressure to provide locally resolved and temporal HTC based on these parameters, which can be used in the simulation. In order to compare the quality of the two models, the resulting cooling curves, such as the pressure development at the inner core and the gap development on the outside of the casting, are compared with those from the experimental measurement.

Results

- Implementation of a physical HTC model Figure 2 gives an overview of the heat transfer curves resulting from the HTC model:

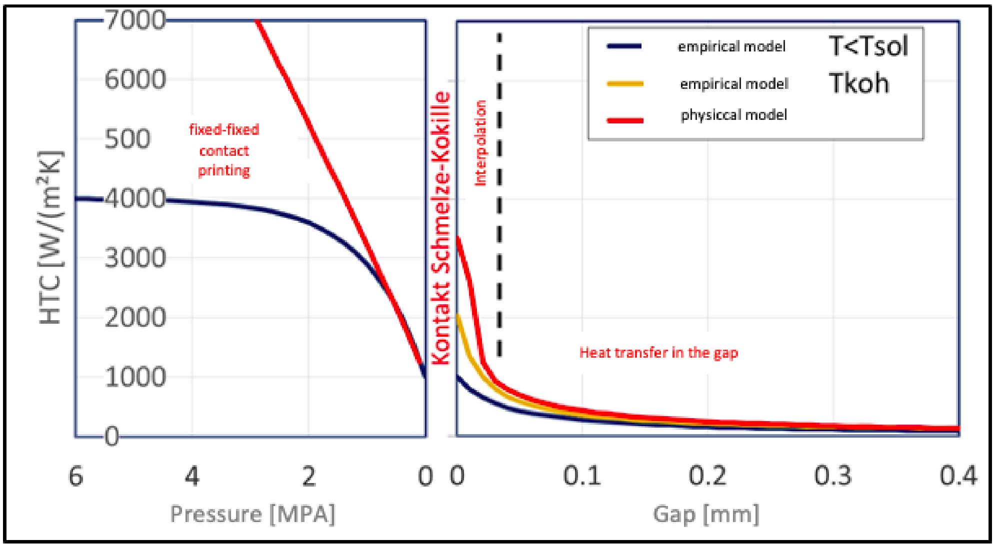


Figure 2: HTC curves of the empirical and physical heat transfer model for the case of contact pressure and gap formation

The modelling depicts three different contact conditions:

- Contact melt – mould
- Fixed-tight contact under increasing contact pressure
- Fixed-tight contact with an air gap between the contact surfaces

The molten-mold contact models the heat transfer between liquid melt in the mold walls. The surface roughness is taken into account and the extent to which the melt is able to wet this surface. This is necessary to be able to make a statement about the actual liquid-solid contact surface between the melt and the mould wall. As soon as the melt solidifies, there are two variants for the solid-solid contact that is then present: Either the volume shrinkage during cooling causes air gaps to form between the contact partners, or there is still a direct solid-solid contact, which can take place precisely due to the effect of shrinkage under increased contact pressures. The modeling of gap formation takes into account in particular the heat transfer through the air, which is the decisive factor in this case and leads to comparatively low HTCs compared to the other contact conditions. For contact under contact pressure, elastic modelling approaches according to Mikic can be selected, for example, in which physical data such as the modulus of elasticity of the two materials in contact can be incorporated. The heat transfer coefficient increases with increasing pressure.

- Inverse simulation of HTC development

As expected, the HTC curves of the inverse simulation differ significantly with respect to an existing gap formation or pressure increase (see Figure 3). Since the simulation with magma is not a coupled thermomechanical calculation, the gap formation is not simulated concretely, and its consequences are only shown via changes in the HTC in order to correspond to the cooling curves of the experimental measurements where this effect naturally occurs. Thus, even without knowledge of the prevailing gap width or contact pressure on the inside of the casting, a statement can be made about the HTC suitable for the experimental measurement. The curves for the heat transfer coefficient resulting from the experimental set-up used are shown in the following diagrams. In the case of gap formation, the HTC drops from a value that reflects the liquid-solid heat transfer to very low values, since the heat transfer across an air gap is comparatively ineffective. On the shrinking side of the casting and as a consequence with increasing contact pressure, the HTC increases continuously

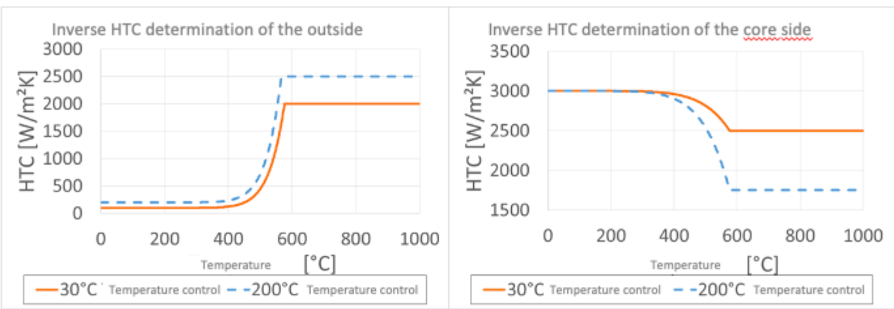


Figure 3: HTC(T) Progressions from the inverse simulations for two temperings of the setup

- Model comparison of the heat transfer models

If one compares the cooling curves shown (see Figure 4) for experimental, inverse and empirical HTC models, it can be seen that both HTC models are in very good agreement with the experimental values, especially in the solidification range. However, the empirical model shows a better agreement with the measured values after the end of solidification. This can be attributed to the possibilities of the model to consider the gap formation and contact pressure increase phenomenologically in the HTC, whereas the inverse HTC model here is dependent on a purely temperature-dependent description, which cannot take these effects sufficiently well into account.

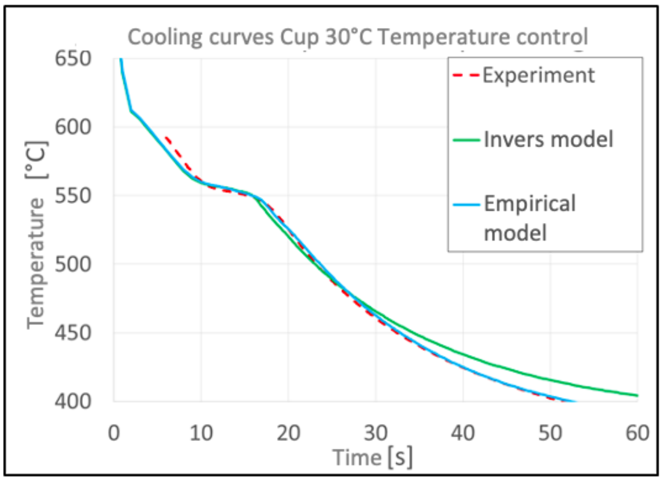


Figure 4: Cooling curves for inverse and empirical HTC model and measured values from experimental measurement

Summary and Conclusion

The results obtained enable a more precise picture to be obtained of the heat transfer in a casting process. It turns out that the rough estimates for the HTC frequently used in process simulations offer a lot of potential for a better description of the heat balance, as they are not only a rough estimate in the progression of the assumed HTC values, but cannot be used generally - especially a distinction between regions with air gap and contract pressure is essential for a sufficiently good description of the existing heat transfers. Furthermore, the simulations carried out make it possible to observe the development of e.g. pressure or gap also at positions beyond the experimental measurement in order to gain additional knowledge.

In the further course of the project, heat transfer will be further investigated, especially with regard to the physical HTC model, which will be used for a process simulation in order to be able to draw comparisons with the inverse and empirical models already applied. The aim is to have a general approach through the physical model that can be applied in process simulations without the need to have measured data for an inverse HTC determination and without the need to make empirical statements about the present contact.

Publication

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