Die Cavity Shape Determination

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The die casting process involves filling liquid metal into a steel die having a cavity with the negative shape of the part. In order to produce a required part geometry after casting, the shape of the die cavity has to compensate for all the mechanical influences from the manufacturing process.

During process development the distortion or shrinkage allowances are usually determined through experience and trial castings. Simulation can help to determine these allowances.

In order to predict the shape of the part after casting one should consider the following:

- *the evolving shape of the die cavity during heat up and thermal cycling;*
- *the shrinkage of the part during solidification and cooling;*
- *the creep effects at high temperatures;*
- *the constraints on the part from the die and cores;*
- *the ejection of the part;*
- *the removal of the gating system.*

Introduction

At the start of production the dies are pre-heated and cycled until steady-state conditions are reached. The parts produced during start-up are rejected and only those produced at steady-state operating conditions are accepted. The number of cycles to reach steady-state conditions depends on the part and the size of the die.

During casting, since the density of the steel die is temperature dependent, hot areas are expanding more than colder areas. The cyclic changing of the temperature profile in the die leads to a respective time dependent shape deformation of the die cavity.

After filling, the metal starts to solidify and undergoes changes in phases where different material laws are valid. In the fluid state the metal is almost stress free but as the part starts to solidify and shrink, stresses are induced in the casting due to constraints from the die. Some of the induced stresses are relieved through creep effects corresponding to the visco-plastic behaviour of the material. In some areas a gap is formed and in other areas a contact pressure condition is produced between the casting and the die.

Immediately after ejection, the external constraint from the die on the part disappears, and the stresses which originated during solidification and cooling are greatly reduced. Furthermore, the final shape of the casting is only obtained after removing the gating system.

Simulation

In the simulation software ProCAST it is possible to predict the distortions of the die and casting. For cast parts and moulds (dies), the models in the software include an elastic model, a thermo-elastoplastic and a thermo-elasto-viscoplastic model. In addition, a rigid body model and a vacant model are also available for mould (die) materials.

In the software the thermal contact between parts is automatically taken into account by adjusting the interface heat transfer coefficient with respect either to the air gap width or the contact pressure.

In order to determine quantitatively the required shape of the die cavity one has to consider both the distortions in the die and casting. The method for determining the die cavity shape using simulation is shown in Figure 1.

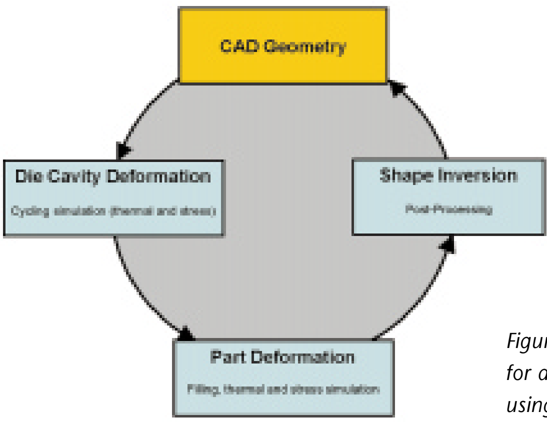


Figure 1: The diagram illustrates the method for determining the shape of the die cavity using the casting simulation software ***ProCAST****.*

Predicting the shape of the die cavity

In the first analysis, a thermal simulation is completed for a few cycles in order to reach a steady-state temperature condition in the die. In this simulation the various stages of the process are considered, including solidification, die opening, part ejection and die spraying.

The thermal history from the cyclic analysis is then used in a coupled thermal-stress analysis. The result is then the shape and stresses of the die at steady-state conditions.

Predicting the final shape of the part

During this step, using the results from the die stress analysis, a fully coupled thermal, filling and stress analysis is completed for one whole cycle, with the casting eventually cooling down to room temperature. The result of this simulation is the deformed geometry of the casting.

In the post-processor of ProCAST, the geometry of the required die cavity shape can be determined automatically by reverse calculating the inverted displacements of the part.

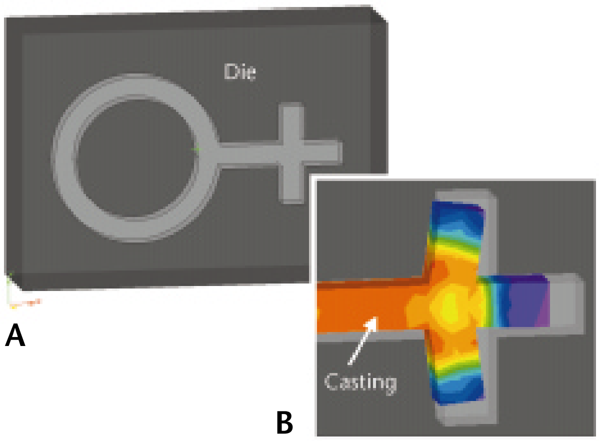
This geometry can then be read into a CAD software and modifications made to the original CAD model. This model can also be used for machining the mould. Furthermore, the resulting residual stresses can be exported to other FEM packages and used for further analyses.

Example

In Figure 2 & 3, a simple example of an aluminium male cross sign is used to demonstrate the method for correcting the distortions of the part.

In Figure 2 (B), a part is shown distorted after casting due to constraints from the die. These distortions were automatically inverted in order to determine the correct die shape. Figure 3 (A) shows the modified die in order to produce the final required shape of the part after casting, as shown in Figure 3 (B).

*Figure 2 (Right): Original die (A) and casting (B) with effective stresses in the part after casting (red is high). Shown with exaggerate distortions (evidencing thereby the mould-casting gap). The simulation was completed using **ProCAST**.*



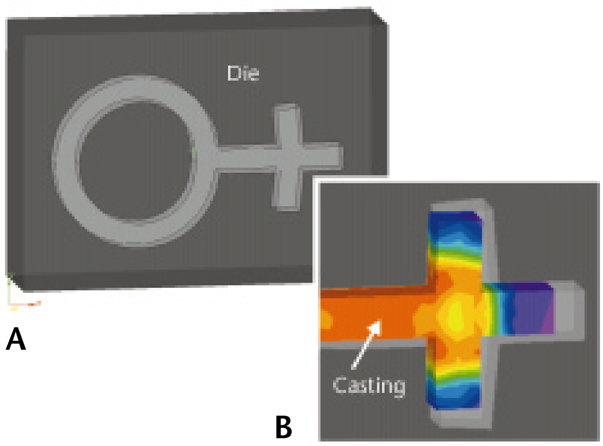


*Figure 3 (left): Modified die (A) and casting (B) with effective stresses in the part after casting. Shown with exaggerated distortions (evidencing thereby the mould-casting gap). The simulation was completed using **ProCAST**.*

Conclusions

Probably one of the most important issues in casting is the geometry requirements of the part. During development, making allowance for casting shrinkage is often an iterative process where distortions are determined through trial and error castings. Each iteration requires re-machining the die cavity.

Simulation can help to predict the final shape of the part as well as the required die cavity in order to produce the parts within the specific geometric tolerances.

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