MOULD OPTIMISATION OF THE THIXOFORMING PROCESS BY NUMERICAL MODELLING

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ABSTRACT: Numerical modelling of mould filling and of solidification has been used for the optimisation of thixoforming production moulds. Rheological data and boundary conditions for the modelling were deduced from several sets of instrumented experiments. The simulation results could be correlated with several types of known defects. Using this simulation tool for the identification of potential defects, the geometries of gates, parts, overflows and vents have been optimised.

KEYWORDS: Mould optimisation, Defect identification, Simulation

1 INTRODUCTION

The design stage of a mould is decisive for the quality of thixoforming parts. Once a mould is built, only minor adjustments can be made. An a priori optimisation requires that potential defects of a thixoforming part can be identified. Numerical modelling has proven to be a good tool for defect identification if the major physical phenomena are taken into account and if adequate boundary conditions and material data are being used.

2 PHYSICAL PHENOMENA INSIDE THE MOULD

For the description of the relevant physical phenomena inside the mould, 3 areas may be distinguished: the mould, the cavity and the mould/part interface.
Inside the steel mould, mainly thermo-mechanical effects due to the high temperature variations during the shot cycles are felt. These effects usually influence the mould fill and solidification behaviour inside the cavity only to a lesser extend.
Inside the cavity, the mould filling and the subsequent solidification largely influences the part quality. Local viscosities may change over several orders of magnitude during the mould filling due to the competing effects of shear thinning and of solidification. The back-pressure of the compressed cavity gases may alter the fill front position and favour the formation of gas inclusions.
At the mould/part interface, the filling and solidification behaviour can be largely influenced by the formation of hydrodynamic and thermal boundary layers. For instance, the velocity gradient at the wall causes the solid particles to rotate and to move away from the wall leading to the accumulation of a thin eutectic layer at the wall. The surface roughness and the die parting/lubrication agents may also influence the boundary slip condition and the heat transfer conditions at the mould interface.

3 NUMERICAL MODELLING

The flow behaviour of the thixotropic aluminium alloy A356 was modelled by a 1-phase Navier-Stokes model with a Non-Newtonian power-law viscosity. The shear thinning history of the partially solid/partially liquid aluminium was taken into account by defining distinct cut-off regions for the shear rate. Within a cut-off region, the local shear rate needs to surpass the given cut-off value to allow additional shear thinning.
These models have been developed during a joint project with the Federal Institute of Technology in Lausanne [1-3] and have been implemented into the commercial simulation software ProCAST (Thixo-Module). Additionally, the ProCAST gas model was used. The necessary rheological data and boundary conditions for the modelling have been determined by several sets of instrumented experiments on a shot controlled thixoforming machine [2,3]:

- The wall slip was determined by pressure measurements on a horizontal tube rheometer. Metallography of the wall layer confirmed that there must be considerable slip at the wall as a liquid eutectic layer is formed.
- The rheological data was measured on capillary rheometer where the thixotropic A356 was forced through a narrow gap until it solidified. The recorded pressures were used to determine the temperature dependant parameters of the power-law model.

4 RESULTS

As already mentioned above, the largest potential for optimisation by numerical simulation lies inside the mould cavity. Therefore, this paper will restrict to the optimisation of the gate, component, overflow and vent geometries. A good identification of potential defects [4] is a necessary requirement for this purpose. The optimisation of the mould itself (i.e. heating/cooling channel arrangement) will not be discussed.

Gating system

For the construction of a thixoforming gating system, the standard procedure may be followed:

- Choice of the gate location
- Definition of the fill time of the component
- Calculation of the gate area
- Dimensioning of the gating system

For the determination of the gate location and the gate geometry, the numerical simulation tool is being used systematically. One difficulty in optimising the gating system is that completely different filling behaviours are to be expected within the processing window. Fill stops made on a two-fold ingate system (figure 1) show a different fill characteristic at 2 different piston velocities. For this particular case, the fill position can be simulated with reasonable accuracy using a simple 2-dimensional simulation with a constant viscosity. For each piston speed, however, the correct viscosity value is different and has to be adjusted. To avoid such cumbersome adjustments, a shear history dependant power law model [4] is being used for the optimisations. With the choice of a particular gating system, the piston velocity is fixed at the same time. As the gating geometry and the piston velocity are linked, they need to be chosen together.

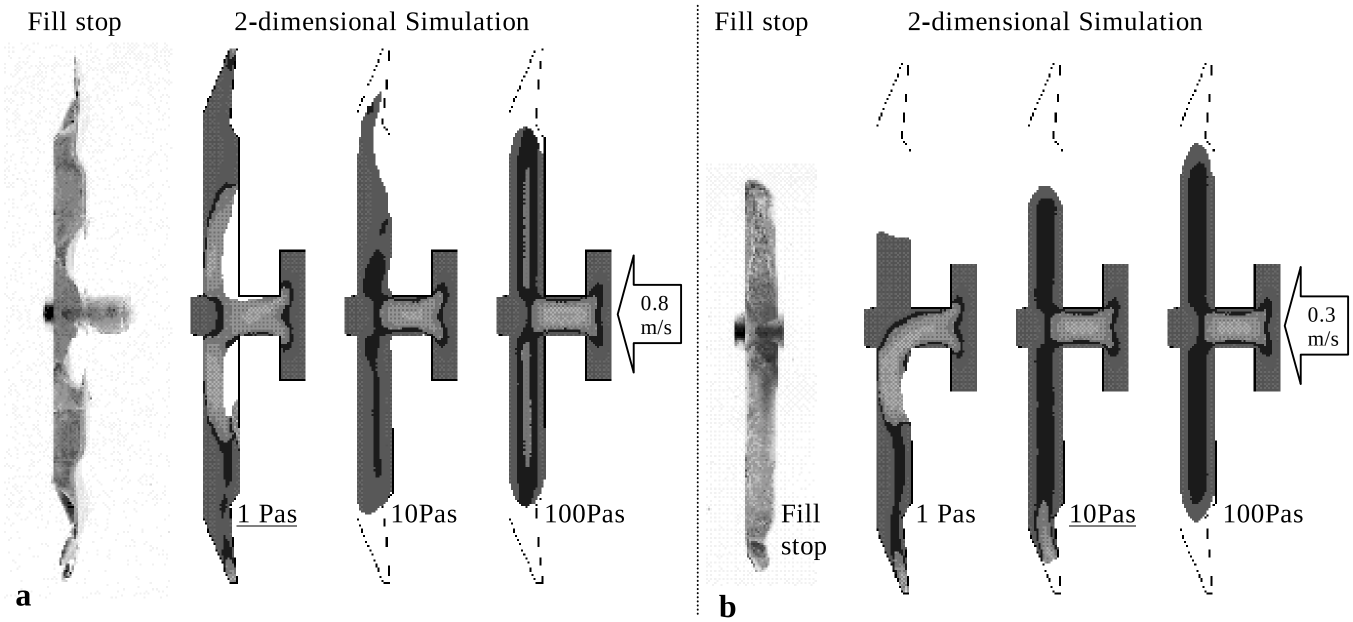

Fig. 1: Gating system for a 2-cavity mould. Comparison between experimental fill stops and 2-dimensional mould fill simulations using constant viscosity values.
a) Piston velocity of 0.8m/s. Best fit for a viscosity of 1Pas.
b) Piston velocity of 0.3m/s. Best fit for a viscosity of 10Pas.

Other criteria such as the velocity distribution, the feeding behaviour and the sensitivity to the formation of gas inclusions also need to be considered for an optimisation of a gating system (table 1). Within certain limits, the desired viscosity range for an optimal filling of the component may be adjusted by a smart geometry of the gating system. The flow characteristic inside the gating channel should be such that the effectively used cross section is maximum and that the velocity distribution is as uniform as possible. Sticking due to high local velocities at the wall is to be avoided. If feeding through the gate is required, the gate thickness should be as large as possible. On the other hand, the shot weight should be minimised.

Optimisation criterion (gating system)	**Goal of the optimisation**	**Geometrical implication**
Shear characteristic	Yield desired viscosity range	Adequate reduction diameter Entrance edge radius
Fill behaviour of ingate system	Avoid gas inclusions	Cross section continuity Smooth deflection
Flow characteristic	Maximum effective cross section Uniform velocity distribution Minimal heat loss No sticking	Circular shape No 90° turns Diameter surplus Short channel length
Feeding behaviour	Transmit piston pressure as long as necessary, supply liquid metal	Gate thickness Channel-Gate Transition
Weight	Minimum weight	Circular shape Minimal cross section Short channel length

Table 1: Criteria for the optimisation of a thixoforming gating system and their geometrical implications for the design.

An example of a gating system, where gas inclusions are formed and transported into the part is shown in figure 2a. The optimised gating system shown in figure 2b has a minimal weight, a good flow and feeding characteristic and is not sensitive to gas inclusions [5].

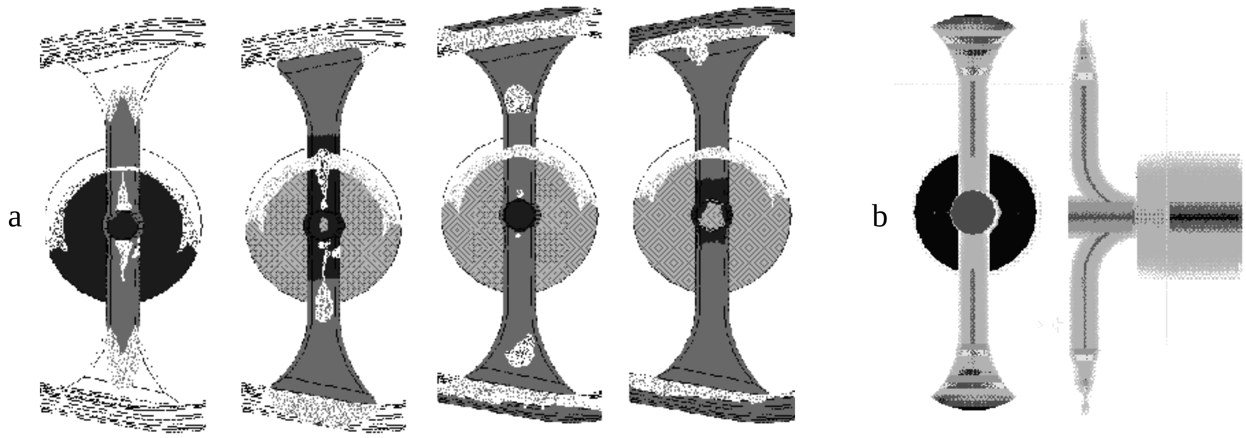

Fig. 2: a) Mould fill simulation with gas model. The formation of gas bubbles inside the gating system and their transport along the channel is shown.
b) Optimised gating system for thixoforming [5]

Component

During the filling of a component by the thixotropic aluminium, the local viscosities may change by several orders of magnitude. Figure 3 shows the example of a thin walled component where the apparent local viscosity in certain areas raises to very high values (several hundred Pas). The raise in viscosity corresponds to an increase of the local solid fraction and overwhelms any additional shear thinning. The simulated piston pressure raises due to the filling of the first (B) and of the second overflow (C) but also due to the important increase of the overall viscosity level. This example illustrates the optimisation potential of the component geometry.
Hence, it is important to adjust the parts geometry as long as it does not affect functional requirements. However, a small modification of the part geometry can improve the mould fill behaviour and/or the feeding characteristic decisively. Numerical simulation can help to convince the customer to agree to minor modifications which improve the part quality.

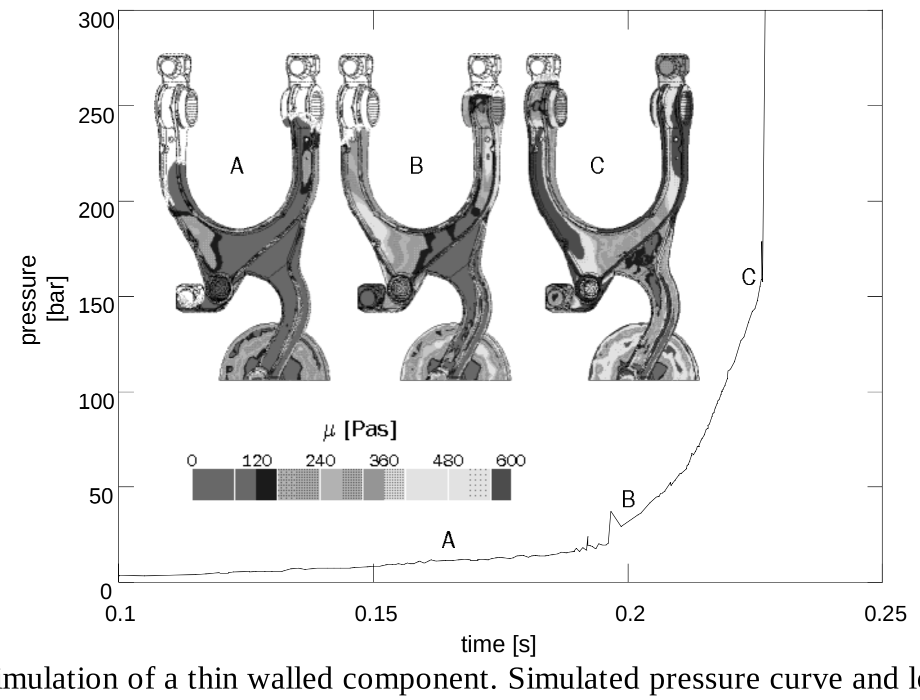

Fig. 3: Mould fill simulation of a thin walled component. Simulated pressure curve and local viscosity distribution during filling.

Overflow and Venting

The positioning and design of vents and overflows is decisive for the quality of a thixoformed part. Potentially harmful defects such as gas inclusions, cold shuts and sticking have to be avoided. The position of the last volume to be filled needs to be known precisely as it contains compressed gases and impurities of the fill front. The gases should be evacuated by the vents whereas the overflows should accommodate eventual impurities.

The influence of the initial liquid fraction and of the piston velocity on the last filled position is demonstrated in figure 4. The simulated filling of the experimental part [6] shows that the last filled position is shifted along the circumference of the cylinder with increased liquid fraction (fig. 4a+b) and with increased piston velocity (fig. 4b+c). Both parameters determine the resulting viscosity. The effect of an increase in viscosity is opposed to the effect of an increase in inertia. The simulated fill position for a 40% liquid fraction has been compared to a fill stop made with the experimental mould (fig. 5). About 50 parts have been produced with these process parameter settings. The last position to be filled could be seen as a slight surface mark and showed a very good reproducibility.

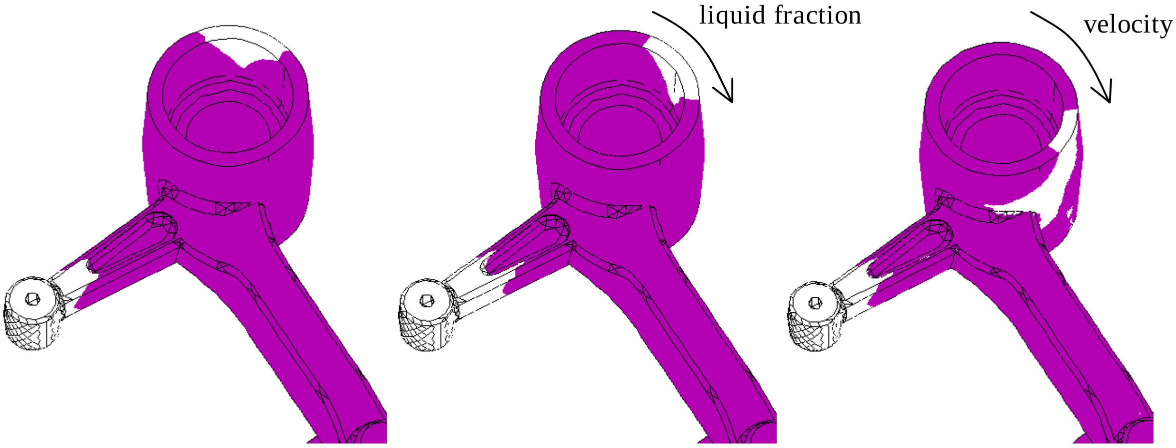

Fig. 4: Mould fill simulation of an experimental part.

a) Fill position for a billet with 40% liquid fraction, piston velocity 0.2m/s

b) Fill position for a billet with 50% liquid fraction, piston velocity 0.2m/s

c) Fill position for a billet with 50% liquid fraction, piston velocity 0.4m/s

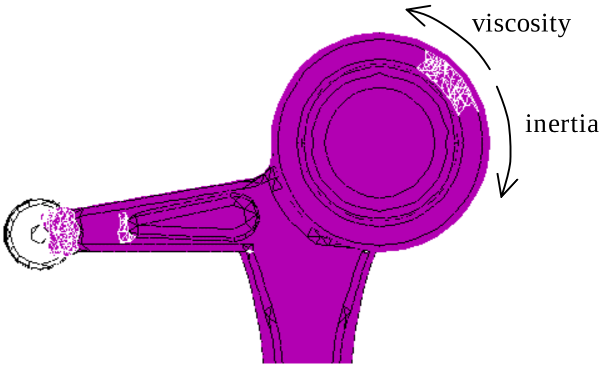

Fig. 5: Comparison of a fill stop of an experimental part with the simulated fill position with 40% liquid fraction and a piston velocity of 0.2m/s (The white lines show the position of the free surface).

However, the last filled position is not the only parameter which needs to be taken into account for an optimisation (Table 2). The fill behaviour itself should be looked at if cold shuts and gas inclusions are to be identified. During the filling of the overflow, with the part being full, the local velocity distribution inside the part helps to identify other defects such as sticking.

Optimisation criterion (overflows and vents)	**Goal of the optimisation**	**Geometrical implication**
Fill behaviour (in front of the vent)	Avoid gas inclusions Avoid cold shuts	Correct position of overflow Size of venting channels Small cross section of overflow connection
Flow characteristic (local velocity distribution)	Avoid sticking	Large cross section of overflow connection
Weight	Minimum weight	Size of overflow

Table 2: Criteria for the optimisation of a thixoforming overflow and venting system and their geometrical implications for the design.

5 CONCLUSIONS

The modelling tools used to simulate the thixoforming process have now reached a state where a relevant input for the design of a mould can be given. The geometries of the gating system, the component and of the overflow can be optimised using numerical simulation along with the process parameters such as piston velocity and the temperature distribution of the mould.

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