Simulation under Pressure

3D-Simulation of Gas Injection Moulding

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Gas injection moulding (GIM) is increasingly being applied also to flat fabricated parts. The processes in the mould can be realistically simulated in a 3D-modell since the geometry has three-dimensional regions and the process of displacing the plastic melt by the gas is three-dimensional.

In gas injection moulding (GIM) the mould cavity is partly filled with an exactly defined quantity of melt. Thereafter an inert gas under pressure, usually nitrogen, is injected after a defined delay time. The gas injection takes place through the gate or through gas nozzles arranged in the cavity. In the moulded part gas channels are formed in places where the plastic has been displaced by the gas. After complete formation of the cavity, the gas provides holding pressure to compensate for shrinkage. Very good pressure transfer is thereby guaranteed in all parts of the moulded part accessible to the gas. At the end of the gas injection phase and during the advanced phases of the cooling process the interior pressure is reduced and gas is recovered. When the mould removal temperature is reached and the pressure is released the moulded part is ejected.

The moulded parts produced in the gas injection moulding procedure can be divided in three geometry families as in Fig.1:

- Thick Walled, Oblong Moulded Parts:
Compact injection moulding fails virtually completely with this geometry family since extremely long cooling times are necessary and at the same time the moulded parts shrink a lot because of the high material concentrations.
- Flat Moulded Parts with Gas Channel Ribs:

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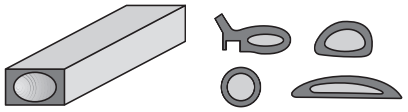
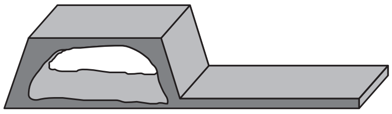


Thick walled oblong moulded parts

Moulded parts with ribs



Flat thin walled moulded parts with some thick parts

Fig. 1. Geometry classification for GIM moulded parts

The gas flow channels stiffen this fabricated part. Flat, virtually warp free moulded parts with low residual stress can be produced.

- Moulded Parts with some Thick Sections:

Flat, thin-walled moulded parts with some thick places can either not be produced or produced using compact injection moulding only with significant sink marks in the thick regions. When using gas injection moulding a gas nozzle is positioned near the thick place.

In the literature [1, 2, 3] the opinion is often expressed that round or circular gas cavity cross sections tend to form during the gas blowing process. If the geometrical forms of the gas channels actually formed in GIM moulded parts are analysed (for instance in perpendicular rib applications), no circular gas channel cross sections can be observed. Fig. 2 shows examples of the gas channel form in thick walled sections of moulded parts. In principal the gas channel's geometrical format follows the given outer contour. Furthermore, from Fig. 2 it can be concluded that sharp changes in direction comprise very unfavourable shapes. While there are thin places on the inside edges, thick places can be seen on the outer areas.

Standard Programmes not Realistic

For years manufacturers of programs for injection moulding simulation have also offered modules for simulation of the gas injection process. These programs are based on a so-called shell model. With it the midplane of the moulded part is modelled, the wall thickness is assigned to the surfaces as an attribute and a two-dimensional steady flow is calculated. The filling distribution and the ratio of the plastic layer thickness to the entire thickness of the moulded part are obtained as typical results.

A problem with this method of modelling is that the geometry of the moulded parts and the gas cavity formation process are three-dimensional. Therefore, to make statements about the exact geometry of the gas cavities 3D simulation is necessary. On the other hand, particularly with very complicated moulded parts 3D simulations are very time consuming. For the 3D calculations in this contribution the Fidap program was used [4]. It is a general flow simulation program and makes calculation of the flow of two media (plastic melt, gas) possible. Since 3D flow requires extensive calculation, at present only calculations for simple basic geometries can be made.

Calculation with the $2^1/_2$D Model

Modelling using a $2^1/_2$D model is frequently insufficient since for instance thick walled areas or ribbed geometries must be described (Fig. 3). Although a rib geometry can be represented approximately in a $2^1/_2$D model, surely it cannot be used to describe three-dimensional temperature and flow fields.

For calculation of the permanent residual wall thickness with $2^1/_2$D models theoretical similarity considerations and the so-called capillary number are used. When a gas penetrates into a viscous liquid the gas does not displace the viscous liquid completely but leaves a certain portion behind at the wall. The portion in the remaining layer depends on the dimensionless capillary number Ca. The capillary number is defined as the ratio of the viscous force to the interfacial surface tension.

$$\mathrm{Ca} = \frac{\eta\,\mathrm{U}}{\gamma}$$

η: Viscosity of the plastic
U: Characteristic speed
γ: Border-surface-tension of the plastic

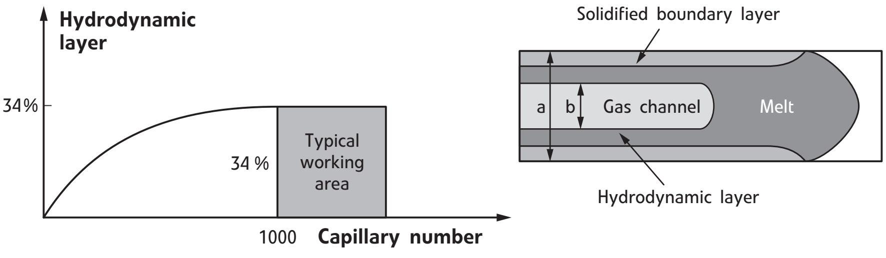


Fig. 4. Experimentally determined residual wall thickness as function of the capillary number for a Newtonian melt (left). Layered structure of the moulded part (right)

A relation between the capillary number and the residual wall thickness could be found in experimental investigations on Newtonian fluids. For isothermal flow through a tube the residual wall thickness increases toward 34 % of the radius with increasing capillary number. However, in a real injection moulding process the permanent residual wall thickness depends also on the surface layer solidification during the form filling process. The shear rate and temperature dependent viscosity should be used as a characteristic measure.

For the injection moulding simulation program Moldflow the following model is the basis for calculation of the residual wall thickness: After injecting the plastic and beginning the gas injection the layered structure of the moulded part shown in Fig. 4 results. There is a so-called hydrodynamic layer between the solidified surface layer and the gas channel. This layer of plastic is still molten at the time of the gas injection and cannot be displaced by the gas. To determine the hydrodynamic layer thickness the experimentally established relation in Fig. 4 is used. To determine the position of the gas front accurately the program must calculate the quantity of displaced and remaining plastic exactly. When the gas front reaches a new element the capillary number is calculated and the amount of plastic that can be displaced by the gas is determined while taking the solidified surface layer into account.

Calculation with the 3D Model

A moulded suitcase grip is an example of a thick walled three-dimensional geometry. In this case the moulded part can be described only approximately using a $2^1/_2$D model. Precisely for such moulded parts 3D simulation is necessary.

On the one hand the geometry can be described using the 3D model and on the other hand the three-dimensional flow and temperature fields can be calculated. With the 3D calculations it is not necessary to use the capillary number. The residual cross section is obtained from the flow fields and the thermal conditions. Fig. 5 shows that in the corner area of the inside of the grip a thinner wall must be reckoned with than on the outside. These single sided wall thickness conditions have a strong influence on the distortion of the moulded part.

For flat moulded parts ribs are used as stiffeners and as gas transmission channels. For ribs a gas channel takes a three dimensional form. Geometrical and physical modelling with a $2^1/_2$D model is only approximate. Fig. 6 illustrates discretisation in a volume model. If the calculation is done three dimensionally the three dimensional form of the gas cavity is obtained.

Conclusion

For an as exact as possible calculations of the gas cavities in thick walled moulded parts extensive 3D FEM simulations are necessary. The previous $2^1/_2$D models for calculating gas cavity formation can only be applied to flat moulded structures with varying wall thickness. A disadvantage of the $2^1/_2$D model is also that the residual wall thickness depends on an experimental relation (the capillary number Ca) while for 3D calculations the moulded cavity form is given by the flow fields and the thermal conditions.

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Fig. 2. Moulded part geometries with characteristic gas blowing cross sections

Fig. 3. Modelling a GIM moulded part with a $2^1/_2$D programme
Produktgeometrie = Product geometry; Gaskanal = Gas channel; Modellierung des Teiles = Modelling the part

Fig. 5. Formation of the cavity with a 3D bowed geometry
Schnitt = Cross section

Fig. 6. Simulation of the GIM process for a ribbed geometry