

Calculating the mold-filling process for thin-walled injection moldings

- Wall thicknesses of less than 1 mm
- Finite element difference method
- Good approximation of the actual situation

The application of rheological analysis software in the design of injection moldings and injection molds is now state-of-the-art. The software required have undergone constant further development over the past few years. With the latest generation of software, it is possible to divide up the flow channel cross-section into a number of layers and thus calculate injection moldings with very thin walls as well. Freezing effects can be simulated under conditions similar to those that prevail in practice (these effects play a key role, particularly with thin-walled molded parts). The possibilities offered by the layer software, and the difference compared with calculations without layers, are presented in this article, based on the example of an actual component.

Improved software ...

New software offer facilities for dividing up the model into layers over its cross-section (i.e. in the direction of shear). In this way, it is possible to model the temperature profiles over the flow channel cross-section more accurately, and hence also the thickness of the frozen edge layers. This calculation method combines the finite element method (FEM) with the finite difference method. When the parameters of temperature, shear rate, viscosity and flow rate are calculated, allowance is made for differences not only over the length of the flow path, but also over the cross-section.

Conventional calculation software describe the filling process for thermoplastic moldings with the aid of FEM and the shell elements. Temperature peaks and freezing effects can only be calculated to a limited extent. With shell elements, calculations have typically only been performed with values averaged out over the wall thickness for temperatures, viscosities and shear rates. In the case of molded parts with very thin walls or with big jumps in wall thickness (e.g. parts with film hinges), this only permits a very imprecise advance calculation of the filling process. Areas with a low melt flow rate and with freezing effects in the outer layers are found on such parts in practice, but can scarcely be modelled.

... with the finite difference method ...

The more recent computation software combines FEM with the finite difference method. This involves the wall thickness of the flow channel being divided up into a specific number of layers. The temperature, shear rate and viscosity are calculated in each layer, resulting in a different value for the temperature in each layer, for instance. This is established by making allowance for heat conduction to adjacent layers or to the cavity wall, as well as for heating due to shear.

The heat transfer to the mold wall is frequently calculated with a specially defined transitional layer. The continued transport of heat from the mold surface to the cooling channel can then be taken into account by dividing the distance between the cooling channel and the mold surface into additional layers (Fig. 1). In this way, it is possible to include the position and the spacing of the cooling channels in the calculation. This provides more accurate statements on flow rates and freezing effects.

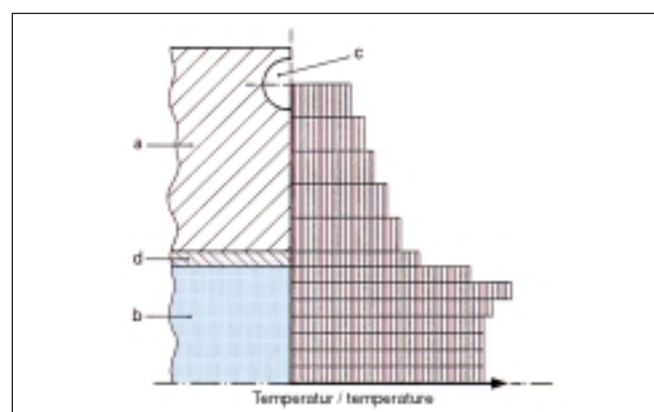


Fig. 1: Layer model for molded part and mold for rheological calculations in injection molding
a: mold,
b: melt-filled cavity,
c: cooling channel,
d: layer for the mathematical modelling of heat transfer from the melt to the mold

... lead to more precise results.

The filling process imposes high mechanical and thermal stresses on the melt in the nozzle and gate system. The main influencing parameters are:

- The nozzle and gating geometry
- The molded part wall thickness
- The filling rate
- The temperature of the molding compound
- The mold wall temperature

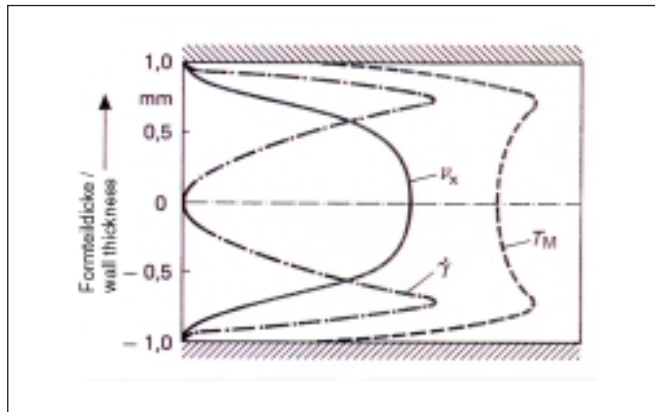


Fig. 2: Qualitative profile of the speed v_x , shear rate and temperature T_M over the cross-section of the molded part

The speed over the molded part cross-section shows the characteristic flattened profile for fluids with structural viscosity (Fig. 2). The shear rate displays a peak in the layers close to the edge (higher velocity gradient). The temperature distribution can similarly have a more or less pronounced peak. The temperature distribution profile results from the elimination of heat towards the channel wall and the introduction of heat through friction, including internal friction. The influence of the shear heat can be of great importance with small diameters, thin wall thicknesses, low melt temperatures and high flow rates, and can lead to pronounced temperature peaks.

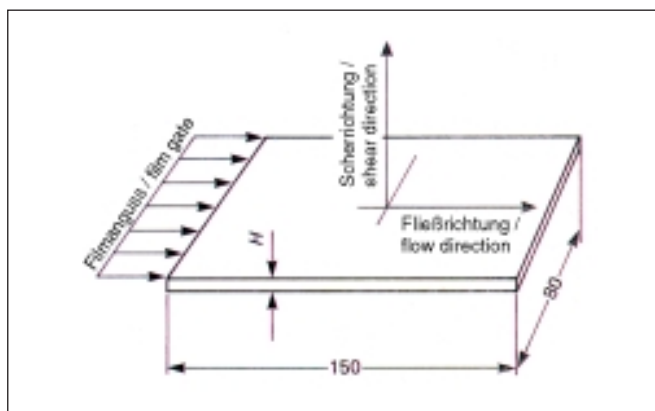


Fig. 3: Geometry of the plate mold for rheological calculations

A plate-shaped cavity (Fig. 3) shows the influence of melt temperature and wall thickness on the shear rate and the temperature profiles. The results presented have been calculated with a finite difference software. Figure 4 shows the influence of different melt temperatures on the temperature profile for an identical filling time. With a lower melt temperature, the peak temperature is more pronounced than with a high melt temperature. At the lower temperature, the viscosity, and hence the shear energy introduced into the melt, are higher. The maximum temperature increases with the melt temperature [1].

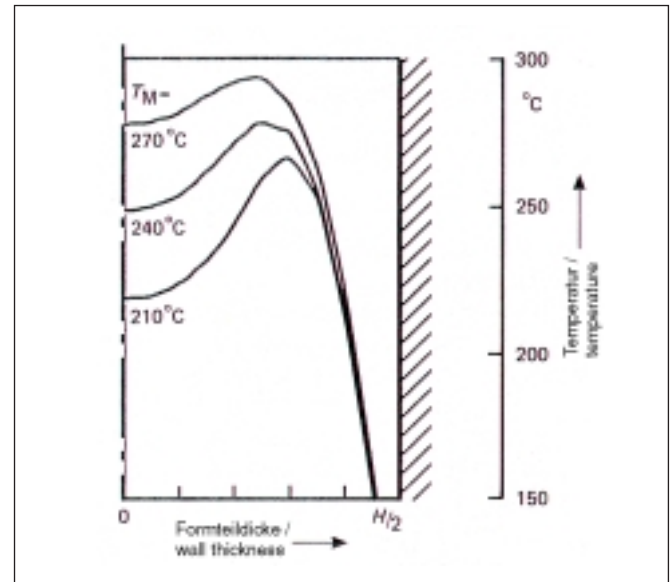


Fig. 4: Influence of the melt temperature T_M on the temperature profile in the flow channel (software: Mold-flow MFLP, material: ABS, type Novodur P2MT, processing conditions: mold temperature 60 °C, filling time 0.4 s)

Figure 5 shows the influence of the molded part thickness on the temperature and shear rate profile. On the left-hand side of the Figure, the wall thickness is 3 mm, and on the right-hand side, 1 mm. The filling time is identical in both cases. In the thin-walled area, the more pronounced shear leads to a temperature increase that is almost twice as high. Despite a higher maximum temperature, the temperature averaged out over the cross-section is lower for the thinner part on account of the more pronounced cooling [1].

With this type of calculation using the layer calculation, it is possible to describe the flow conditions in a thermoplastic melt more accurately than without the division into layers. This division into layers is particularly important with extreme processing conditions, with flow channel cross-sections that vary a great deal and, in particular, with thin wall thicknesses. The interaction between pronounced cooling and shear heating can only be recorded by a layer calculation over the flow cross-section.

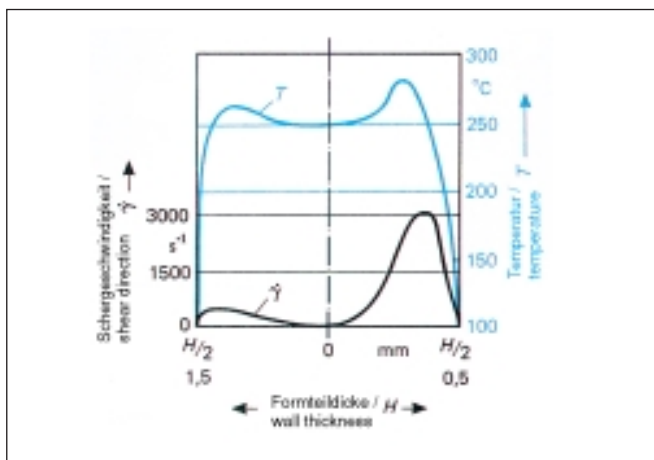


Fig. 5: Influence of the wall thickness (left, 3 mm, right 1 mm) on the course of the temperature T and the shear rate (software: Moldflow MFLP, material and processing conditions as per Fig. 4, melt temperature 240 °C)

Twin-shell edge connector with film hinge

The example of a twin-shell edge connector (Fig. 6) in polymer-modified polybutylene terephthalate (PBT) has been included to highlight the potential offered by a layer software and the differences compared with conventional software.

The edge connector is made of a basic connector and a cover. The two parts are connected via a film hinge. The wall thickness of the basic connector and the cover is between 0.9 and 1.6 mm. The wall thickness in the film hinge falls from 0.45 mm at the transition points to 0.3 in the central section of the hinge. At the upper and lower edge, a thin connector bar (1 mm in diameter) between the basic connector and the cover serves to align the connector in a mounting device. This is automatically destroyed when the connector chambers are closed. The gate is on the right-hand side of the front end of the connector.

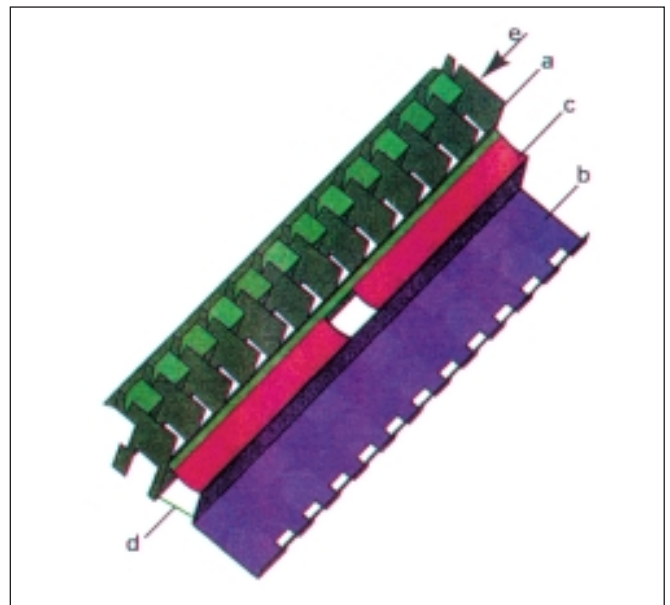
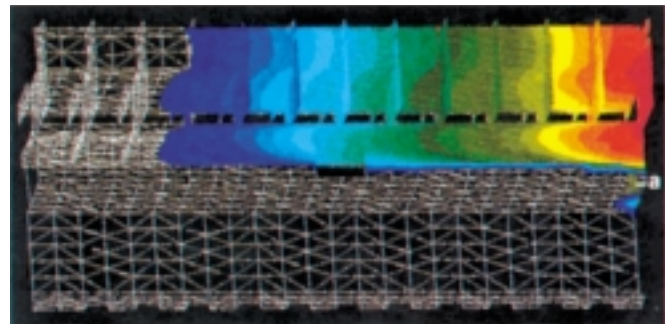


Fig. 6: Geometry model of an edge connector comprising the basic connector a and the cover b with a film hinge c and connector bars d; the gate e is on the front end of the basic connector.

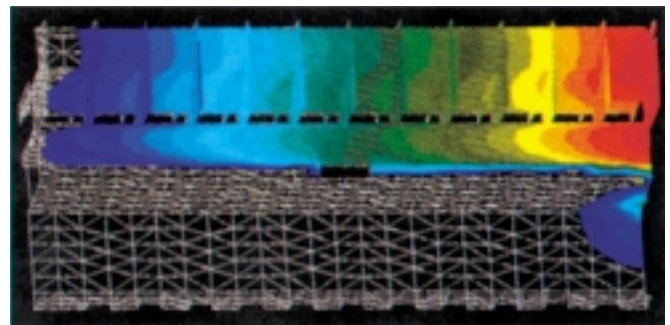
Course of filling process with layer calculation

The position of the cooling channels in the mold is not taken into account for the calculations. Instead, a uniform surface temperature of 80 °C was taken for the entire cavity.

Figure 7A shows the calculated filling process with the cavity about 45 % full. The melt flows into the basic connector and, from there, perpendicularly into the film hinge. At the same time, another flow front reaches the cover through the right-hand connector bar.



A



B

Fig. 7: Partial filling of the connector from Fig. 6 with the cavity 45 % full (A, at connector bar, a, melt flows into the cover) and 60 % full (B)

In Fig. 7B, the mold is around 60 % full. The basic connector is almost completely filled while virtually no melt has flowed through the film hinge. The high flow resistance in the film hinge causes the basic connector to be filled first. This leads to a temporary standstill of the melt in the film hinge and to a partial freezing of the melt front in the hinge. The cover continues to be filled through the right-hand connector bar.

Even when the cavity is 85 % full, the melt has still not flowed through the hinge zone (Fig. 8). Melt is now also flowing through the left-hand connector bar into the cover. The temperatures at the flow fronts in the film hinge have fallen to below the melt's freezing temperature.

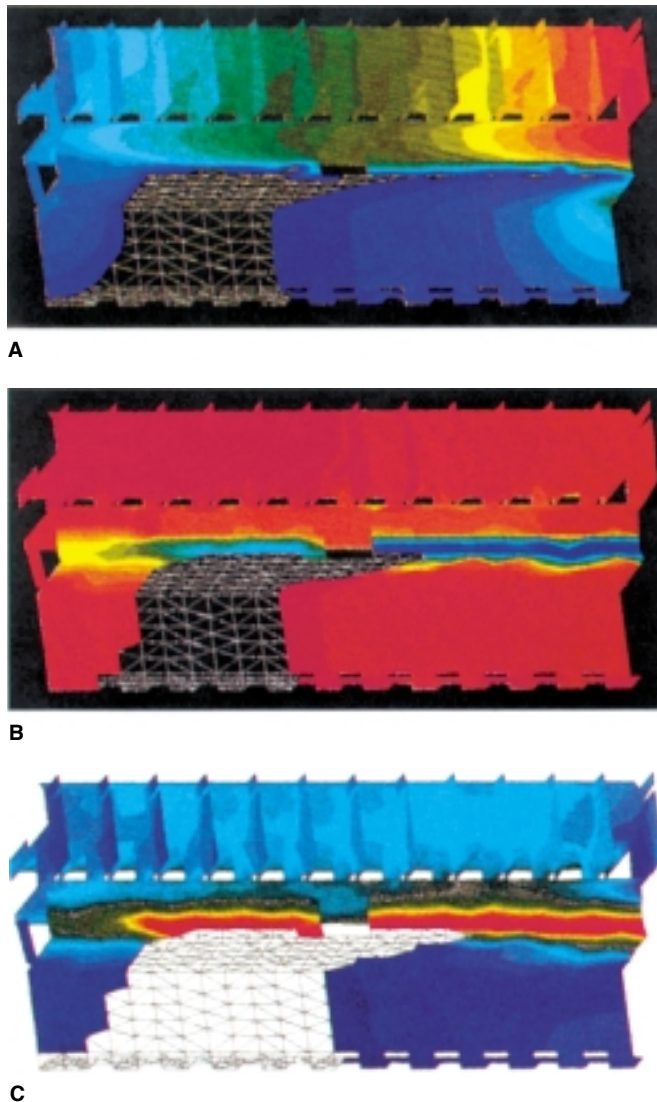


Fig. 8: Different calculation results for an edge connector with the cavity 85 % full
A: Computed flow pattern,
B: Temperatures in the center of the channel (blue: 95 °C, flow limit temperature 210 °C)
C: Percentage of frozen edge layer (red: 100 % of the flow channel frozen)

The position of the melt fronts in the film hinge is still unchanged when the cavity is 95 % full (Fig. 9A). In the left-hand section of the film hinge, a flow line forms from already-solidified melt and the flow of melt from the cover into the hinge. There are signs that air will become entrapped on the side surface of the cover. Figure 9B shows the situation when the mold is completely full (obtained as the result of the calculation).

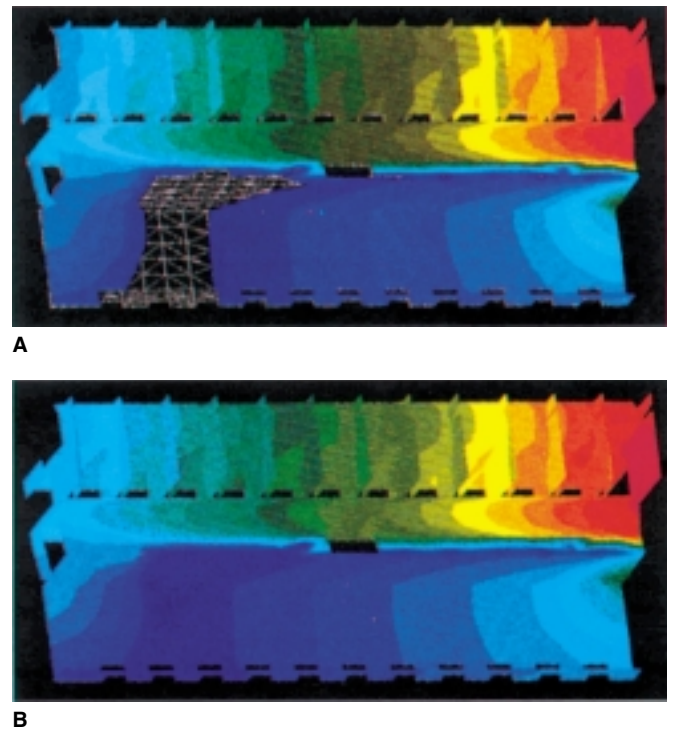


Fig. 9: Filling state of the edge connector with the cavity 95 % full (A) and 100 % full (B)

Injection molding tests confirm the calculation

The calculated filling levels tally well with the partial filling of the injection mold (Fig. 10). The sharp deceleration of the melt flow in the film hinge, the development of a flow line in the film hinge and the filling of the cover virtually exclusively via the two connector bars reflects the calculation by the layer software with a good degree of accuracy.

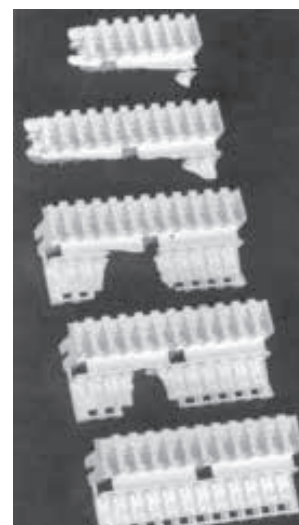
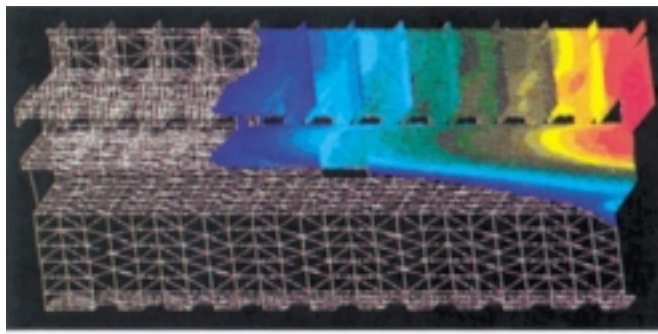
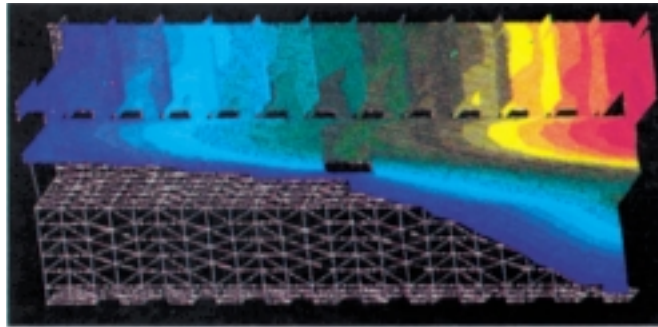


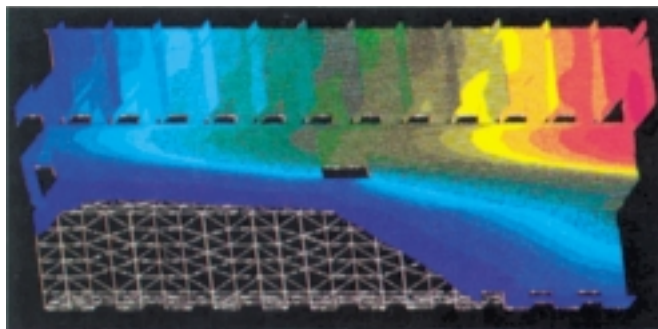
Fig. 10: Partial fillings of the edge connector, as obtained in injection molding tests with a lateral gate position



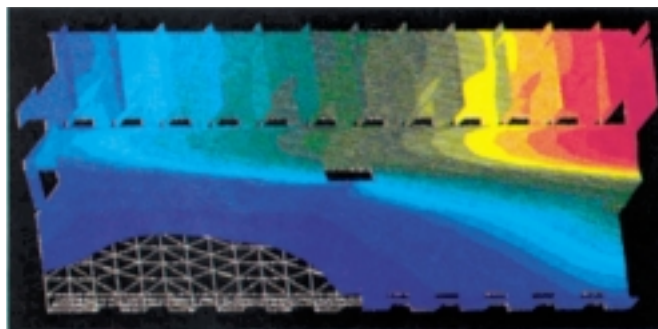
A



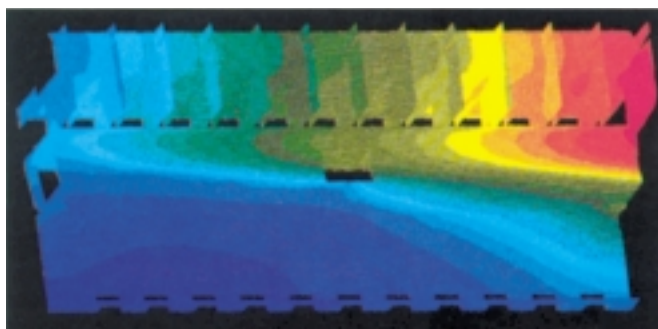
B



C



D



E

Fig.11: The flow patterns obtained for the edge connector without the use of a layer software (arranged according to an increasing filling level) display considerable deviations from the actual short shots in Fig. 10. Software: Moldflow MFL4.

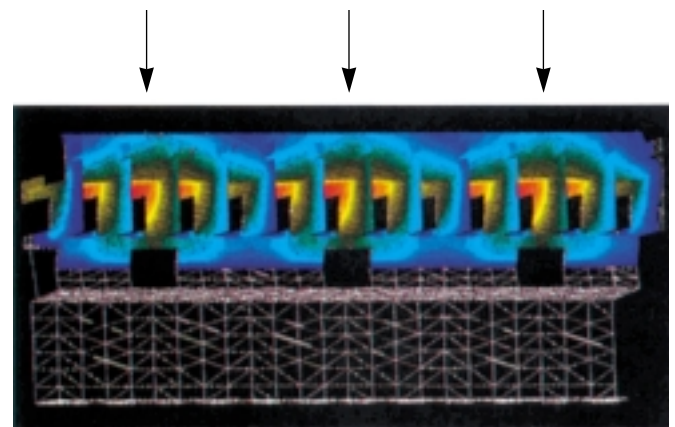
The calculation using a conventional software without division into layers produces a filling pattern that deviates greatly from the actual filling phase. Figure 11 shows this for five filling levels. On the basis of this result, the melt flows through the film hinge as a scarcely noticeable flow resistance.

Better results with three injection points

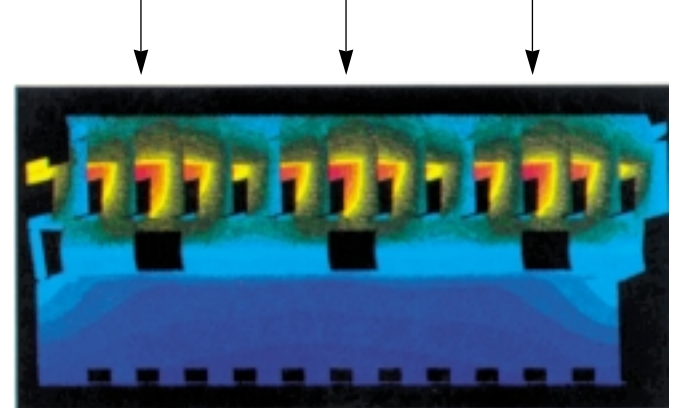
It has been seen both from the calculation and in practice that, when the gate is positioned on the front end, the melt freezes in the film hinge. Freezing effects of this type are evident on a large number of plastic moldings where areas with highly differing wall thicknesses have to be filled at one and the same time.

Molten plastic flows in the direction of the least flow resistance, i.e. into thick-walled areas to begin with. It scarcely penetrates the thin-walled section. For the melt to flow further into the thin-walled section, it would be necessary to have a higher pressure than in the thick-walled zone. As a result, the melt can come to a temporary standstill and can start to freeze in thin sections.

Freezing effects in the film hinge can be avoided with the injection concept shown in Fig. 12. The basic connector has three gates along the lateral surface. This ensures that it can be filled very quickly. Following this, the melt is forced to flow through the film hinge. Two additional perforations in the hinge prevent the melt from flowing too fast into the film hinge through the chamber walls located close to the gate. This makes it possible to avoid melt freezing.



A



B

Fig. 12: The triple gating on the side of the edge connector ensures favorable filling behavior
A: filling level 50 %,
B: filling level 100 %

The triple lateral gating shown in the Figure constitutes the optimum solution for plastic articles such as the edge connector in terms of filling behavior. In practice, however, it frequently becomes necessary to accept a compromise.

The lateral gating proved impossible to achieve due to mold design constraints. The highly complex structure of the mold (slide, combination mold for different plug sizes), made it necessary to retain the gate on the front end). The filling problems that arose to begin with were eliminated by partially increasing the wall thickness in the hinge and through optimum processing conditions, thereby permitting perfect, functional parts to be produced.

Concluding appraisal

The experience acquired to date in the calculation of thin-walled moldings with the aid of finite difference software can be rated as positive. The computation outlay is considerably higher, however, than for calculations without a division into different layers. In the present case, the computation time with the layer method was five times as long.

With the hardware currently on the market and making allowance for the constant further development of increasingly higher-performance computers, the computation times for the layer method are within acceptable limits and will become increasingly short. On the basis of the experience acquired to date and according to information supplied by software producers, the layer process ought to be applied for molded parts with a wall thickness of less than 1.5 mm. This is particularly important if the wall thicknesses in a component also vary a great deal. The freezing effects that occur with these parts and the different flow front velocities are not reflected sufficiently accurately by software without layers.

Layer software can also be used to calculate the conditions prevailing in the holding pressure phase. The results of the filling calculation serve as the input variables here. With data on the correlation between the specific volume and the temperature and pressure (pvT data), it is possible to calculate volume shrinkage and warpage in different areas of the molded part, among other things. Initial software for this have been undergoing testing for some time, and the reports on the experience acquired make an optimistic impression. However, it will doubtless be some time before the entire injection molding process and all the factors that influence the injection molding can be described accurately and in a manner that does justice to the actual situation.

The trend towards increasingly complex and also higher-performance computing software is doubtless set to continue. Such software will not be able to replace the experienced plastics expert, however. The expert will be called upon to critically assess the wealth of calculation results obtained and to implement these in practice.

Reference

- [1] Thienel, P.: Der Formfüllvorgang beim Spritzgießen von Thermoplasten. Diss., RWTH Aachen 1977

Typical value

These values are typical values only. Unless explicitly agreed in written form, they do not constitute a binding material specification or warranted values. Values may be affected by the design of the mold/die, the processing conditions and coloring/pigmentation of the product. Unless specified to the contrary, the property values given have been established on standardized test specimens at room temperature.

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