Turbulence in the Cooling Channel

Springs Increase the Efficiency of Mold Cooling and Temperature Control

To achieve short cycle times, the heat-transfer medium or cooling water must dissipate the heat introduced during injection of the plastic melt as rapidly as possible from the cavity – with the least possible flow rate for reasons of energy efficiency. As a current series of trials shows, the heat transfer in the tempering channel can be improved with simple measures. This benefits the part quality just as much as the economy of production.

It is well known that a well designed mold temperature control is the basis of economic and repeatable injection molding production. Against this background, a working group at the Institute of Polymer Injection Molding and Process Automation (IPIM) at Johannes Kepler University, Linz, Austria, investigated various measures for optimizing the heat transfer in the tempering channel.

The test rig used for this consists of insulated and tempered steel blocks, whose surfaces are heated with infrared radiation (Fig. 1). The heat flux density that reaches the surfaces of the steel blocks is about 6 W/cm², and is thereby in the range of conventional injection molding processes [1]. With this construction, the heat load of the plastic melt into the injection mold can be modeled in a steady-state process. As a representative parameter for the average mold wall temperature, the surface temperature of the steel blocks is measured by means of a temperature-triggered thermal imaging camera.

The relationships for obtaining lower mold wall temperatures are described in detail in the literature [2, 3]. From a Reynolds number of only about 2,300, the turbulent flow components increase. In addition to thermal conduction, turbulences transport the heat transversely to the flow direction and thereby improve the heat transfer in the tempering channel. In the injection molding process, the flow should be high enough to achieve a Reynolds number of 20,000 [2, 3]. However, higher flow rates do not achieve a further improvement of the heat transfer.

Even at high Reynolds numbers, there is laminar flow nearby the tempering channel wall which hinders heat transfer and acts as an insulating layer. In typical injection molding processes, this laminar outer layer has a thickness of about 30 to 250 µm. A specific disturbance can swirl the outer layer and thereby improve the heat transfer. To investigate this effect, various disturbance elements are introduced into the tempering channel and the mold wall temperatures are compared with those that occur in the conventional, empty channel. As disturbance elements, two compression springs with different wire diameters (Title figure) and a spiral, such as that used for core tempering, are used.

As shown by the measurements for the different channel configurations, the disturbance elements reduce the surface temperature significantly compared to the reference channel (Fig. 2). The effect is particularly high in the range of low flow.
rates with high laminar flow components. The spring with the smaller wire diameter reduces the temperature most. This is logical, since disturbance elements reduce the flow rates – to an increasing extent as the wire diameter increases. The results are particularly favorable if the diameter of the springs approximately corresponds to the thickness of the laminar boundary layer. The effect of the springs is increased at higher heat flux densities.

Reducing Energy Costs

Spring inserts can be used for various reasons. If, for example, the temperature of the central cooling system prevents a shorter cooling time because other processes operate at higher temperatures, the average mold wall temperature can be selectively reduced to achieve this. If all injection molds for one production are equipped with spring inserts, the supply temperature can be raised for the same average mold wall temperature. The resulting saving potential depends on the construction of the cooling system.

To estimate the saving potential, a central cooling system with a water temperature of 15°C is used on the assumption that it is operating at full capacity. Due to the use of spring inserts, it is possible to raise the flow temperature by 5 K, for example. In addition, the cooling system can be modified: Free cooling system

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References & Digital Version

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Fig. 1. The test rig makes the heat transfer in a tempering channel transparent. The steel blocks (dark gray) equipped with insulation (beige) are heated with infrared radiators (orange) at one side

Fig. 2. Disturbance elements in the tempering channel, such as springs and spirals, influence the surface temperature to different extents dependent on the flow.

Fig. 3. Possible energy savings in three-shift operation of a central cooling system with and without a free cooling system. Due to the use of spring inserts in injection molds, it is possible to raise the flow temperature from 15 to 20°C, for example. The actual saving potential left depends on the design of the chiller.
tems can supply the entire cooling capacity if the ambient temperature is 4 to 5 K below the flow temperature. The possible energy savings for different configurations of the central cooling system and the injection molds, determined on the basis of the climate data for the Rhenish Massif (Bergisches Land or Sauerland), are just as convincing as the cost savings calculated for an average cooling capacity for a mold circuit of 200 kW (Fig. 3).

If the tempering channels of all molds are equipped with springs, the energy demand for a simple central cooling system with a chiller can be reduced by 20 to 40%. The range is the result of the different designs of chillers. The greatest savings can be obtained with a modern cooling system (chiller supported by a free cooling system) together with spring inserts in the injection molds. This combination reduces the energy demand by over 90%. The spring inserts offer a very favorable ratio of investment costs and savings potential; users can reckon on a purchase price of less than EUR 10 per running meter.

In addition, the profile of the average mold wall temperature flattens over the flow (Fig. 2). As a result, mainly at low flow rates, the influence of flow fluctuations on the process is reduced.

**Optimizing Temperature Distribution**

The temperature distribution at the mold wall can be actively influenced by using spring inserts locally, for example to mitigate hotspots. Therefore, for demonstration purposes, the production of a plate-like part with openings is analyzed (Fig. 4). Immediately after demolding, the part is viewed with a thermal imaging camera, which shows three further high-temperature regions apart from the sprue. They are melt accumulations and, in region R3, can be attributed to the proximity to the gate.

To reduce the hotspots, the flow direction is first changed and spring inserts with 0.63 mm thick wire are introduced into the relevant regions of the tempering channel. With this, the temperatures in the considered regions can be lowered significantly. In region R3, the measured temperature difference is over 7 K. Consequently, the cooling time could be reduced and problems with dimensional stability could be solved.

The entire temperature reduction in the regions R1 and R2 can be attributed to the spring inserts. The change of the flow direction does not show any effect here. In region R3, the spring inserts contribute about 80% to the temperature reduction. With production molds, even more distinct improvements can be expected, since, in the test mold, an overproportionally long cooling time had been set to ensure reliable demolding of the sprue. This leads to a low heat-flux density, which limits the effect of the spring inserts.

Locally installed spring inserts make it necessary to check the modified temperature distribution at the mold wall and in the part using a thermal imaging camera. Due to the improved heat transfer, the heat-transfer medium is heated more strongly locally than in regions without spring inserts. Downstream, conventionally cooled regions therefore have a higher temperature in some cases than in the initial state. In complex molds, numerical simulations may be appropriate to determine the optimum position of the spring inserts.

**Reaching a Stable Process Faster**

After a mold change, the manufacturing cell should return to a reproducible part quality again as fast as possible. The
prerequisite for this is high precision and reproducibility of the drives of modern injection molding machines, but also uniform tubing of the tempering system. It is advisable to check the temperature or at least the flow with suitable sensors [3].

The production of a stamp bracket illustrates the effect of incorrect tubing. Here, the three tempering circuits of the movable mold half are supplied with tempering water in different configurations. In Variant A, the slides and the centered mold insert are connected to one another in series. Variant B connects the slide, which is tubed in series, to the centered insert in parallel. Variant C is characterized by completely parallel connection (Fig. 5).

The geometry of the parts is digitized with an optical 3-D measurement system (type: Comet L3D 2M; manufacturer: Steinbichler Optotechnik GmbH, Neubeuern, Germany) [4]. To analyze the tubing, the distance of the flanks of the stamp bracket is evaluated at four different positions (Fig. 5). The range of, e.g., dimension 4 for the different tubing variants, with a measurement inaccuracy of about ±30 µm, is already over 0.4 mm. If the influence of different process parameters on the part geometry is considered (Fig. 6), the comparatively strong influence of the tubing, e.g. with respect to changes of the cooling time ($t_c$), of the holding pressure ($p_{HP}$) or of the mold temperature ($T_m$) can be seen [5].

**Summary**

From these results, it can be derived that the correct connection of the injection molds to the tempering medium supply is essential for the production of high-quality parts. The tubing fixed in the design or sampling should therefore be completely documented and the connections to the mold should be correspondingly identified. The use of different couplings or multiple coupling systems can therefore be appropriate. Errors in the setup and start-up can be reduced by defined workflows. In the case of poor dimensional stability, those responsible in the production should be certain to check the tubing and flow. 

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Fig. 5. The dimensional accuracy of the stamp bracket is measured at four different points (top). In the test series, three different connections of the tempering channels to the temperature-control unit are investigated (bottom).

Fig. 6. Influence of selected process parameters on the change of dimension 4. The type of tubing greatly exceeds all other parameter changes.