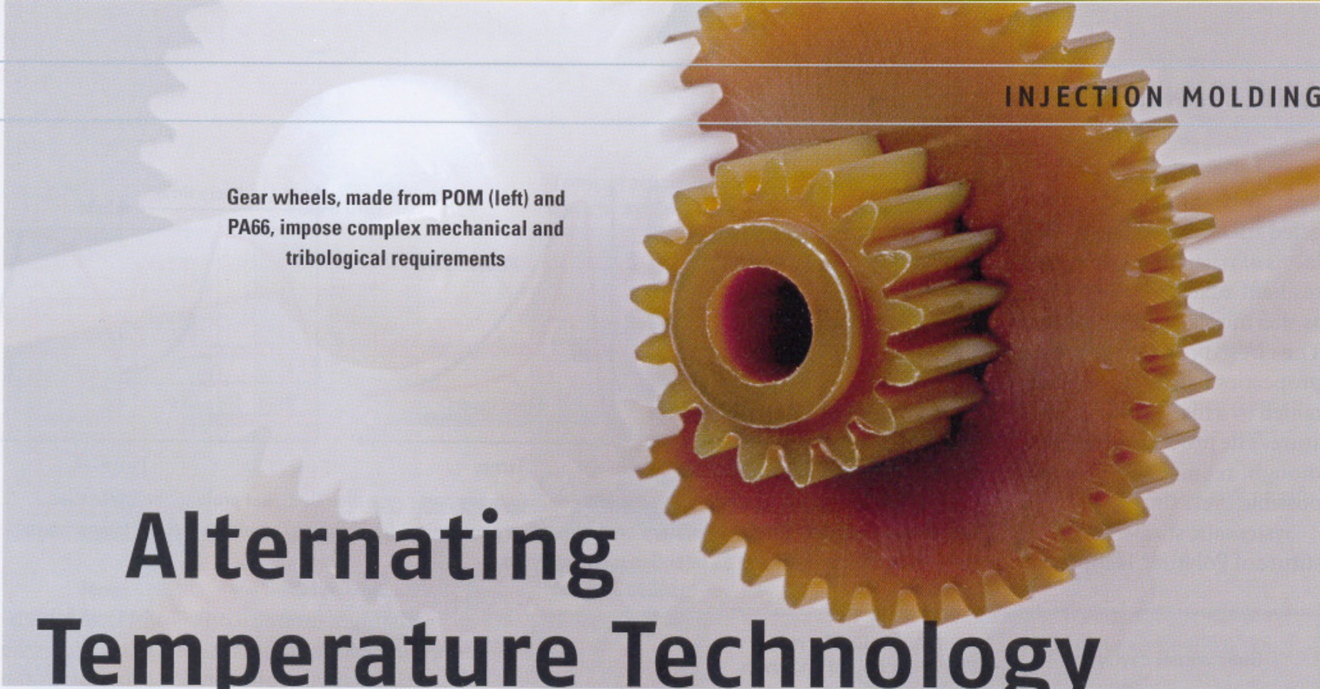

Gear wheels, made from POM (left) and PA66, impose complex mechanical and tribological requirements

Alternating Temperature Technology Controls Parts Properties

Process Optimization. Active temperature-control systems employing alternate heating and cooling phases can optimize not only the rheological characteristics of the process but also the morphology and hence the properties of molded parts overall – without lengthening the cycle time. This has been confirmed by recent injection molding studies on gear wheels.

DIETMAR DRUMMER
KARLHEINZ GRUBER
STEVE MEISTER

Dynamic, cyclic or variotherm mold-temperature control is a technology for boosting the quality of injection molded parts that is increasingly attracting the attention of plastics processors [1,2]. Essentially, the mold wall is heated prior to injection – this has a beneficial effect on the resultant morphology in the part, particularly in the boundary layer. In the ideal case, the temperature is raised near to or above the crystallization temperature of the polymer. Targeted morphology formation of the polymer benefits both the mechanical [3] and the tribological properties [4].

Dynamic Process Control

Mold-filling at elevated wall temperatures confers a number of advantages on the process, the economics, as well as the surface finish and strength of the molded part. It

- exploits the fact that non-cooled or heated molds are easier to fill with hot melt than well-cooled molds,
- reduces the required injection pressure and clamping force,
- reduces shear stress on the melt,
- maintains the holding pressure for longer, even in the areas furthest from the gate,
- reduces residual stresses in injection-compression molding of optical parts,
- promotes surface effects, such as self-cleaning and anti-reflection, the replication of micro- and nano-structures, and the production of very smooth surfaces and high-gloss finishes with a "piano finish",
- ensures more homogeneous orientation of glass fibers in technical parts,
- lengthens the welding time for melt fronts, reduces weld lines, and
- lowers the risk of shrinking-induced warpage and improves the dimensional accuracy and stability of molded parts.

In variotherm temperature control, the mold is not intensively cooled to the requisite demolding temperature until after the cavity has been filled. As a result, the quality of molded parts can be increased, without the cycle time being extended. The variotherm method is easiest to realize with an alternating temperature-control system, which passes hot and cold fluids alternately through the existing cooling channels.

Process control in injection molding not only influences the aforementioned rheological effects, it also affects the internal properties of a plastic part and hence its mechanical properties. Thus, in the case of semi-crystalline polymers, a higher mold temperature leads to greater rigidity and strength, due to the increasing degree of crystallization, associated with reduced elongation at break. Evidence of this has been provided by experiments on mold materials of different thermal conductivity [5]. In contrast, marked temperature gradients perpendicular to the flow direction lessen the degree of crystallization within the material and therefore promote inhomogeneities, anisotropy and warping.

Conflicts Resolved

Controlling the temperature in the mold also allows the tribological properties of →

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a part to be influenced in a targeted manner (**Fig. 1, left**). This fact is of particular interest for resilient machine parts, such as thermoplastic gear wheels. The best-possible material properties in this case are obtained by a high mold temperature. The process economics, though, require the shortest-possible cycle times.

Systematic studies at the Institute of Polymer Technology (LKT) at the University of Erlangen-Nuremberg, Germany, have shown that variotherm temperature control resolves the physical contradiction of the need for high temperatures during injection for good morphology formation in the boundary area of the part and the need for low temperatures for short cycle times.

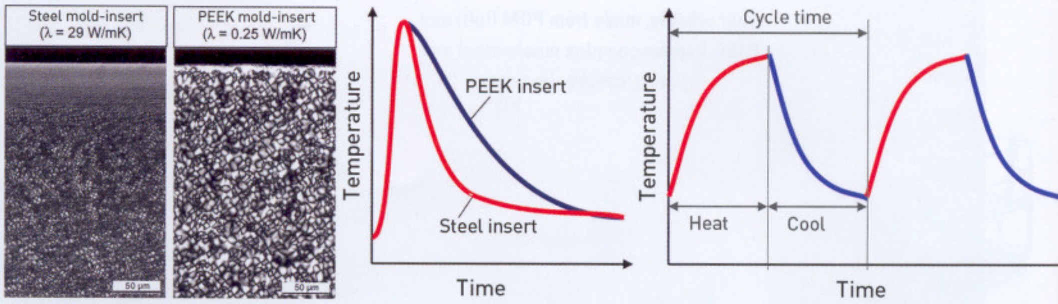

Fig. 1. Low thermal conductive mold materials improve many part properties (left), but prolong the cycle time (center); active alternating temperature control is more economical (right); the example shows the temperature gradient in the cavity during an injection molding cycle

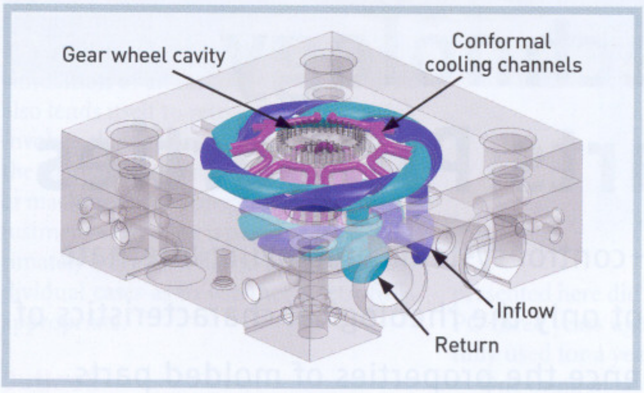

Fig. 2. The mold for gear wheels has conformal cooling channels

In a proving mold for polyoxymethylene (POM) gear wheels (**Title picture**), the compact cavity inserts are thermally insulated from the master mold by insulating platens. The mold is maintained at a constant temperature for the purpose of process stability, and only the temperature of the cavity inserts (**Fig. 2**) is actively controlled. The cavity inserts were built up layer by layer from a steel powder using laser cusing, based on the design data. The combination of insulation from the master mold and conformal cooling channels conduces to particularly rapid temperature changes in the cavity. Sensors near the cavity wall detect the prevailing temperature conditions directly, enabling the process to be specifically controlled, particularly the synchronization of the injection process with the temperature-control phases.

Fig. 3. The STWS 200 alternating temperature control system can effect heating and cooling changes of more than 100 °C

Injection at 150°C, Demolding at 80°C

For tempering the mold a variotherm temperature control system (type: STWS 200; manufacturer: Single Temperiertechnik GmbH, **Fig. 3**) was used. The system employs water as the circulating fluid and has a heating and a cooling circuit with a hydraulic circuit-switching device. The system has two separate circuits in which water is held at different feed temperatures and can actively provide alternating heating and cooling (**Fig. 4**). As a result, it can effect an 80 °C change in temperature in the mold inserts within 10 s. The machine tells the valve controller whether cold or warm fluid is to be conveyed into the mold circuit.

For the type of POM used (type: Hostaform C9021, manufacturer: Ticona GmbH), this highly dynamic temperature control allows the mold temperature to be brought to the level of the crystallization temperature: with the wall at a temperature of 150 °C, the POM melt is injected into the cavity. The high wall temperature avoids the formation of boundary areas of low crystallinity or which are quasi-amorphous. At the same time, a homogeneous structure can form throughout the part. After filling and during the holding pressure phase, the part is cooled to below 80 °C, which is appropriate for demolding this particular material. As the heating and cooling phases take approximately the same time, the heating phase begins at the end of the cooling phase of the previous cycle (**Fig. 1, right**). The cycle time is thus much shorter than is the case for cooling of less heat-conductive mold materials.

Improvements in Morphology

The cavity temperature significantly affects morphology formation. For technically sophisticated parts, a cavity temperature of 100 °C is common. The only way to avoid the formation of a boundary layer that has a different microstructure is to raise the temperature to 140 °C. The resultant longer cooling time doubles the cycle time for the gear wheel under review (**Fig. 5**). With active alternating temperature technology, however, the part can be demolded after an overall cycle time of less than 20 s.

Differential scanning calorimetry measurements (DSC) confirm the uniformity of crystallization across the thickness of the gear tooth. Thus, gears manufactured with the aid of variotherm temperature control have greater crystallinity, especially in the tribologically stressed boundary layer, than gears injection molded at a mold temperature of 100 °C. The much narrower melting peak also confirms the more homogeneous size distribution of the crystalline structures.

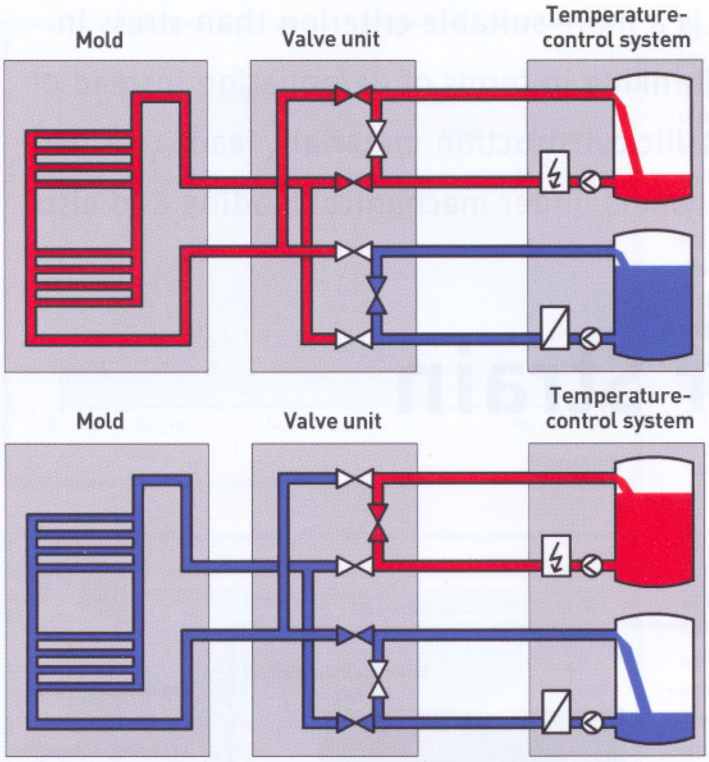

Fig. 4. Alternating temperature control systems cause hot and cold fluid flow to flow alternately through the temperature control circuit

Summary and Outlook

Targeted temperature control allows the property potential of semi-crystalline materials to be better exploited, optimizes and homogenizes the part's microstructure and prevents the formation of weak boundary layers. Unlike alternative approaches, variotherm temperature control of injection molds or targeted variotherm temperature control of thermally insulated mold inserts conduces to a substantial reduction in cycle time.

Variotherm temperature control yields parts that exhibit improved internal and external properties and increases fidelity of reproduction of the injection molding process. It offers the potential to exert tighter control over crystallization during processing and actively utilize the specific temperature-time relationships of nucleation and crystal growth through the use of precise temperature control. Especially in the case of gear wheels, with their tight tolerances and high service loads, it is possible to improve part properties, such as the fidelity of reproduction with regard to meshing quality, mechanical characteristics such as tooth root strength, and tribological properties such as tooth wear.

The influence of variotherm temperature control on other target parameters in optical and technical parts, such as residual stresses and associated fluid resistance, surface properties and optical properties should be studied. The benefits which variotherm temperature control offers injection molding processes as regards parts performance is by no means exhausted. ■

Contact

Lehrstuhl für Kunststofftechnik
Universität Erlangen-Nürnberg
D-91058 Erlangen / Germany
TEL +49 9131 85-29700
→ www.lkt.uni-erlangen.de

Single Temperiertechnik GmbH
D-73269 Hochdorf / Germany
TEL +49 7153 3009-0
→ www.single-temp.de

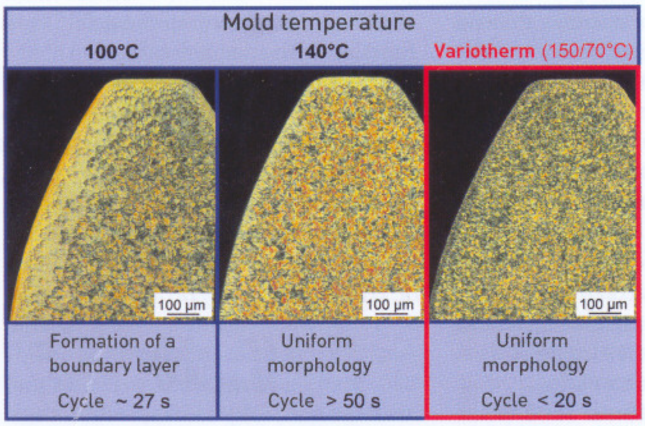

Fig. 5. Alternating temperature control improves the morphology of the gear wheel, without lengthening the cycle time

(photos: LKT/Single)

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THE AUTHORS

PROF. DR.-ING. DIETMAR DRUMMER, born in 1971, is head of the Institute of Polymer Technology (LKT) at the University of Erlangen-Nuremberg, Germany; drummer@lkt.uni-erlangen.de

DIPL.-ING. KARLHEINZ GRUBER, born in 1964, is Managing Director of Single Temperiertechnik GmbH, Hochdorf; kh.gruber@single-temp.de

DIPL.-WIRTSCH.-ING. STEVE MEISTER, born in 1982, is a scientific assistant at the LKT; meister@lkt.uni-erlangen.de