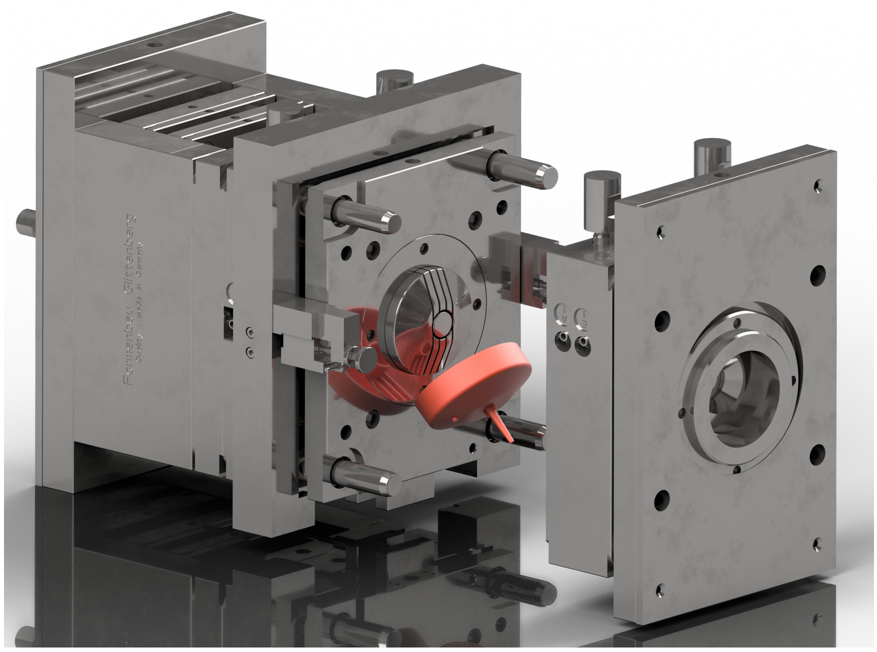
Fine Channels, Maximum Efficiency

Improving Conformal Cooling with Design, Simulation, and Processing Know-How

The production costs for complex injection molded parts not only depend on material costs but also to a considerable extent on cycle time. The cycle time is divided into the injection, holding pressure, (residual) cooling phases and the tool movements. The cooling phase takes up 60 to 90 % of cycle time, depending on the particular plastic material and part component. Adequate cooling can therefore reduce not only cooling time but also cycle time.

In conventional mold designs, cooling channels are manufactured cost-effectively into the mold by straight drilling holes. But with complex part geometries, this method prevents a uniform distance between the cooling channels and the surface of the component cavity. This leads to an uneven temperature distribution in the mold cavity. Ideally, the design of the cooling system of the component geometry should be adapted to conform to the cavity shape. With additive manufacturing processes this becomes reality. It enables complex cooling channel geometries to be achieved and cooling time to be shortened. Productivity and energy efficiency can be increased and production costs reduced. Molding quality can also be improved through a more homogeneous temperature distribution.

However, conformal cooling requires considerably more expenditure of time and effort than conventional cooling channels – right from the development of the cooling channel design and necessary pre-simulations through to the mold manufacturing itself. Because of this complexity, BASF SE, Ludwigshafen, Germany, and Autodesk Inc., San Francisco, CA/USA, have been cooperating on this problem for the last two years. BASF contributed its long-standing experience in the areas of plastics processing [1] and CAE to the project [2, 3]. The software manufacturer Autodesk deployed its expertise in the CAD program Autodesk Inventor and the injection molding simulation software Autodesk Moldflow. Using a test component, the partners analyzed the process step by step in order to make it available to their mutual customers.



This mold determined the maximum cycle times (rendering) (© BASF)

Design and Simulation of the Conformal Cooling System

The **Title figure** shows the mold used by BASF to determine cooling times for its thermoplastics. The closely arranged ribs without any draft angles intentionally make ejection of the test component more difficult. In this way, differences in the minimum cycle times of the various materials can be clearly identified. Based on its long-standing experience with this mold, BASF in consultation with Autodesk selected it to be able to directly measure any improvements in cycle time achieved by a conformal cooling concept. The conventional cooling concept relies on baffles (riser holes with separator plates) in the core, which, however, does not extend between the fine rib structure inside the component (**Fig. 1**). The distance between the ribs is only 6 mm, which is too narrow for conventional cooling channels with a typical diameter of 6 to 10 mm. With conventional cooling, therefore, the baffles end about 5 mm below the ribs. To examine what effect this has on cooling, the injection molding cycle was simulated with Autodesk Moldflow. To this end, the component and cooling channels were meshed as a 3D model and a Cool FEM analysis was run. The results clearly show that the highest temperatures occur between the ribs (**Fig. 2**). 14.5 s after injection of unfilled polyamide 66 (Ultramid A3K) in the conventionally cooled mold, the mold surface temperature in the rib region, for example, is more than 70 K higher than in the well cooled external surface.

To reduce cycle time, the areas in the core between the ribs should be better cooled. The opposing fixed mold half, on the other hand, is not critical; here conventional cooling works well because of the largely even surface. Autodesk therefore designed various conformal cooling concepts for the core based on additive manufacturing. All these concepts were tested by simulations with Moldflow software to ensure that an adequate water flow and improved cooling between the ribs could be achieved. The initially contemplated helical and fan-like structures were quickly rejected as the pressure loss of the water was too great here and the overall flow became uneven. After a total of 15 design iterations for the conformal cooling channel in the core, a design was eventually found consisting of a single cooling circuit that passed through the space between the ribs (**Fig. 1**) which was also suitable for additive manufacturing. With this concept, the temperature between the ribs can be reduced by up to 70 K, which according to the simulation reduces cycle time by 10 to 20 %, depending on the material.

To check whether the residual wall thickness of the mold core between the ribs, which is only 1.9 mm in some areas, could withstand the high pressures during injection molding, a final FEM analysis with Abaqus was carried out. However, the stress and deformation values obtained proved to be non-critical. So, through simulation, all questions were cleared up in order to proceed with manufacture of the core.

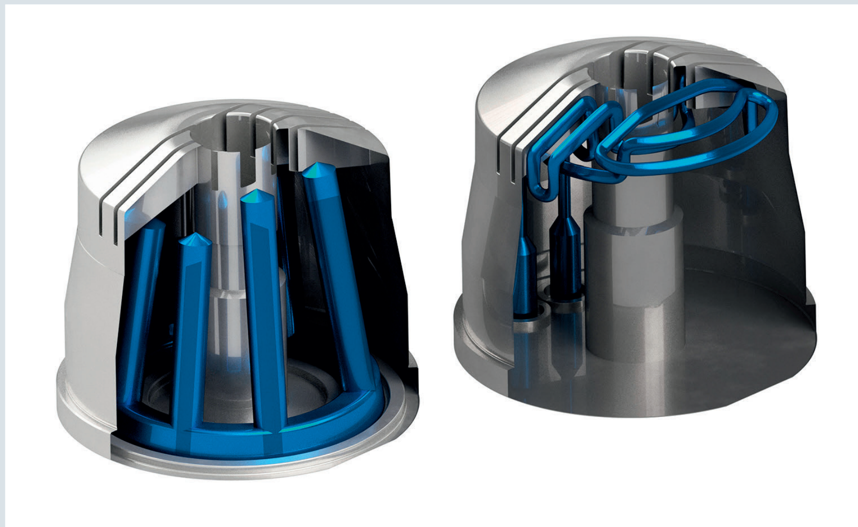


Fig. 1. Mold inserts with straight drilled holes, conventional (left), and additively manufactured conformal (right) cooling channels (© BASF)

Production of the Additively Manufactured Core

In the present mold, the core that reproduces the inner contours of the component, is relatively long, which means a hybrid, two-stage manufacturing process is more cost efficient. Two thirds of the core can be produced with conventional methods such as turning, drilling, milling, and grinding, since only straight drilling holes are needed for the inlet and outlet of the cooling channel, as well as a groove for the seal. The last third is built up additively on the pre-manufactured blank by selective laser sintering (SLS). Construction time and manufacturing costs are significantly reduced through use of the hybrid process.

After setting up the blank in a Matsuura Lumex production machine from Matsuura Machinery GmbH, the additive manufacturing process begins with demagnetization. Then the powder is applied in layers and laser sintered. Between the ribs, the cooling channels have an elliptical shape to achieve the largest possible cross section, while at the same time retaining sufficient residual wall thickness. For production reasons, the channels are not circular in other areas either but have a teardrop shape. For this reason, no supporting material is required. It is also important for the correct contour of the cooling channel that unmelted metal powder can be subsequently removed. Besides "growing" the component by the SLS process, the Matsuura production machine can mill the component at high speed in the same set-up to near net shape with a surface roughness of 0.4 µm. The final machining of the whole core is carried out by milling, turning, and drilling, as well as polishing the shape-forming surface. Finally, a heat treatment is carried out to increase hardness. »

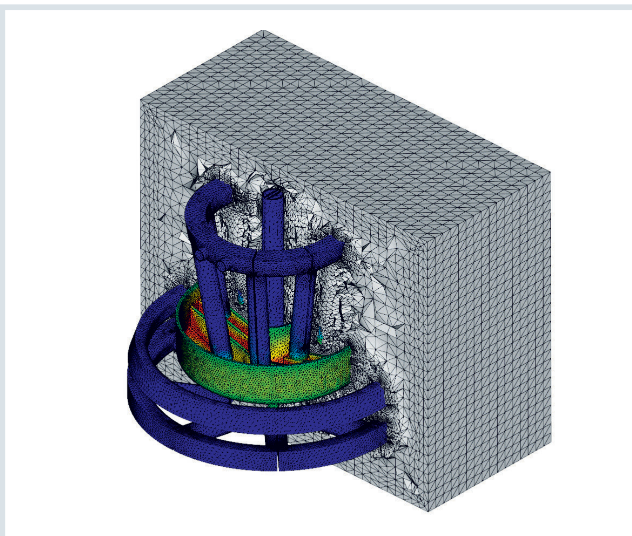


Fig. 2. Heat development in the component for the conventional cooling concept simulated with Autodesk Moldflow (© BASF)

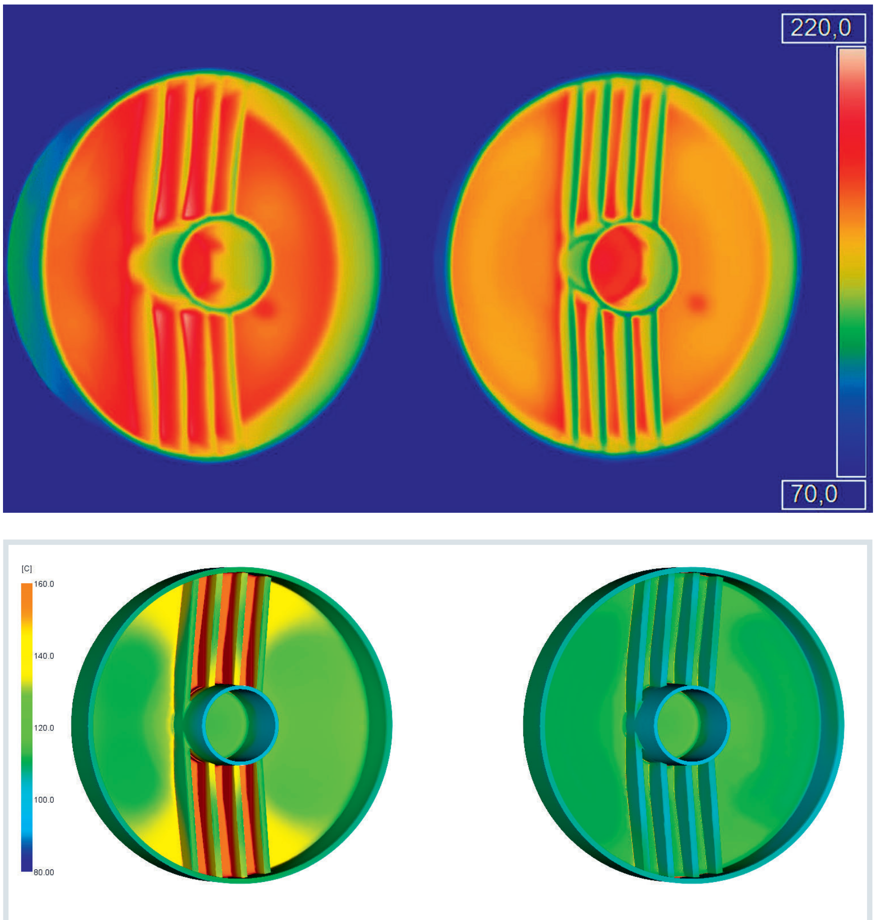


Fig. 3. Molded part temperatures (above) recorded with an IR camera directly after demolding and mold and molded part surface temperatures (below) during the cooling phase (14.5 s after injection) with conventional (left) and conformal (right) cooling (© BASF)

Cycle Time Measurement for the Molded Parts

The processing trials were undertaken to check if conformal cooling brings improvements with respect to the quality of the moldings and cycle time. The injection mold offers the possibility of installing cores with different cooling system designs.

Figure 3 shows the temperatures of the molded parts directly after demolding, as measured with an infrared camera. With conformal cooling (right) the entire component has already cooled down significantly more. The conventionally cooled core heats up between the ribs by 70 K with short cycle times, whereas the other core heats up by only 10 to 20 K (**Fig. 3, below, Table 1**). The separately cooled inner mandrel, on which the injected melt directly impinges, is in both cases some 20 to 30 K hotter than the target temperature. The simulation and experimental results show good quantitative and qualitative correlation. The critical mold areas with very high temperatures were well predicted.

Because the molded part is ejected only via the outer round edge, it undergoes severe mechanical stress and deformation. If it is sufficiently cooled, it has the necessary stiffness and strength to withstand these forces. The deformation of the part during ejection is then virtually reversible. But if the molded part has not yet adequately cooled down, damage occurs such as stress whitening or cracks, and plastic deformation that cannot be reversed (**Fig. 4**). Visual defects are, however, not readily machine-detectable. The criteria used for determining damage to the molded part during demolding, besides visual inspection, were a mechanical loading test, measurement of permanent deformation, and delay time measurement integrated into the mold. In the mechanical loading test, the test specimens showed no evaluable differences after demolding, irrespective of the

Fig. 4. Molded part, after sufficiently long cooling time (left) and inadequate cooling time (right) (© BASF)

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References & Digital Version

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Mold set temperature: 100 °C	Conventional cooling	Conformal cooling
Temperature between the ribs T_{rib}	171 °C	108 °C
Temperature of the inner mandrel T_{IC}	128 °C	125 °C
Minimum cycle time (deformation)	2.7 s	1.5 s
Minimum cycle time (damage)	23 s	17 s

Table 1. Comparison of experimentally determined temperatures and cycle times by the example of Ultramid A3K (source: BASF)

material or "damage condition". Even specimens that showed severe damage on visual inspection withstood the same high forces with virtually identical deformation paths.

The height of the molding as a measure of plastic deformation may only be measured after a sufficiently long cooling phase, otherwise thermal expansion of the material falsifies the result. The occurrence of plastic deformation can also be detected immediately after demolding by means of a photoelectric sensor that measures the time difference between the start of the ejector movement and release of the part from the inner mandrel [4]. Many comparative tests have shown that the minimum cycle time can be accurately determined with both methods. Although their curves follow different paths, the critical limits that describe extreme deformation correspond.

Table 1 lists the minimum cycle times for a part produced from unreinforced PA66 (Ultramid A3K). Irrespective of the criterion used, a cycle time reduction of about 25% can be achieved for this molding with conformal cooling, which is even higher than predicted by simulation.

Summary and Outlook

Autodesk and BASF have together identified the advantages and disadvantages of conformal cooling concepts. With the aid of extensive Moldflow simulations a conformal cooling concept was developed for a BASF mold performed by both cooperation partners and the corresponding mold core was additively manufactured. The trials on the test component carried out by BASF in its injection molding competence center show that conformal cooling offers significant advantages with respect to cycle time. Warpage reduction is also possible but could not be verified with the component geometry used.

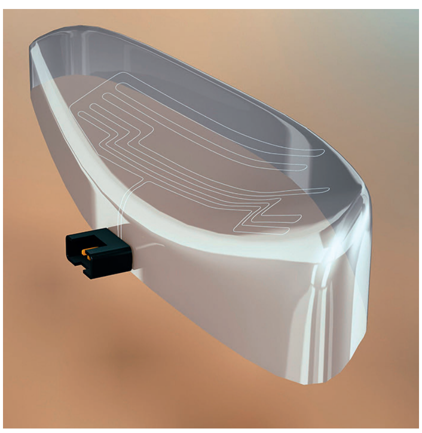
Due to strong competitive pressure additively manufactured mold inserts will only become established if their advantages during use outweigh the higher costs. While the additional production costs for the mold inserts are generally manageable, the significantly higher development expenditure, in particular, should not be underestimated. As the present example demonstrated, many simulation and design loops were necessary before the conformal cooled insert could be produced. In the future, it is therefore vital to reduce these development times and costs, for example through automated optimization algorithms. The potential of conformal cooling is in any case very great and could make injection molding more efficient in the long term. ■

Technology from New Albea Provides Reliable Contact for Film-Heating

Heated Surfaces

Heatable, flexible surfaces are opening up interesting possibilities for industry. **New Albea Kunststofftechnik GmbH**, Seelbach, Germany, has launched a heating module that utilizes conductive wires or printed circuits embedded in polymer. This makes it the ideal solution for automotive applications, especially with regard to such hot topics as electromobility and autonomous driving. The technology can be used, e.g., not only to heat parts of the bodywork but, when combined with conductive paints, to heat interior surfaces as well. But it could readily find its way into other fields of application too.

A special feature of the film-heating technology is its flexibility. The thin film – containing embedded heating wires which are thinner than human hair – is just 0.25 to 0.37 mm thick and can be molded into 3D shapes. Alternatively, conductive printed surfaces or circuits can take the place of the heating wires. These allow the film to adopt the contour of the surface for heating and to be back-injected too.



Heating wires embedded in sheet film are thinner than human hair. This 3D contoured film was back-molded with polycarbonate (© New Albea)

Penetration by moisture is prevented by means of New Albea's patented contact method which keeps the outer layer of the film sealed. The connectors and contacts are available in different variants to suit customer requirements.

To keep systems functioning reliably in autonomous winter driving, it is essential that any surfaces behind which important sensors are installed remain ice-free. The heating module can be used to heat three-dimensional shapes and radomes without causing radar interference. The technology can also help keep the cabin at a comfortable temperature: as electric vehicles have no engine heat available for heating purposes, the heating film can be used to heat interior surfaces such as armrests and door panels.

To the product presentation:
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