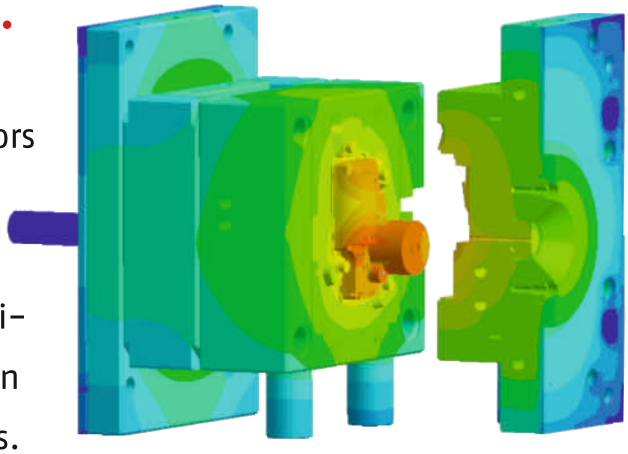
Process-oriented Injection Molding Simulation. Besides the part geometry, 3-D injection molding simulation now also takes into account other factors promoting the efficient design of injection molds and assisting process control during production. A case study makes clear the benefit of process-oriented simulation with the example of a decision in favor of a cooling concept tailored to requirements.



Properly Cooled by Design

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Currently, there are only a few plastics articles that are still developed without injection molding simulation, which usually focuses on predicting the filling pattern and part warpage. Nevertheless, the use of this software tool has reached a stagnation level. In the 20 years and more since injection molding simulation became established in the plastics industry, a general opinion about the benefits and reliability of simulation has become established in the industry. If we look more closely at this judgment, we can often see that it is the result of experience with conventional or 2.5D Hele Shaw-based approaches to simulation.

However, the state of the art has really moved on significantly from this. Besides plastics articles, all mold components, such as platens, cores, slides and ejectors, with their physical material properties, can now be modeled completely three-dimensionally, and therefore physically correctly, in the injection molding simulation. On this basis, the entire injection molding process can be described in detail, and its quality and energy efficiency assessed. These comprehensive possibilities are based on the three-dimensionally coupled simulation of transient heat transfer between the melt, mold and cooling system, and therefore a physically precise description of the interaction between the rheology of the polymer and the mold's thermal performance.

With this approach, known as "process oriented", an injection molding simulation using Sigmasoft (supplier: Sigma Engineering GmbH, Aachen, Germany) can register all the relevant influencing factors, such as the article, mold, hot runner and process control. This gives the user two advantages – increased accuracy and validity, together with a broader scope of applications.

The Mold Is Still a Mold

Both plastic parts and the associated injection molds are now developed using 3-D CAD. In this phase, detailed 3-D data of all the components relevant for the subsequent injection molding process are generated step by step. A conventional injection molding simulation only uses the article geometry from this data pool. The reason why only a limited set of the available data is used lies in the challenge of meshing complex 3-D CAD assemblies with volume elements. Simulation engineers well know how much work is required to generate such a consistent 3-D mesh. With conventional meshing techniques, users often required from many hours to several days of manual work to generate a computable mesh. Meshing times of this order are unacceptable for injection molding simulation.

However, the Sigmasoft program features a meshing technique that supports the entire product creation process step by step, and which, starting with the article geometry, successively inserts all the relevant components into the simulation. Generating a volume mesh for a complete 3-D CAD data set of an injection mold takes less than two minutes – without any finishing work. After over 25 years of steady development, automatic meshing is now robust enough to allow the user to concentrate on the essentials, namely the simulation results.

Multicycle Simulation: Closer to Reality

Once the entire mold can be modeled in the simulation, it no longer makes sense just to simulate one injection molding cycle. The potential of process-oriented simulation is rather to use the simulation of multiple sequential injection molding cycles to determine the thermal-rheological state of the mold during actual production. To achieve these production conditions, heating of the mold through multiple complete cycles (mold closing, injection, cooling, mold opening, demolding, mold closing …) is simulated, and the energy input and removal of the different components is simulated appropriately.

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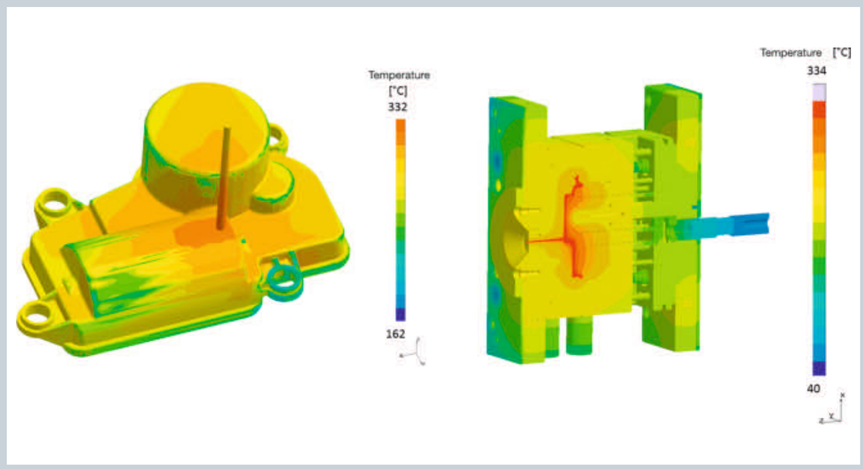

Fig. 1. Filling study of a housing design of PA66-GF50 (left). The process simulation, at the end of the filling phase in the 22nd production cycle in this case, illustrates the 3-D temperature distribution through the entire mold (right)

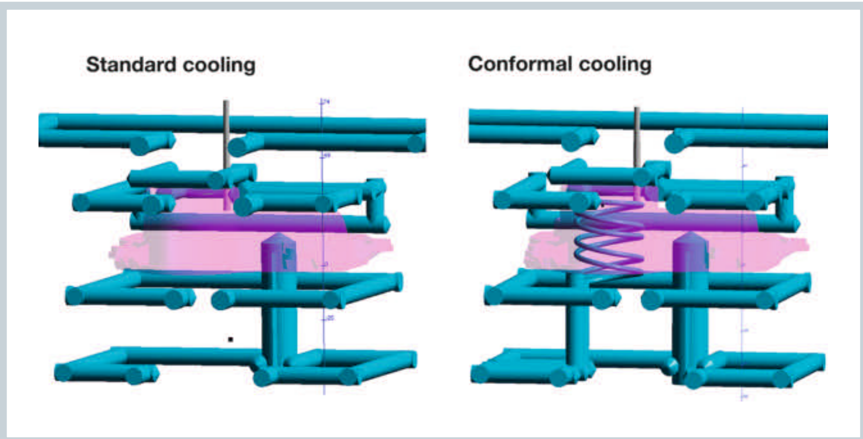

Fig. 2. Practical example: A process simulation allows the efficiency of alternative cooling concepts to be compared (figures: Sigma Engineering)

This makes it possible to determine, for example, how many starting cycles are used for the production start of a mold, or after a production interruption, in order to reach a steady state again – a simple approach for minimizing rejects. This method also illustrates the actual performance of the chosen cooling system, which can now be assessed in terms of cost efficiency, article quality and energy efficiency, as is shown by the following practical example.

Practical Design of the Cooling System

A typical housing application of PA66-GF50 **(Fig. 1, left)** illustrates the potential of process-oriented injection molding simulation with the selection of a cooling concept. The result of the simulation of a standard cooling concept is shown by the cutaway view of the entire mold, and, in colors, by the local temperature distribution at the end of the filling phase in the 22nd production cycle. The heat exchange between the article, mold components and cooling system can be clearly seen, as can the temperature profile in the mold resulting from the transient heat transfer **(Fig. 1, right)**.

After approval of the part design, the development team was confronted with the question of whether a standard cooling system is sufficient for efficient cooling of the part, or whether conformal cooling improves the cycle time, part quality and energy efficiency. There are currently many conformal cooling systems on the market, and, without process-oriented injection molding simulation, it is difficult to quantify the advantages in advance.

In a first step, two alternative cooling concepts were therefore drafted and compared **(Fig. 2)**. Process simulation with Sigmasoft was carried out to analyze and evaluate the performance of the respective mold design, and provide facts to support the decision for the most suitable cooling system.

To assess the cooling systems, 15 successive injection molding cycles for the two models were simulated. A comparison of the temperatures at the stationary mold half shortly before the end of the filling phase makes it clear that the mandrel-shaped mold core in the foreground is only poorly cooled by the simple cooling concept **(Fig. 3, left)**. Here, the temperatures at the core surface are between 130 °C and about 142 °C, which prolongs the solidification time at these points, and therefore the cycle time as a whole. The solution with conformal cooling **(Fig. 3, right)**, on the other hand, shows a more homogeneous temperature distribution over the entire mold cavity with temperatures on the core surface of about 95 °C, which reduces the solidification time by up to 23 % **(Fig. 4)**.

The differences in the part solidification are illustrated by colored regions, which indicate hotspots in the part **(Fig. 5, top)**. At these points, the polymer stays fluid for longer than at the surface, and in particular longer than in adjacent part regions. In the comparison of the two results, the sig- →

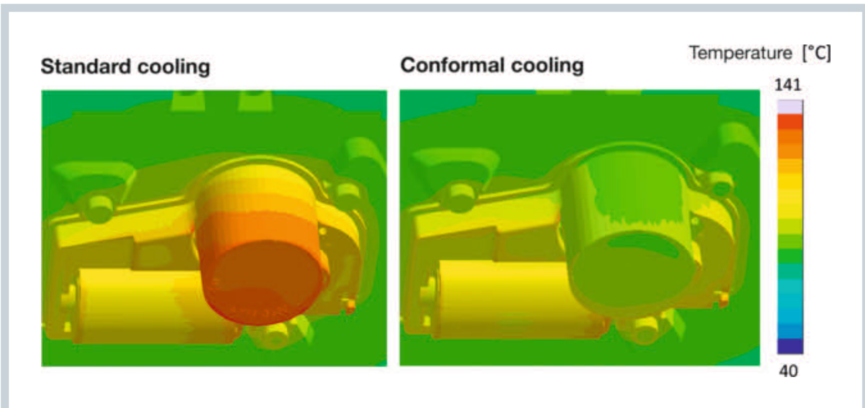

Fig. 3. The evaluation at the stationary mold half at the end of the filling phase after 15 production cycles shows a more homogenous temperature distribution throughout the mold cavity for conformal cooling

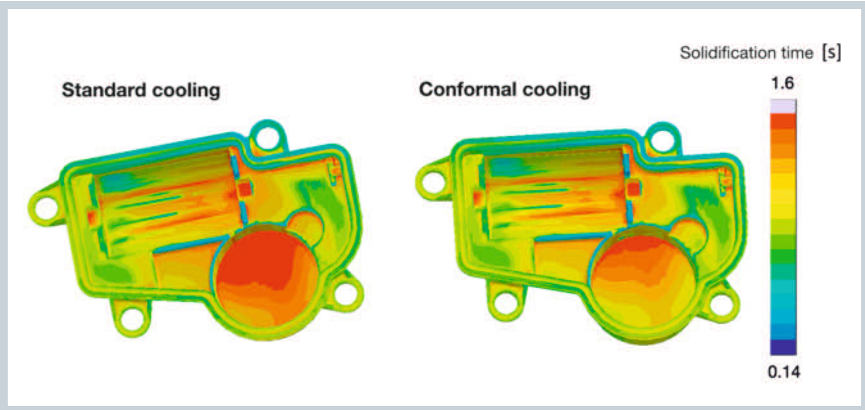

Fig. 4. Conformal cooling reduces the solidification time by almost a quarter compared to the standard system

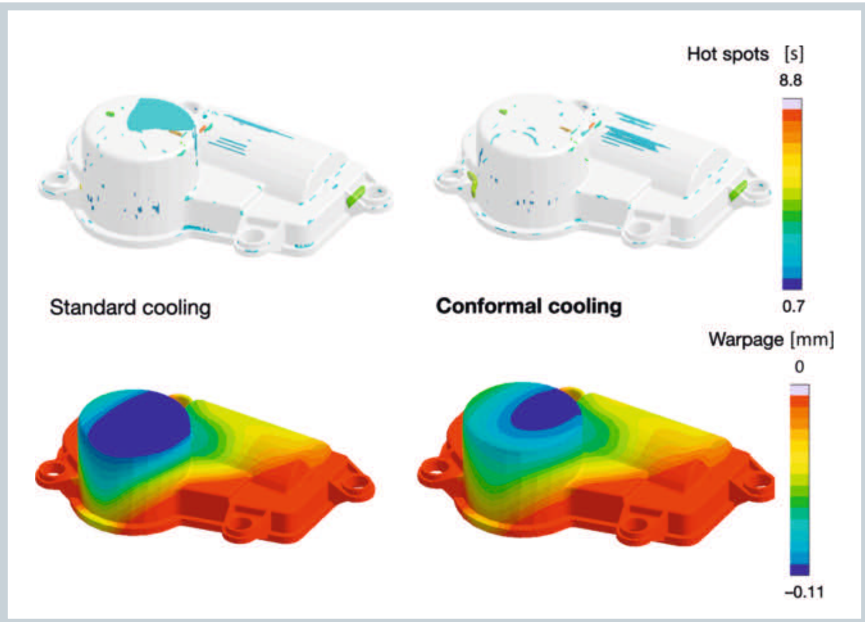

Fig. 5. The part quality is affected by the choice of cooling concept. Simple cooling shows more hotspots (top), recognizable by the colored areas, and worse warpage (bottom) than conformal cooling

nificantly more voluminous hotspots that occur in the mold with standard cooling are immediately conspicuous. With the simple cooling concept, liquid regions can actually still be found after 2 s cooling time.

In this application, conformal cooling reduces the cycle time as well as the warpage **(Fig. 5, below)**. Although for a polymer reinforced with 50 % glass fibers, the fiber orientation clearly dominates the warpage, the differences in the mold temperatures still show an effect. More homogeneous cooling reduces internal tensions in the region of the core, and improves the warpage behavior at these points by up to 13 %.

Evaluation of the Energy Efficiency

Besides the cycle time and article quality, energy efficiency is also increasingly becoming a determining issue. If the heat balances of the two cooling concepts are compared, it can be read from the curves how much heat (in kJ) per cycle is exchanged in the mold **(Fig. 6)**. The melt introduces energy into the mold; the mold platens lose energy to the surroundings, and the cooling systems are required to bring the entire energy balance into equilibrium by absorbing and emitting energy. Over time (multiple cycles), the absorbed energy becomes smaller. If this decrease stabilizes, the mold has reached the quasi-stationary thermal state, and production can begin.

The curve profile proves that the energy requirement for heating the mold with the simple cooling concept is greater than with conformal cooling. Conformal cooling achieves an asymptotic energy absorption at a comparatively early stage – after about eleven cycles – while simple cooling is still not stable even after 15 cycles. Conformal cooling thereby consumes less energy overall in this case, and production can start earlier.

Summary

Injection molding simulation is no longer only limited to the part development phase, but can also act as an effective aid in the subsequent development phases, and provide detailed information for supporting many decision-making processes during mold development, trial moldings, identification of process windows and troubleshooting during production. The application example clearly shows how conformal cooling has been quantitatively analyzed based on an integrated consideration of the results, and it can be assessed at an early stage whether the extra costs are worthwhile. ■

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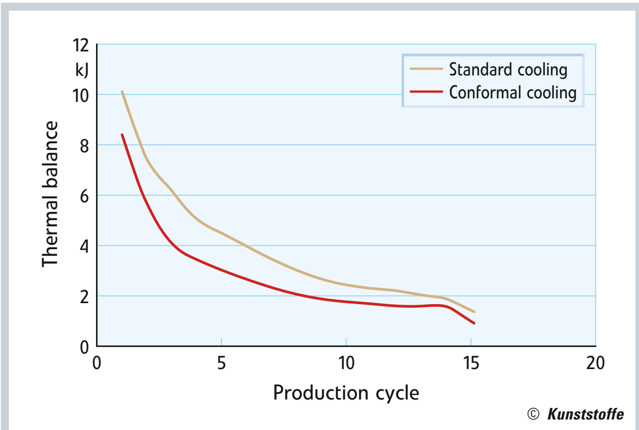

Fig. 6. Energy balance over the first 15 production cycles. The curve profile proves that the energy requirement for heating the mold with the simple cooling concept is greater than with conformal cooling

