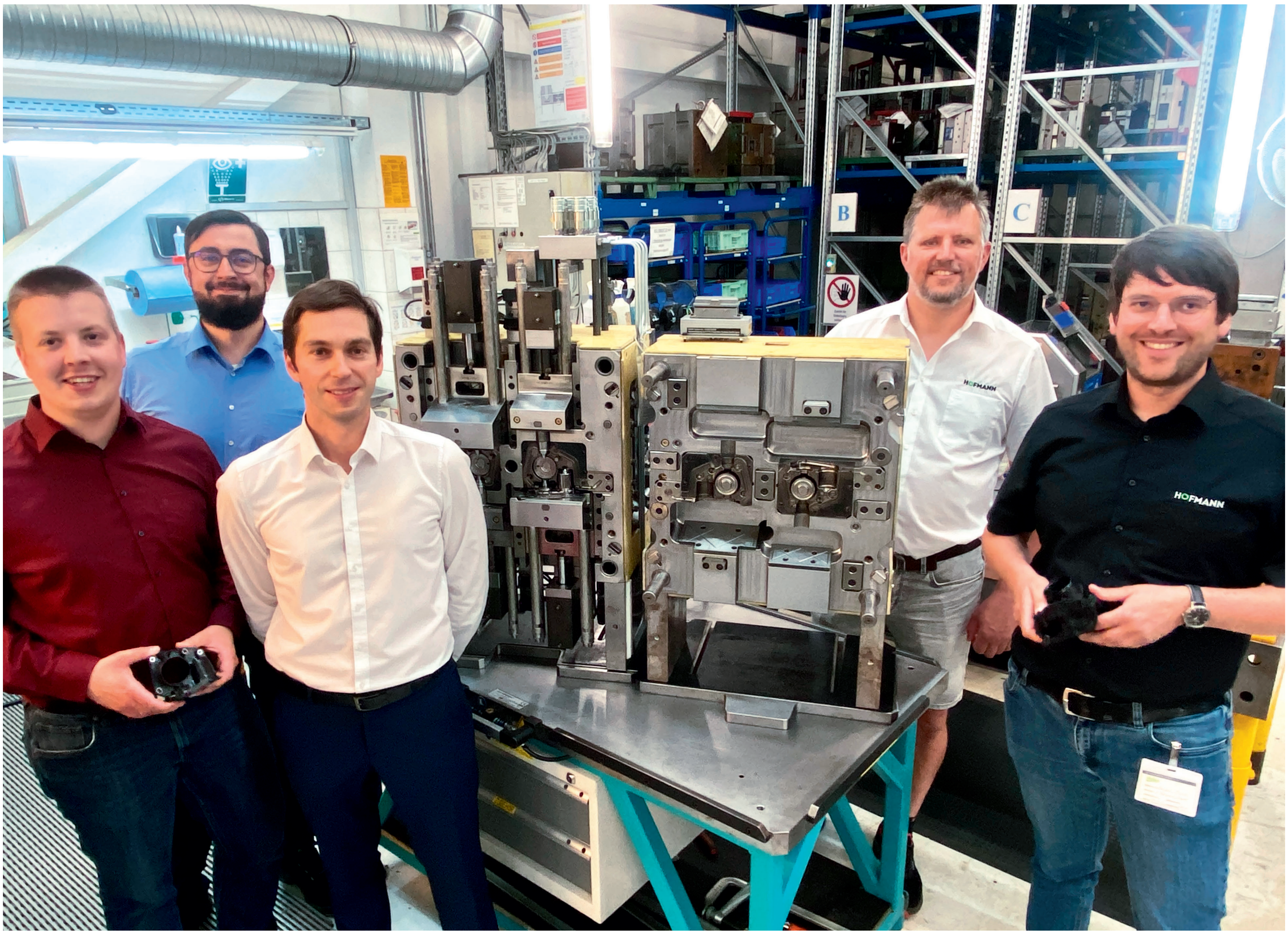

In the center of the image, the two halves of the injection molding tool can be seen. The inner cavities were created by additive manufacturing. The contributors from left to right are: Nicolas Büttner, Dominik Lawatsch, Dr. Sebastian Neubauer (all Valeo), Christian Hellmuth, Michael Vosswinkel (both Hofmann). Pawel Uchyla (Valeo) is missing. © Valeo/Hofmann

Housing Made of Fiber-Reinforced Polybutylene Terephthalate (PBT)

Additive Manufactured Mold Cavity Increases Production Efficiency

Based on simulations and prototype production, the influence of an additive manufactured injection molding tool cavity on the manufacturing process was investigated. Due to the improved cooling performance, the cycle time can be reduced by approximately 10 %, whereas at the same time, a high dimensional stability of the polybutylene terephthalate (PBT) component can be achieved.

The automotive powertrain is undergoing a groundbreaking transformation. It is driven forward by ever stricter thresholds of pollutants and carbon dioxide emissions for future cars, aiming to countermeasure the global climate change and to meet sustainability targets [1]. Taking this into account, the energy efficiency of a modern vehicle represents a key engineering priority towards e-mobility.

Metal Substitution for the New Mobility

In the Valeo project involving Siegfried Hofmann GmbH as supplier, the aim was to improve the manufacturing process of a housing for an electromechanical actuator. As a first step, an adapted design was developed to replace the previous aluminum material by a PBT filled with 45 % glass fibers. This alone resulted in a weight reduction of the housing by approximately 35 %, which in

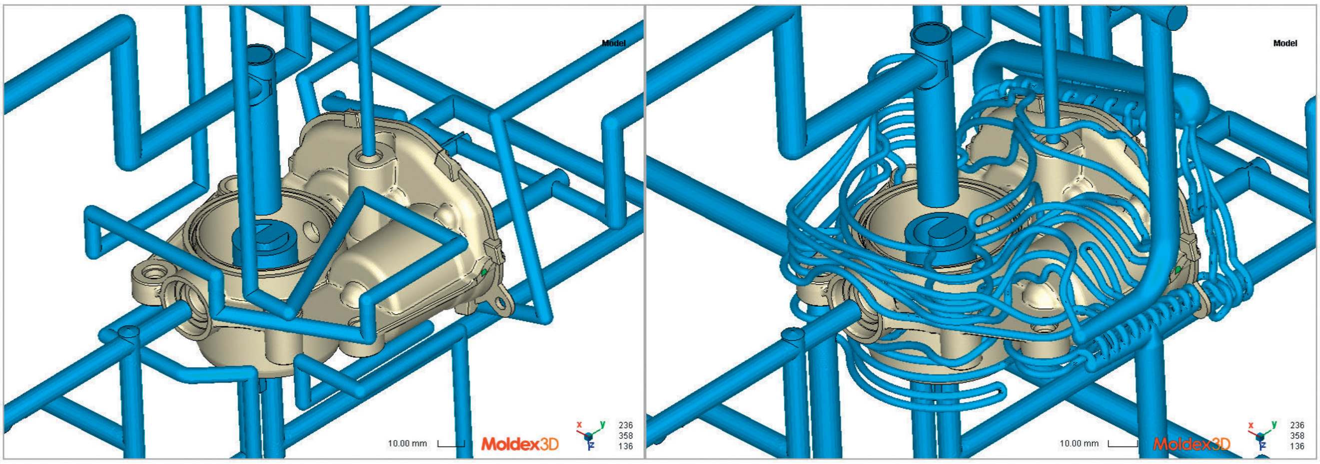

Fig. 1. Left: conventional cooling (blue) and component (beige). Right: conformal cooling channels from additive manufacturing and component.

turn positively contributes to the energy savings of the vehicle. The present study compares rheology simulations among each other and refers them to prototype parts in advance of series production. The function of the end product itself is the regulation of gas flows, as it can be used in the turbocharging of modern hybrid vehicles or for those equipped with fuel cells.

The detailed simulations on the rheology and cooling behavior of the plastic were carried out before and during molding tool design. Conventional and conformal cooling of the component were compared. The subsequent dimensions of the molding tool including typical preholds were taken into account.

Conformal Cooling from Additive Manufacturing as the Method of Choice

In the past, this type of housing was made by aluminum die casting in order to, for example, achieve a certain level of media resistance and the required dimensional precision. The latter is associated here, among other things, with a tolerance of ± 0.1 mm on a diameter of 48 mm and a position tolerance of 0.2 mm on a length of 78 mm. For gas supply applications and therefore lower necessary chemical resistance, aluminum could now be replaced by a thermoplastic. Due to the high demands on dimensional accuracy and the goal of optimizing economics, a large part of the molding tool cavity was designed as an additive manufactured contour including a cooling close to the contour in order to increase the cooling performance [2]. The selected SLM process allows the cooling geometries to be guided much closer to the surface than by conventional manufacturing of the channels by milling or deep drilling. In addition, the density of the cooling channels can be increased and otherwise inaccessible areas can be accessed. The more uniform cooling is expected to lead to a lower warpage tendency and a shortened cycle time. The corresponding 3D models used in the simulations are shown in **Figure 1**. The conventional cooling is depicted on the left side and conformal cooling on the opposite side. On this right side, a clearly increased packaging of the cooling channels around the component can be seen.

Highest Dimensional Accuracy as a Must for Metal Replacement

The dimensional quality of the first off-tool parts is predicted from the simulation data. The position tolerance between the centering of the electric motor, an intermediate gear and the axis of the flap are in the center of interest. These axes define the kinematics of the product by transmitting the motor torque to the flap. The system ensures a rotation of the flap by up to 90°, which can thereby minimize and maximize the airflow within 65 ms. The tolerance chain of the axes to each other should ideally not exceed 200 µm. For the variant of conformal cooling, this result is achieved within the faster cooling time.

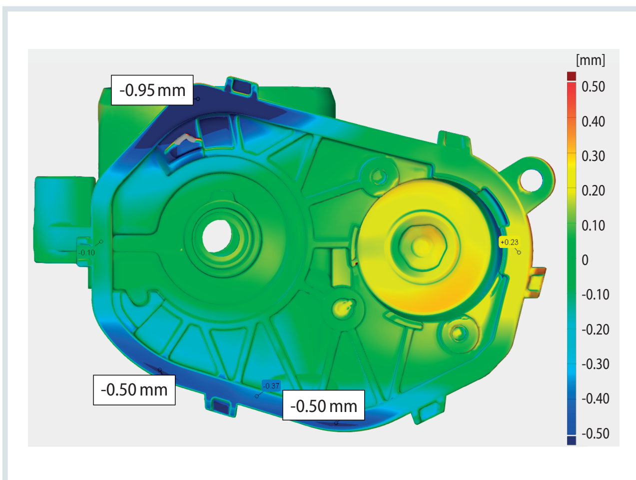

Fig. 2. Top view of the housing. The warpage of the component after simulation with conformal cooling at the interface to the cover is visualized.
Source: Valeo/Hofmann; graphic: @ Hanser

In the next step, the planarity of the interface to the subsequent compo- »

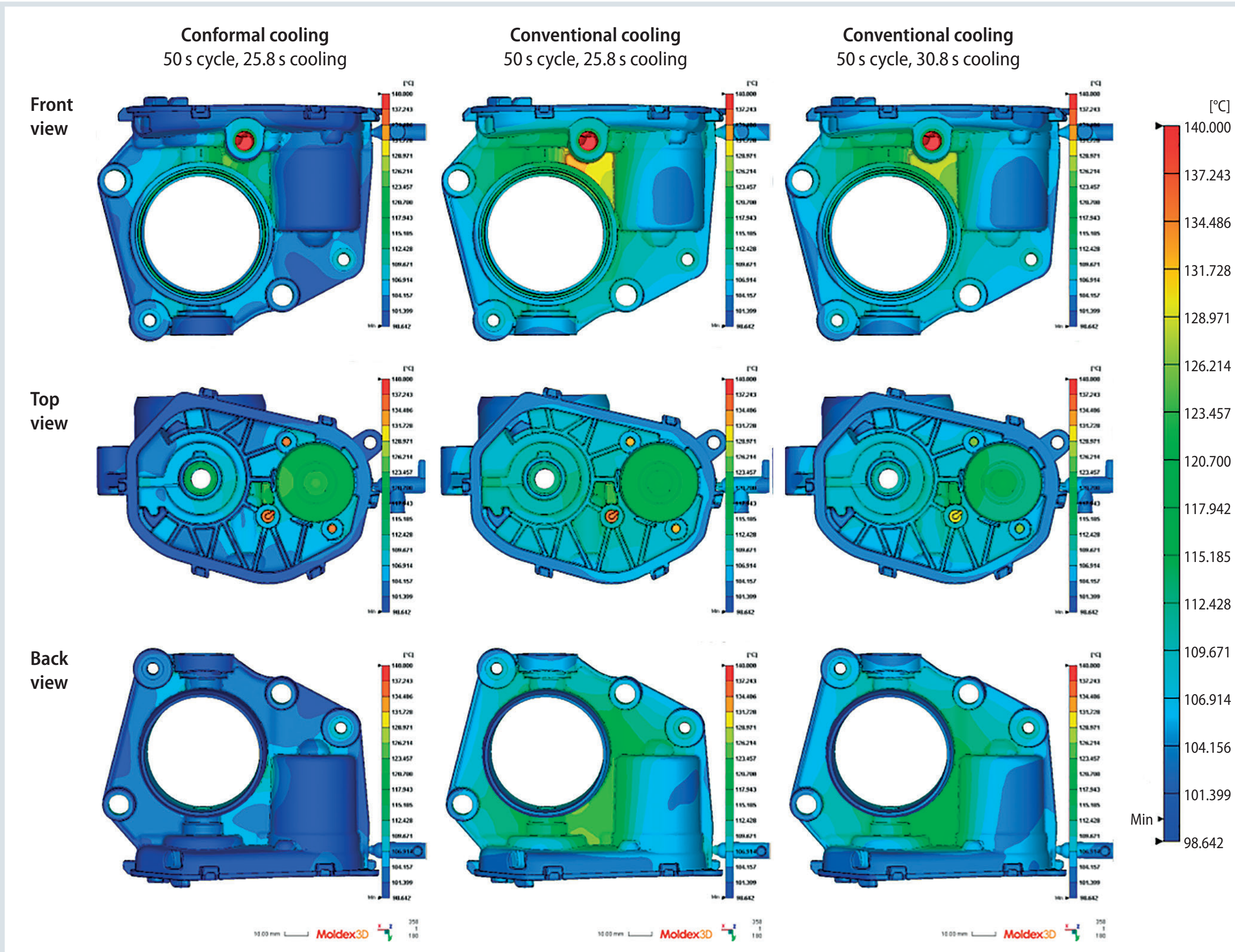

Fig. 3. Comparison of surface temperatures at the end of the cycle for different cooling methods. Source: Valeo/Hofmann; graphic: @ Hanser

nent cover is evaluated. The cover contains a complex overmolded leadframe structure, a circumferential seal and counterparts to the above mentioned kinematic axes. The planarity tolerance is maximum 0.35 mm, with a maximum tolerance of 0.20 mm between two fastening points. **Figure 2** represents the warpage after using the conformal cooling. The area with the largest distance to the gating point shows a warpage of 0.95 mm. Whereas in the conventional cooling approach, a warpage of 1.05 mm is generated here, which is 100 µm higher. Regarding the warpage figures on the bottom of the image, conventional cooling performs 30 µm worse than conformal cooling.

The prototype production using conformal cooling confirms these good results for the planarity of the first off-tool parts. The planarity deviation between the fastening points is 0.068 mm, and 0.348 mm over the entire surface.

Increasing Cooling Performance for Higher Production Efficiency

The focus of the investigations is given to the comparison of the methods with regard to their cooling performance. **Figure 3** illustrates the surface temperature of the part at the end of the cooling time. Three views of the part are shown. The left column of the figure spotlights the conformal cooling, the middle column the conventional cooling and the right column presents the conventional cooling including extended cooling time by 19 % (5 s). The pronounced appearance of the blue areas in the left column clearly shows the cooler averaged surface temperature of the part with the conformal cooling method.

In the top view, an approximately 10 °C higher surface temperature of the component can be observed with conventional cooling, which even the extension of the cooling time cannot equalize. The higher cooling power causes less intrinsic stresses in the component and less free crystallization, which would result in an increased warpage after ejection of the component.

In the front and rear views, an approximately 10 °C colder surface temperature is determined in the area of the engine mount. Nevertheless, a hotspot is identified in the area of a screw dome in the front view. This hotspot prevents an even bigger reduction of cooling time and thereby a cycle time below 50 s, because otherwise unsolidified plastic would stick to the cavity in this hole during the ejection of the component which leads to delamination.

The difference in the cooling performance of the two technologies is examined more precisely in **Figure 4**. The higher heat flow of the hot melt into the conformal cooled cavity is clearly visible here. The selected measuring point is at the backside of the hotspot mentioned. The curves are congruently overlapping up to approximately 10 s of the cycle, which in the process corresponds to the injection and packing phase. Beginning from this point in time, the difference in cooling performance becomes significantly noticeable in the divergence of the curves per cooling technology. The largest difference is a delta of 7 °C at the time of the assumed mold opening at 40 s in the simulation. The heat flux measured at this point is 1.7 $Js^{-1}cm^{-2}$, which means a 14 % higher value for conformal cooling compared to conventional cooling.

Gentle Material Treatment while Faster Processing

Due to the increased heat flux, a potentially suppressed crystallization and the associated possible post-crystallization could not be ruled out. With the aid of DSC analyses of various locations on the component, this possible effect was checked. No restructuring events could be detected during the entire heating process up to 240 °C. Especially in the range up to 140 °C, which corresponds to the maximum operating temperature of the component, all possible anomalies were excluded here. Furthermore, a viscosity number measurement was carried out on the component. The degradation of the polymer at the end of the flow path was kept at a low and completely acceptable level with a 4 % change in the viscosity number, mainly due to a gentle processing and a sufficient drying of the material.

The capability of the prototype parts was additionally verified in order to demonstrate the robustness of the process. Among other things, the main diameter was evaluated. With a nominal value of 48 mm and a tolerance band of ± 0.1 mm, a Cmk value > 2.00 could be confirmed here.

Successful Realization of the Project

The conformal cooling from additive manufacturing presents itself as the preferred technology for the project shown. With appropriate utilization of the tool, the increased tool costs are amortized by the increased production efficiency of the process. At the same time, the necessary product quality is maintained when replacing metal and a stable process is achieved. ■

Fig. 5. Picture of the finished component: the housing of an electromechanical actuator made of PBT. It is lighter by 35 % compared to aluminum in this design. © Valeo/Hofmann

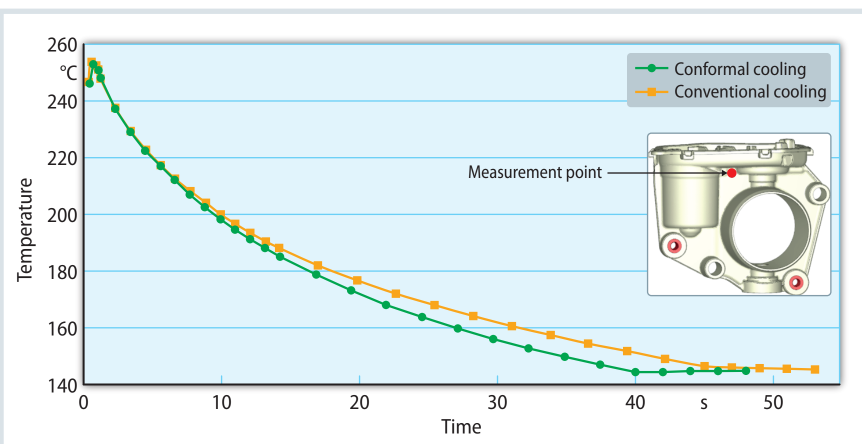

Fig. 4. Comparison of the surface temperature at the back of the hotspot for conformal and conventional cooling. Source: Valeo/Hofmann; graphic: @ Hanser

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References & Digital Version
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