Digital Preview of Bio-Based Parts

Injection Molding Simulation Puts Bioplastics on the Road to Industrial Mass Production

It is difficult to use bioplastics in engineering parts due to a lack of processing data. However, these data are very important for making a change from conventional to bio-based plastics. They are essential for simulating process parameters and designing injection molds for economical processing.

Injection molded plastic parts are used in all areas of life and command a correspondingly high market volume. This processing method is very important if a manufacturer wants to establish a new plastic on the market. The machines and process engineering place high demands on the material to be processed. Therefore it is therefore difficult to deploy new materials such as bioplastics for existing applications. These cases often involve a material substitution, in which existing molds designed for the original material must be used. This is just as true for bioplastics as for conventional plastics.

The simulation of bio-based plastics was tested on the housing of a PC mouse. Starting from material data and commercially available simulation software, process parameters were determined (© IfBB)

In addition, key material data and the empirical values obtained by working with the materials are often lacking for bio-based polymers. Processors therefore face serious challenges due to, e.g., deviations in shrinkage and warpage properties, a different filling pressure requirement or unknown cooling and demolding times for material exchange. Even with an injection mold newly developed specifically for bio-plastics, serious processing problems can result in the absence of empirical values and material data.

The injection molding simulation avoids these problems for bioplastics, too. However, this presupposes that the specific material data are available for calculating the filling and holding pressure phases or warpage. The Institute for Bioplastics and Biocomposites at Hanover University of Applied Sciences (IfBB) together with UL International TTC GmbH (UL TTC), Krefeld, Germany, and Simcon kunststofftechnische Software GmbH, Würselen, Germany, aims to close this gap for commercial bio-based plastics (**see Box p. 49**).

To determine valid material data for the injection molding simulation, the accredited material test lab UL TTC falls back on many years of experience in the processing and testing of thermoplastics. This also allows it to fully characterize novel materials such as the bioplastics investigated here. All the thermal, rheological and mechanical data used in this work were determined by the UL TTC. The material data of the eight bioplastics investigated are subsequently incorporated into the simulation software Cadmould 3D-F.

Feasibility simulations should be performed to determine in advance whether the plastic can be processed in an existing mold that is designed for a plastic with minimum warpage. From this, machine setters should be able to predict the processability and obtain a firm starting point for the machine setting. These simulations have been performed for eight bioplastics (**Table 1**). The simulated warpage of all the investigated bio-based plastics is illustrated in **Figure 1**, and shows clear differences.

Compatibility of Bioplastics for Series Applications

The studies on an industrially manufactured series part were performed on the housing of the computer mouse "The Fair Mouse" from Nager IT e.V. [2]. The mold is available to Simcon as a CAD dataset for the simulation, on one hand, and, on the other, to the IfBB for verification of the simulation based on actual injection molding trials. In this series of studies, the comparison of the simulation with reality is performed exemplary based on polylactide (PLA) Ingeo 3052D (manufacturer: Nature Works LLC, Minnetonka, MN/USA). Before processing, it was dried to a water content of below 200 ppm. On one hand, PLA is one of the most widely used bioplastic grades, on the other, the properties, such as shrinkage and warpage, deviate significantly from the properties of the original material (mold design on materials with 0.2 % shrinkage such as ABS). This is a challenge both for simulation as well as for the actual injection molding, and serves as a test of the processability of the determined material data that are used in the simulation.

First, with the aid of the Cadmould 3D-F software, it was ensured that the PLA was processable by supplying the initial setting parameters for the injection molding machine. For this, recourse was made to values of the processing window proposed by UL TTC, which are to be validated within the scope of these studies. However, a process optimization with the aid of simulation was not performed at this stage yet. Modules implemented in the software for thermal, filling, holding pressure, shrinkage and warpage are used. This made it possible to provide information about fillability, balancing, filling pressure demand, clamping force, warpage, shrinkage as well as the demolding time. In **Figure 2**, based on this simulation, the flow-front temperature of the investigated PLA is modeled. Here, the strong cooling in the keys of the computer mouse can be seen, which can be expected to lead to filling problems and correspondingly to poor part qualities.

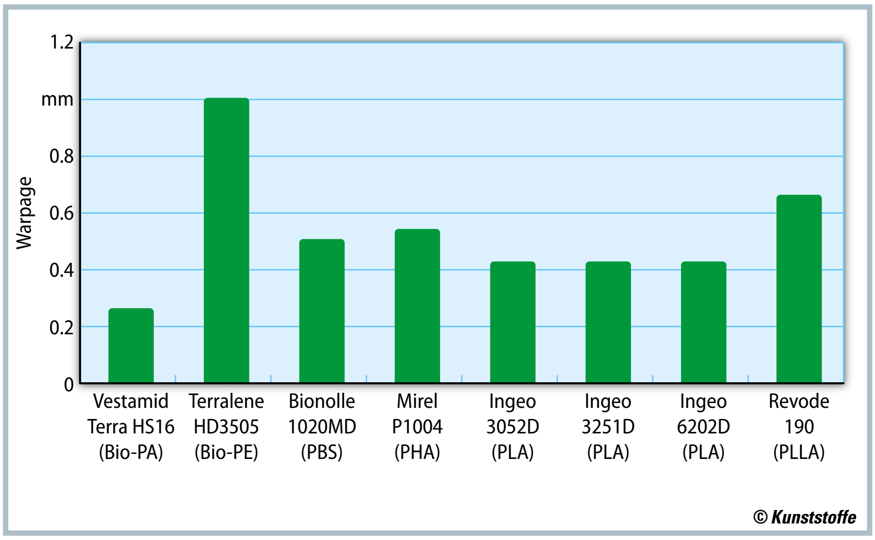

Fig. 1. The simulated warpage shows very significant differences for the investigated bioplastics. This material behavior is one of the big challenges for simulation (source: Simcon)

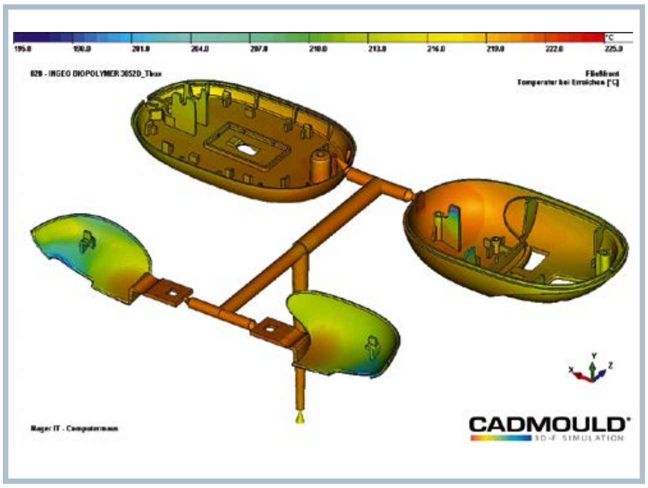

Fig. 2. In the simulation of the flow-front temperature, filling difficulties can be seen by the strong cooling of the melt in the keys (© Simcon)

Simulation versus Reality

To compare the simulation with the actual process, the processing parameters of the simulation (**Table 2**) are then transferred to an injection molding machine (type: Allrounder 720 S, manufacturer Arburg GmbH + Co. KG, Lossburg, Germany) and injection molded to form the housing of the "Fair Mouse". Based on the obtained parameters, it was possible, from the start, to obtain completely filled parts from the injection molding machine. However, as expected, the injection molded housing of the computer mouse is not yet ready for series-production. As predicted by the simulation, it has undulating structures on the surface due to an unfavorable flow front and strong warpage (**Fig. 3**). In addition, a demolding spray is necessary due to the different shrinkage properties and the warpage also prevents demolding.

To make the part quality as close as possible to series production and ensure that the injection molding process is fully automated, the process parameters must be adapted. For this purpose, a filling study is performed first, in which simulation and reality correspond well with one another. It shows the predicted, uneven balancing of the mold at the changeover point to the holding pressure phase at 97 % filling (**Fig. 4**). This can be explained by the fact that the keys are filled later »

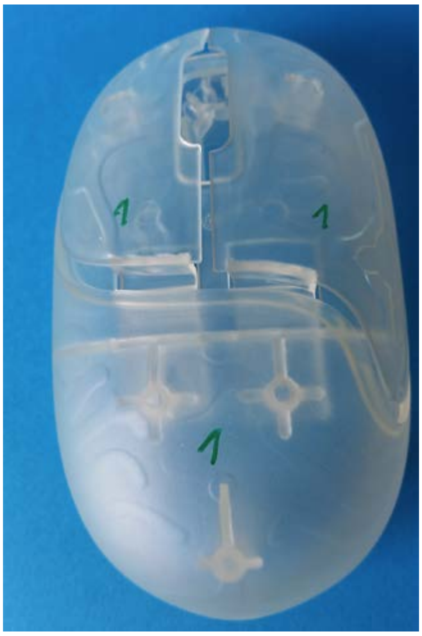

Fig. 3. In the first step, it was only investigated whether the simulation agreed with practice, without process optimization. Undulating structures and strong warpage occur at the surface of the material (© IfBB)

than the upper and lower shells. The important factors here are the set pressure and injection velocity. Another aim is to improve the flow front of the melt so as to avoid the undulating structures in the material. The adjustment of the residual cooling time is necessary, since otherwise impressions of ejectors are imprinted in the still incompletely cooled housing during injection. Here, where holding pressure has not yet been applied, the adjusted parameters already significantly improve the quality in the part. Once again, this is improved after the holding pressure is engaged. Acceptable parts can thereby be produced in fully automated mode in near-series quality. The **Title figure** shows the housing of the "Fair Mouse," which was produced with the adjusted parameters.

Lower Mold and Demolding Temperatures Used

Together with its partners in this series of investigations, the IfBB was able to demonstrate that, with a suitable data basis, bioplastics can be simulated for injection molding. The tests also showed that, the process parameters chosen for the feasibility study by simulation for the PLA used must be reduced as regards the mold and demolding temperatures. PLA

Material class	Manufacturer	Type
Bio-PA	Evonik	Vestamid Terra HS16
Bio-PE	FKuR	Terralene HD 3505
PBS	Showa Denko	Bionolle 1020MD
PHA	Metabolix	Mirel P1004
PLA	Nature Works	Ingeo 3052D
PLA	Nature Works	Ingeo 3251D
PLA	Nature Works	Ingeo 6202D
PLLA	Zhejiang Hisun Biomaterials	Revode 190

Table 1. List of the bioplastics investigated. The tests with Ingeo 32052D are presented in greater detail in the article (source: IfBB)

Process parameters	After simulation	After process optimization
Melt temperature	220 °C	200 °C
Mold temperature	50 °C	20 °C
Demolding temperature	70 °C	
Required max. injection pressure	727 bar	1300 bar
Injection time	1.5 s	4 s
Holding pressure changeover	97 %	
Holding pressure time	7 s	
Holding pressure	500 bar	
Residual cooling time	21 s	36 s
Cycle time	35 s	

Table 2. The injection parameters from PLA Nature Works Ingeo 3052D from the simulation and after the process optimization. Since the bio-based copolymer has a low crystallization rate, a lower mold temperature should be set in practice (source: Simcon/IfBB)

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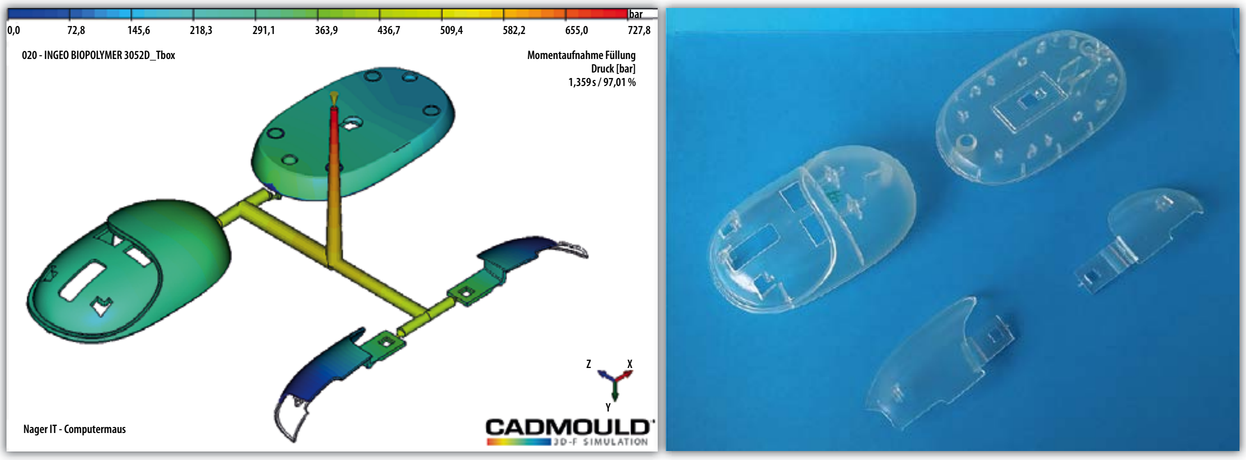

Fig. 4. Simulation (left) and practical result (right) of a process, in which there is changeover to holding pressure at 97 % mold filling. The keys are not completely filled in the front region (© Simcon/IfBB)

copolymers that are designed for, among others, injection molding applications such as the PLA Ingeo 3052D investigated here, have an amorphous character and, compared to PLA homopolymers, have a lower crystallization rate [3]. They therefore do not require recrystallization at high temperatures in the mold. Thus, the mold temperature control of Ingeo 3052D, whose T_G is at 57.5 °C [4], should be set significantly lower [5], which additionally shortens the cycle times. This shows that simulation of bioplastics also involves other factors that must be researched and improved. For the eight bio-based plastics investigated here, IfBB, UL TTC and Simcon identify the material-specific idiosyncracies. So that the simulation can be used to perform reliable process optimization. The specifics of the material are also integrated into the simulation software by means of modified processing recommendations.

Outlook

The opportunities for employing bioplastics should therefore not be reduced by the fact that adequate material data are not available for processing them reliably. This requires material manufacturers to close this information gap and provide extensive, reliable material data. With a sufficient material data basis, it is possible to realistically simulate the injection molding of bioplastics. This was to be expected, since the processing of thermoplastics does not address the question of whether a bioplastic or petroleum-based polymer is processed. However, here, too, it was found that extensive, detailed, and first and foremost correct material data are very important for the simulation. In addition, further research is necessary to identify the key factors for the simulation of bio-based and biodegradable plastics. ■

Processing of Bioplastics

This work is based on a research project on the topic of "Processing of Bioplastics" funded by the German Federal Ministry of Food and Agriculture (BMEL) under the project sponsorship of the German Agency for Renewable Resources (FNR) [1]. The project was performed together with the partners Fraunhofer IAP (Institute of Applied Polymer Research), SKZ (The South German Plastics Center), SLK (Chair of Lightweight Structures and Plastics Processing at the Technical University of Chemnitz) und M-Base Engineering + Software GmbH, Aachen, Germany.
The extensive results were generated in many current areas of bioplastics processing. The results have been entered into both the bioplastics database of M-Base and IfBB's own information platform and are freely available at:
- www.materialdatacenter.com
- www.biokunststoffe-verarbeiten.de