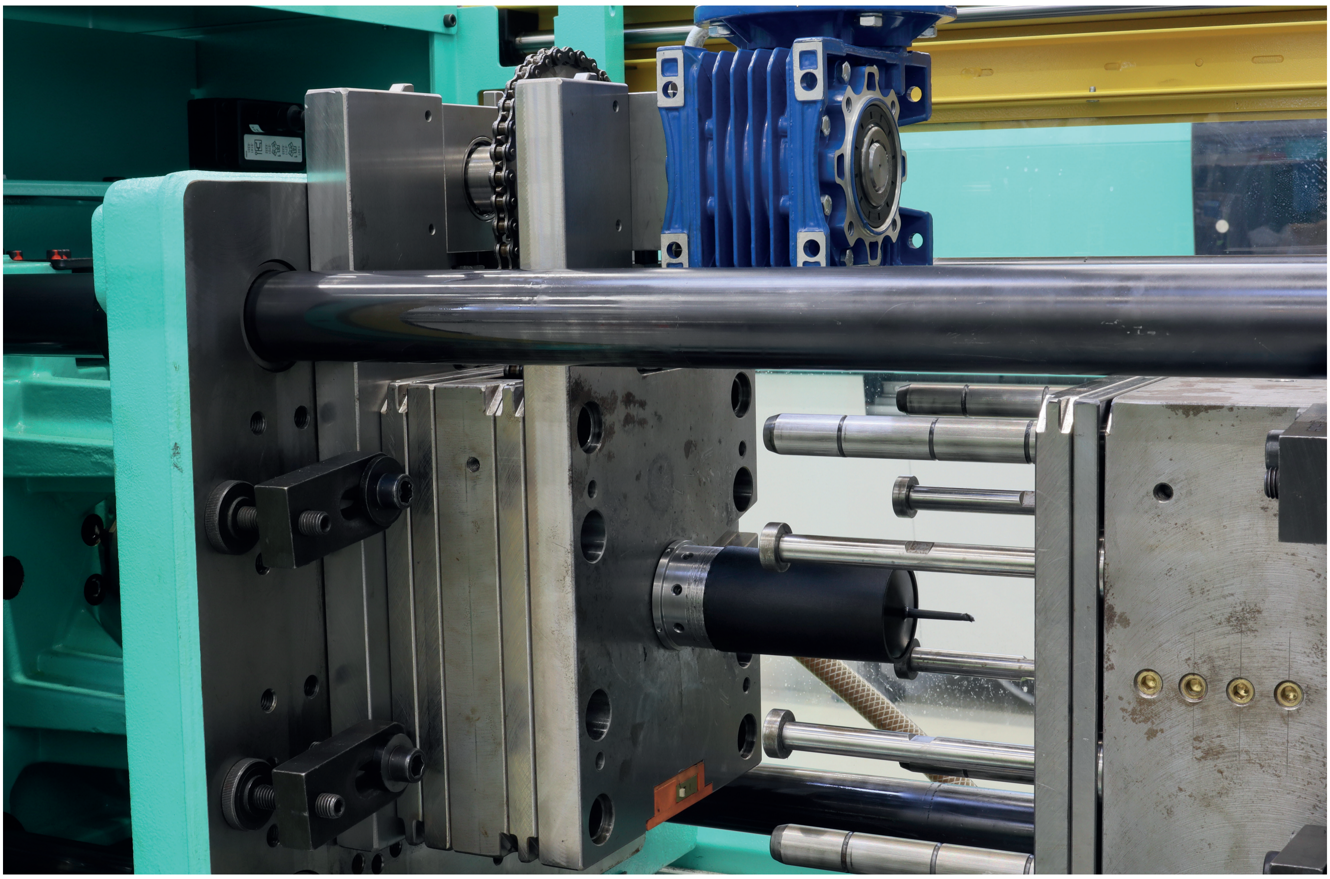
Mold System with Rotating Core Improves Mechanical Properties

Design Methodology for Parts Subject to Internal Pressure

Internal pressure loads are typical for fiber-reinforced plastic components. To increase the burst strength of components, the fiber orientation can be modified in a targeted way during injection molding by means of a rotating mold core. A newly developed simulation method allows this modified fiber orientation to be taken into account at the design stage.



Practical implementation of a mold system with rotating core. © University of Osnabrück

During injection molding of fiber-reinforced polymers, the prevailing flow conditions create a layered structure in which the fibers are oriented in the flow direction at the outer region and transverse to the flow direction in the core [1, 2]. The resulting anisotropic mechanical properties lead to a part stability that is dependent of the position of the gate point [3]. Elongated, rotationally symmetrical parts under internal pressure load are usually filled in the axial direction due to manufacturing restrictions, and most of the fibers are therefore oriented in this direction. However, the internal pressure load leads to stresses in the tangential direction – the fiber orientation and the main loading direction therefore differ and the material is not optimally utilized.

This is where the mold system with rotating core (**Fig. 1**) comes in [4–6]. Due to the relative movement in the mold, the rotation of the mold core leads to shearing of the melt in the tangential direction. This shearing is superimposed on the injection-induced shearing in the flow direction and allows the reinforcing fibers to be reoriented – depending on the ratio between that shearing

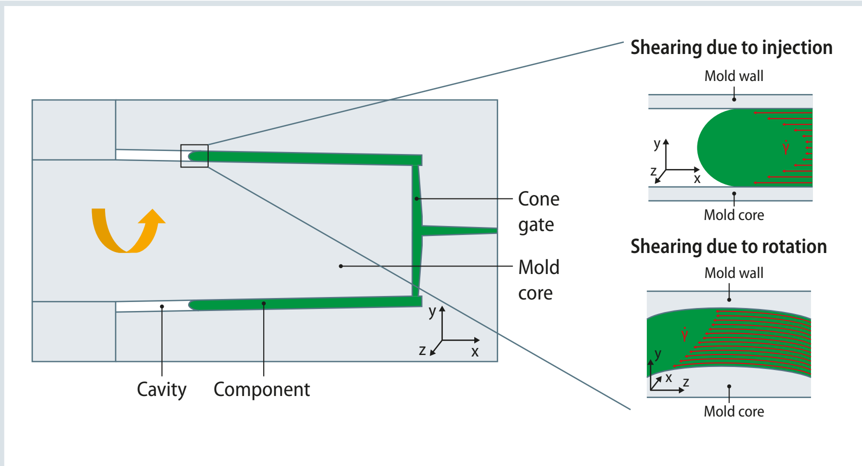


Fig. 1. The superimposition of the injection-induced axial shearing by the tangential shearing due to the rotation selectively influences the fiber orientation in the tangential direction due to the rotation. Source: University of Osnabrück; graphic: © Hanser

induced by injection and that by rotation. This influences fiber orientation so as to have a positive effect on the mechanical properties and improve the burst strength [6, 7].

In order for the potential of this manufacturing process to be exploited, the fiber orientation must also be taken into the structural simulation. In the state of the art [8], the fiber orientation from the injection molding simulation is used as an input parameter in the design of short fiber-reinforced components for calculating the anisotropic properties. In the mold system with rotating core, this is not possible because it is not yet possible to simulate the influence of the relative motion on the fiber orientation. The plastics-CAE and fiber composites lab at the University of Osnabrück, Germany, in cooperation with RIA-Polymers GmbH, Zimmern o.R., Germany, and Helmut Sundermeier GmbH, Hüllhorst, Germany, have developed a design methodology that uses the measurement data for fiber orientation to allow an initial estimation of the part properties.

Measurement of Fiber Orientation

To quantify the effect of rotation on the fiber orientation, the cup-shaped demonstrator (**Title figure**) with a length of 100 mm, an outer diameter at the end of the flow path of 57 mm and a variable wall thickness between 1.5 and 3.5 mm was investigated at varying rotational speeds. Here, the mathematical description of the fiber orientation is performed via the fiber orientation tensor [9], which can be determined, e.g., by evaluating microscopic photographs [10, 11]. The fibers in these sections are visible in the polished surface as ellipses, whose form depends on the orientation of the fibers in space. The principal axes and the tilt angle of the ellipses can be determined with image analysis algorithms, and used for calculating the orientation tensor. This microsection method was used to analyze the fiber orientation in the flow path center, and to determine the average orientation components, as well as the orientation profile across the wall thickness.

In a short fiber-reinforced polypropylene (PP-GF50, grade: Rialene P100 SGF50; manufacturer: RIA Polymers), the tangential degree of orientation can be significantly increased with increasing rotational speed (**Fig. 2 left**). With a wall thickness of 2.5 mm, it is possible to increase the tangential degree of orientation from 0.32 to 0.73. In the profile through the relative wall thickness (**Fig. 2 right**) it can be seen how the local microstructure changes. For unrotated samples, the familiar layer structure, consisting of outer and center layers, can be clearly seen. For a rotation of 0.95 s^{-1}, the center layer is significantly broadened. A further increase of the rotational speed has the result that the »

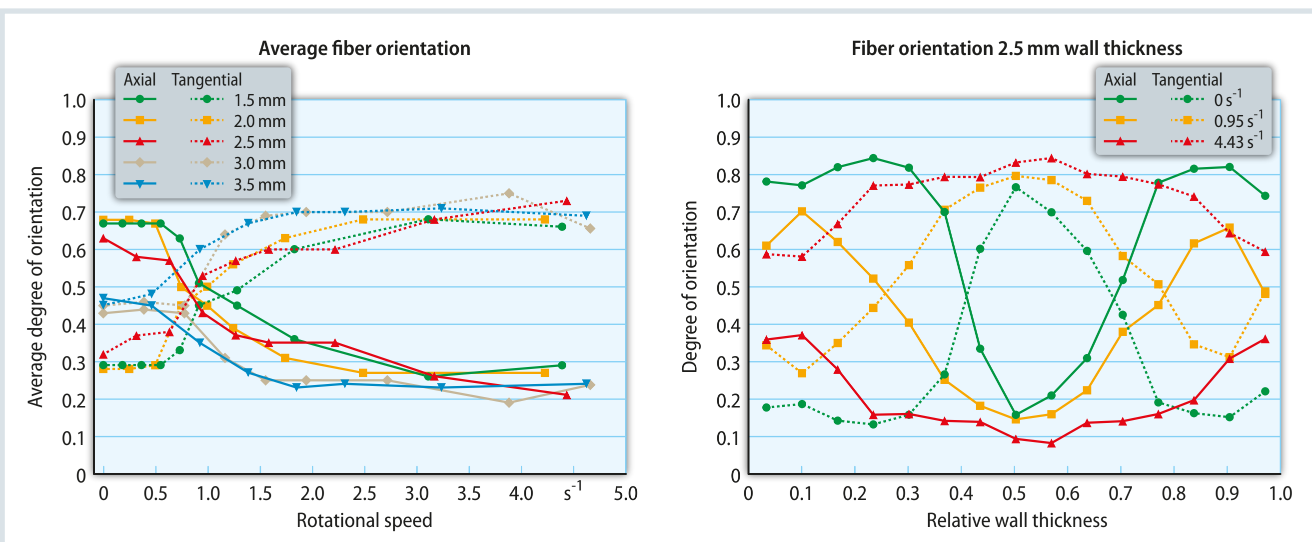


Fig. 2. The rotation core can produce an increase in the tangential orientation component almost independent of the wall thickness (left). At correspondingly high speeds, the tangential fibers dominate the microstructure across the entire thickness (right). Source: University of Osnabrück; graphic: © Hanser

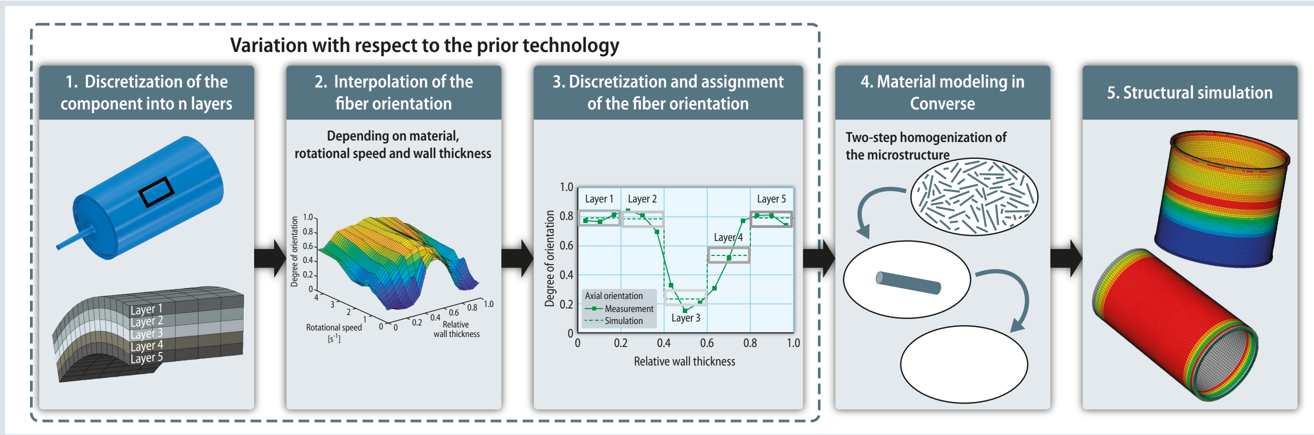


Fig. 3. The layer-by-layer assignment of the fiber orientations, with the aid of Converse and S-Life-Plastics, enables the anisotropic structural simulation of rotated components. Source: University of Osnabrück; graphic: © Hanser

actual layer structure is no longer present and the microstructure is dominated by the tangential degree of orientation across the entire wall thickness.

This information is now available for all measurement points and allows the orientation profile to be interpolated for further rotational speeds and wall thicknesses, and to be transferred to the simulation after suitable discretization.

Stages of the Simulation Methodology

For the development of the simulation methodology, the software program Converse was used for material modeling and S-Life Plastics for strength calculation (Part Engineering), since they offer an open data structure. Together with the structural simulation software Abaqus (Dassault Systèmes), it is thus possible to take into account the measured fiber orientation and perform the first structural-mechanical simulations with anisotropic material charts from Converse.

The new simulation methodology (**Fig. 3**) differs significantly in the manual assignment of the fiber orientation from the technology currently used for simulation of short fiber-reinforced injection-molded parts [8]. For this, the part must first be split into n layers, which should have a constant proportion of the overall wall thickness. Based on the present measured values, the profile of the fiber orientation for a given rotational speed can now be interpolated across the wall thickness. On the assumption that the fiber orientation is constant over the

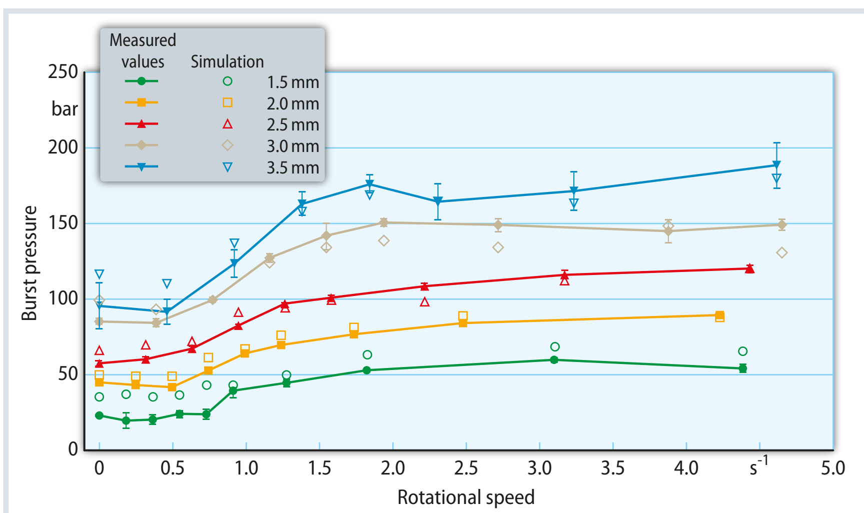


Fig. 4. Application of the simulation methodology allows, for the first time, the increased bursting strength due to rotation of the mold core also to be taken into account in the design of new components. Source: University of Osnabrück; graphic: © Hanser

Info

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References & Digital Version

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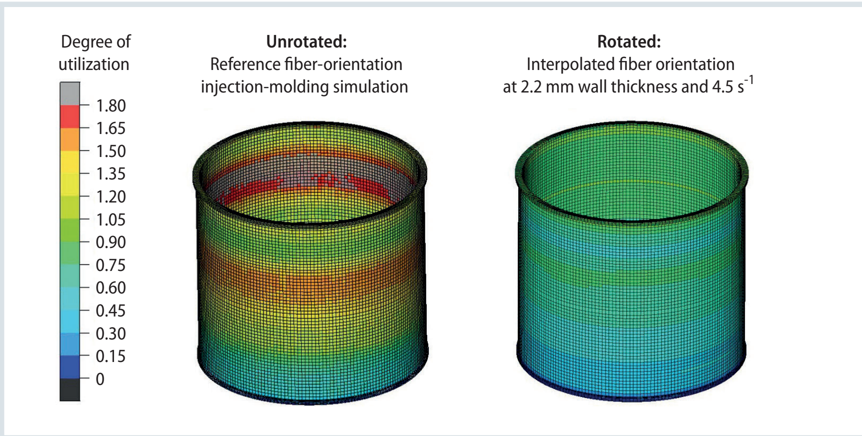

Fig. 5. This application case shows a significant reduction of the utilization ratio due to manufacturing with a rotating core. © University of Osnabrück

entire part length, and the principal orientation direction lies only in the axial or tangential direction, the tensor components of the fiber orientation that are necessary for the micromechanical computation are assigned to each of the n layers.

The same material charts from Converse can subsequently be used, which are also used for designing normal injection molded parts. Finally, the actual structural simulation and the strength analysis with S-Life Plastics are performed using a stress-based Tsai-Hill criterion [8], which takes into account the local orientation state.

The methodology was validated with the aid of burst pressure tests on the PP-GF50 (**Fig. 4**), at the same measuring points as the fiber orientation measurements. The test results demonstrate the significant increase of strength produced by reorientation of the fibers. It increases with increasing rotational speed and can be raised by over 100 % for all wall thicknesses. For a wall thickness of, for example, 2.5 mm, the strength can be increased from 57.5 bar to 120.2 bar.

The use of the simulation methodology for simulating the bursting pressure tests demonstrates that the increases in strength can be readily modeled in this way. In addition, it is possible to calibrate material charts with these simple component tests, which are then used for designing further components subject to internal pressure.

Practical Realization of a Pressure-Loaded Component

The first practical application of this design methodology was a pressure-loaded component from the mobility sector (**Fig. 5**). In the load case presented here, pressures at various levels act along the component, from inside and outside, at a temperature of 80 °C, with a maximum pressure of 23 bar. For this, a reference with the fiber orientation from the injection molding simulation (unrotated) as well as a component with an interpolated fiber orientation at 2.2 mm wall thickness and a rotational speed of 4.5 s^{-1} were simulated. The Tsai-Hill criterion were used to calculate the anisotropic utilization degree, which predicts failure at values greater than 1. Since, according to the requirements profile, the component is required to have a safety factor of 2, the unrotated part would not withstand the stresses with a utilization of 1.8. Due to the rotation of the mold core, the material utilization can be reduced by 50 % to 0.9.

Summary

A mold system with rotating core allows significant influencing of the fiber orientation in the component and a significant increase in the burst strength of components subject to internal pressure loads. In the case of the PP-GF50 investigated here, it was possible to show how, with increasing rotational speed, the axial orientation component decreases and the tangential increases. This change of fiber orientation leads to an increase in the burst strength of over 100 %, almost independent of the wall thickness.

To allow the modified fiber orientation to be taken into account in component design, a simulation methodology was developed and validated on burst strength tests on a demonstrator. When the methodology is transferred to a practical component, it is found that components can be developed that would not meet specifications if produced by conventional injection molding. This illustrates the great potential of this manufacturing process and the practical relevance of the design methodology. ■