Shrinkage and deformation of glass fiber reinforced thermoplastics may be calculated

Further developed calculation programs currently offer the possibility of simulating the injection molding process for glass fiber reinforced plastics, too. The orientation of the fibers in the injection molded part may be calculated in relation to the processing conditions and the mold geometry. The results are used to determine the directional shrinkage values as well as the anisotropic material properties, such as elasticity modulus and heat expansion coefficient. These data may be utilized to pre-calculate the shrinkage, as demonstrated by a practical example.

Glass fiber reinforced plastics, due to their superior mechanical properties, are gaining more and more access to areas of application that used to be the exclusive domain of traditional materials (steel, aluminum). To the user, however, the improvements resulting from the use of glass fibers are compromised by a higher tendency to deform. This must be considered when designing components and molds.

Since any change to a finshed mold creates additional costs and requires extra time, the planning stage has included rheological, thermal and mechanical computations of injection molds and injection molded articles for quite some time.

Newly developed program modules offer the possibility of recognizing deformations and their sources even before practical realization. Deformation effects may largely be controlled by changing the geometry of the molded article, the gate system and the cooling system.

The present article shows the factors that influence shrinkage and deformation. A practical example is described to illustrate the operation of these programs and their results.

Shrinkage and deformation have many reasons

A great variety of factors affect the shrinkage and deformation behavior of thermoplastic injection molded articles. The mutual interaction between different factors is complex and frequently difficult to predict. The influencing factors may be divided into three groups (Fig. 1):

– material
– geometry of the molded article
– process

Computation programs include these parameters and their influence on the shrinkage and deformation.

The process may be described by defining the injection times and the injection and holding pressure profiles, as well as other processing parameters (mass temperature, mold temperature, etc.).

The qualitative relations between these process parameters and the shrinkage behavior, as shown in Fig. 2, may be calculated.

Material	Geometry of the molded part	Process
• p,v,t behavior	• Wall thickness/wall thickness conditions	• Holding pressure level
• Viscosity	• Flow path depths	• Holding pressure profile
• Heat conductivity	• Material accumulation	• Mass temperature
• Mechanical characteristic values	• Edges	• Wall temperature
• Crystallinity	• Position of the injection point	• Cooling time
• Fillers		

Shrinkage/Deformation

Fig. 1: Factors affecting the shrinkage and deformation of thermoplastic injection molded parts [1]

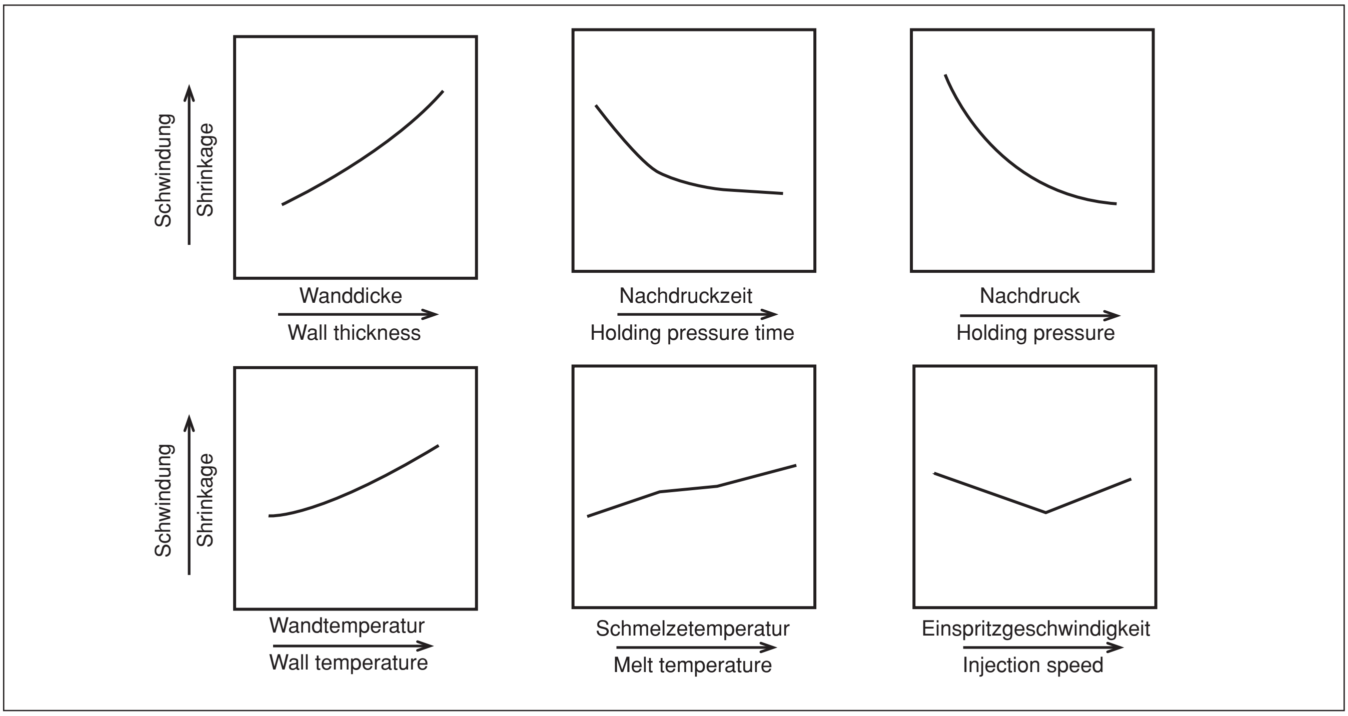

Fig. 2: Qualitative relations between individual process parameters and shrinkage behavior

The tempering conditions are assessed by simulating mold cooling. Effects such as deformation as a result of inhomogeneous temperature distribution, as shown in Fig. 3, left-hand side, are predicted correctly.

The geometry of the molded article is described by the computational model of the molded article (wall thicknesses, flow path depths, breakouts, ribs, etc.). The model can also consider the position and shape of the cutting face and the type of gate (cold runner, hot runner, submarine gate, sprue gate, etc.). The influence of the geometry of the molded article on the deformation is thus included in the overall consideration. The presence of ribs in a molded article, for instance, may considerably affect the deformation of the molded part. Fig. 3, right-hand side, qualitatively shows the deformation of a molded article with one rib. The different wall thicknesses of the rib and the base and the resulting different cooling conditions lead to different shrinkage in rib and base surface. In the case of non-reinforced thermoplastics, this results in the shown warpage of the molded article.

The plastic to be processed, i.e., the material, enters the calculation in the form of material laws from the areas of rheology (flow) and thermodynamics (heat exchange). To this end, the rheological data and thermal parameters (thermal conductivity, heat capacity, yield temperature, crystallization temperature) measured by the raw material producer are needed.

Furthermore, the pvt behavior, i.e., the dependence of the specific volume on the pressure and temperature, is measured, although these measurements frequently neglect the influence of the cooling rate. This enables calculation of the volume shrinkage in the individual zones of the molded article.

In the case of glass fiber filled thermoplastics, not only the listed influencing factors, but also the orientation of these fillers considerably affects the deformation. Computation programs must therefore be able to pre-determine the orientation of the fillers in relation to the processing technique (such as the injection rate) and the geometry of the molded article (cutting face, wall thicknesses, break-outs).

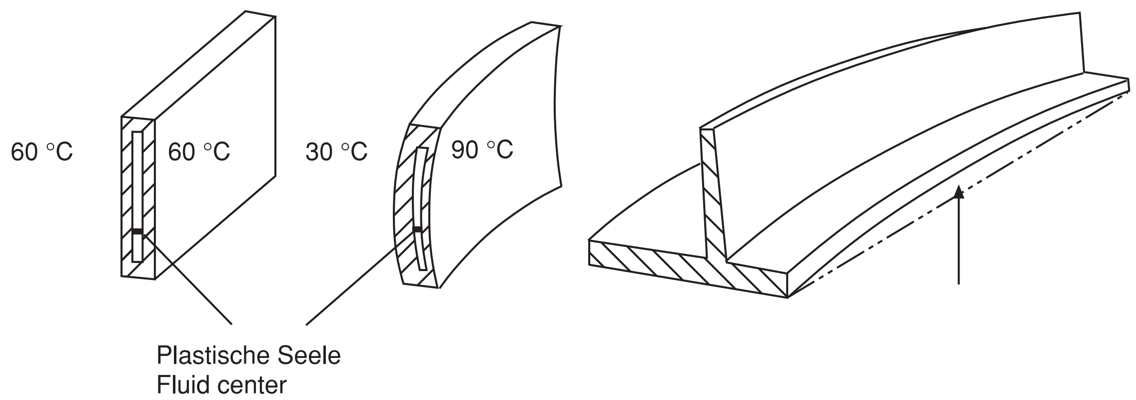

Fig. 3: Deformation of a sheet as a result of differences in the wall temperature (left) and the presence of a rib with a lesser wall thickness (right)

The glass fiber orientation determines the component properties

The orientation of the glass fiber is determined primarily by the flow conditions inside the impression of the mold. Different orientation conditions are found not only in different areas of the molded article, but also in the cross-section of the molded part itself.

If one considers the orientation of the glass fibers in a simple molded article (for instance a rectangular sheet with a film gate), then three different orientation zones emerge in the cross-section of the molded article (Fig. 4).

Fig. 4, left-hand side, shows the relations. In the intermediate layer, the velocity gradient approaches zero, which is therefore also true of the shear rate. The velocity gradient is particularly large in the shear zone. The fiber, due to the different forces acting upon it, will adopt an orientation parallel to the flow direction. As a rule, the layer distribution is 2 x 2.5 % for the boundary layer, 2 x 40 % for the shear zone, and 15 % for the intermediate layer [2]. The exact ratio depends on factors such as the injection rate and the wall thickness, as well as the viscosity of the melt. The thickness of the intermediate layer decreases with decreasing viscosity.

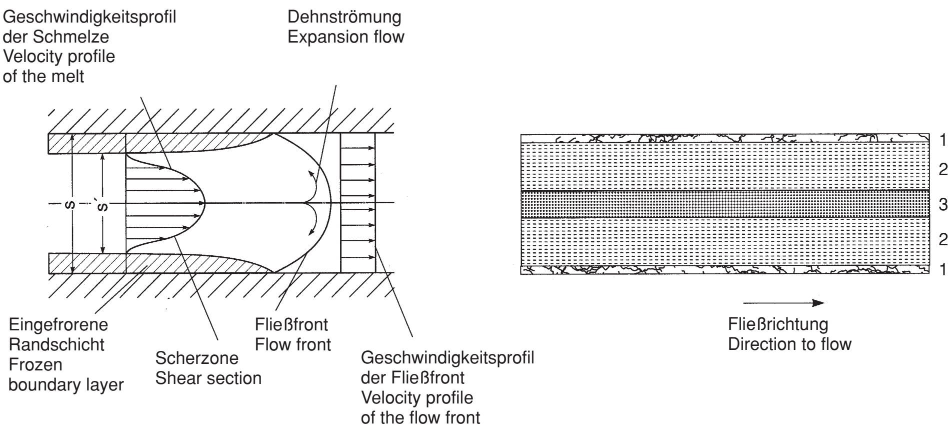

Fig. 4: Flow conditions in a thermoplastic melt (left) and different orientation zones over the flow cross-section (right) [2]

In the wall adhesion zone (1), the orientation is mixed. The fibers in the shear zone (2) are oriented parallel to the flow direction, while the ones in the intermediate layer (3) are oriented perpendicularly to it [2]. The fibers in the shear zone as well as those in the intermediate layer are oriented parallel to the surface of the molded article. This glass fiber distribution results from the fact that the shear rate and the extensional flow contribute considerably to this distribution.

Computation programs offer the possibility of predicting the orientation of the glass fibers in several layers over the cross-section. Fig. 5 shows the calculated glass fiber orientation of a frontally fed PBT tensile bar with GF 20, according to DIN 53 457.

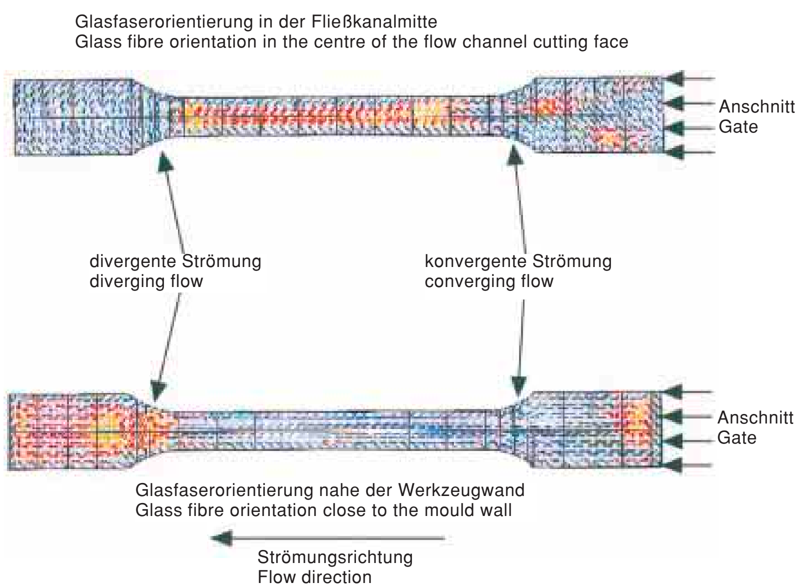

Fig. 5: Glass fiber orientation in a tensile bar (program: Autodesk-Moldflow)

The differences between fiber orientations in the individual layers are clearly visible. In the intermediate layer (above), the glass fibers are slightly oriented perpendicularly to the flow direction. In the shear zone (below), they are highly oriented in flow direction. These fibers, oriented in flow direction, define the deformation behavior. Besides, both layers also exhibit the typical glass fiber orientation resulting from converging flow (flow channel narrows) and from diverging flow (flow channel expands – extensional flow).

The glass fiber orientations are used to calculate not only the directional shrinkage values, but also the directional elasticity moduli (Fig. 6). The highest elasticity moduli (about 7200 MPa) are encountered in the highly oriented areas (transition from the right shoulder to the narrow intermediate range). The mentioned value agrees well with the elasticity modulus values of this material, determined by a tensile test. The distribution of elasticity moduli and glass fiber orientation also points to possible weaknesses of the tensile bar: These are found in the diverging flow area.

Applicational example: toaster covering

The PBT-GF toaster covering shown on the front page is injected twice in the upper, rectangular opening via a cold runner. The considerable collapse (deformation) of the long side faces is clearly visible. The reason for this deformation, detected by computation, was largely eliminated by appropriate constructive measures. The left part of Fig. 7 shows the calculated filling of the molded article (fill time about 2.5 s). The right part of this figure exhibits the calculated glass fiber orientation in the shear zone. The mold geometry – different diameters of the cold runners, wall thicknesses of the molded article, and double gate – enhances the melt flow over the frontal cutting face and creates a weld line along the long side faces.

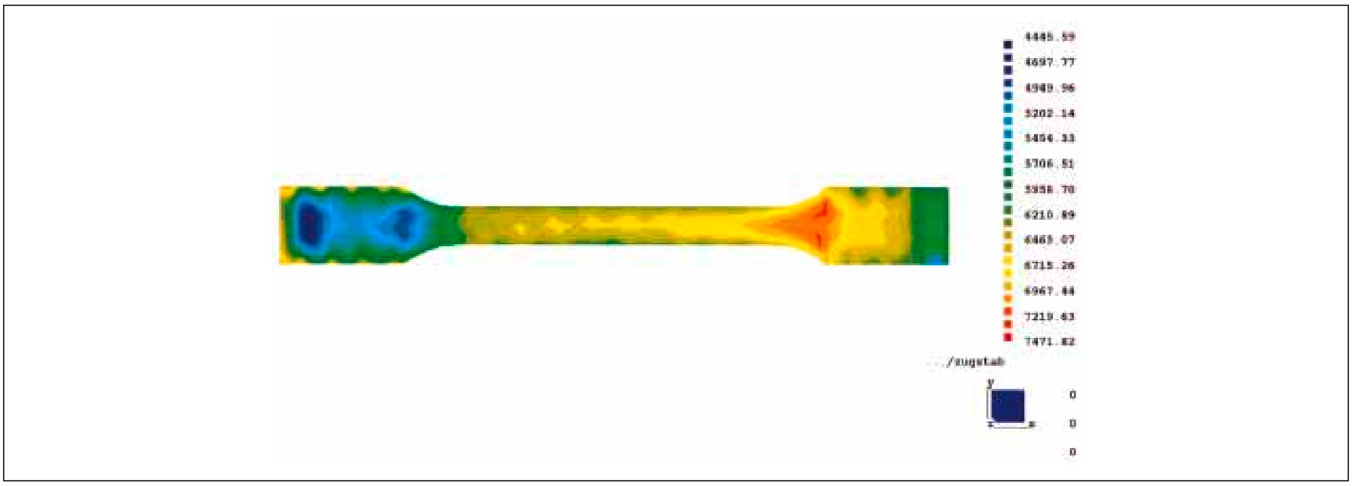

Fig. 6: Distribution of the elasticity modulus parallel to the flow direction, calculated according to the Ogorkiewicz-Weidmann-Counto material law (program: Autodesk-Moldflow)

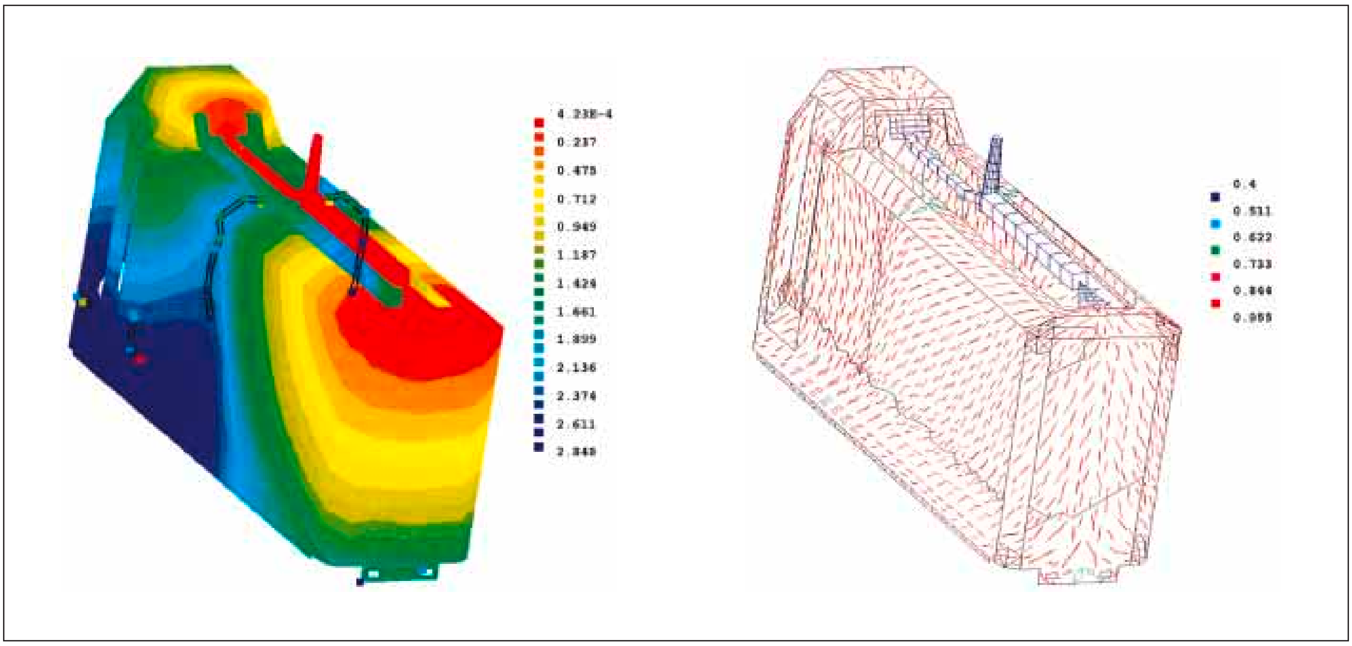

Fig. 7: Computed filling of the molded part (left) and respective glass fiber distribution in the shear zone (right) computed according to Autodesk-Moldflow

The flow conditions during the filling phase and the subsequent holding pressure phase largely determine the glass fiber distribution in the molded article. Fig. 7, right, shows the calculated glass fiber distribution in a shear layer. The glass fibers along the lateral faces are facing vertically downward (red “needles”). The glass fibers along the lower edge are known to orient themselves parallel to the edge. These differences in orientation cause deformation.

The chain of events, from varying orientation (Fig. 7) to deformation (Fig. 8), may be explained by the fact that the horizontally oriented glass fibers along the lower edge cause minimal horizontal shrinkage.

The horizontal shrinkage component along the lateral face, on the other hand, is noticeably higher. As a result, forces act upon the boundary layer, trying to compress it. This causes thermal indentation [3]. A portion of the boundary layer, which has been cut free, behaves like an “Eulerian bar” known from the science of the strength of materials (Fig. 9).

The pressure forces move the lower edge sideways into a new equilibrium position. The angular deformation [4] (thermal tensions on the inside) in this case only makes the material cave in; contrary to popular belief, however, this is not the reason. Without this predetermined direction, the side face would be able to bend outward as well.

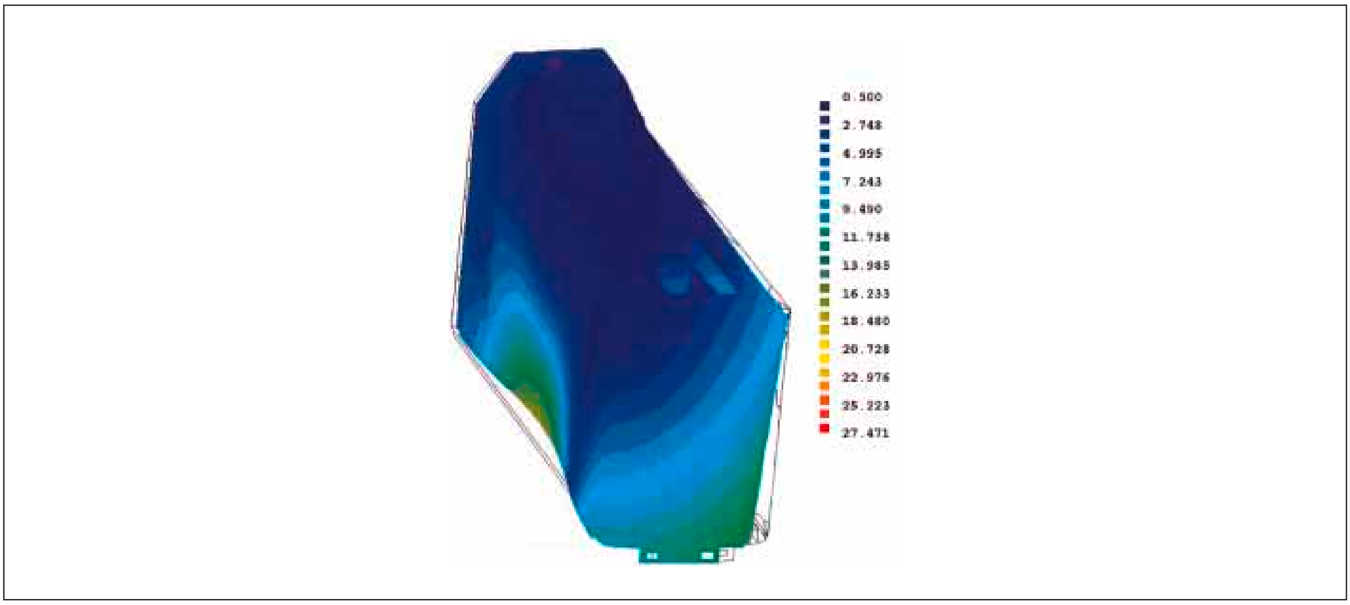

Fig. 8: Deformation of a molded part in its actual condition, computed according to Autodesk-Moldflow

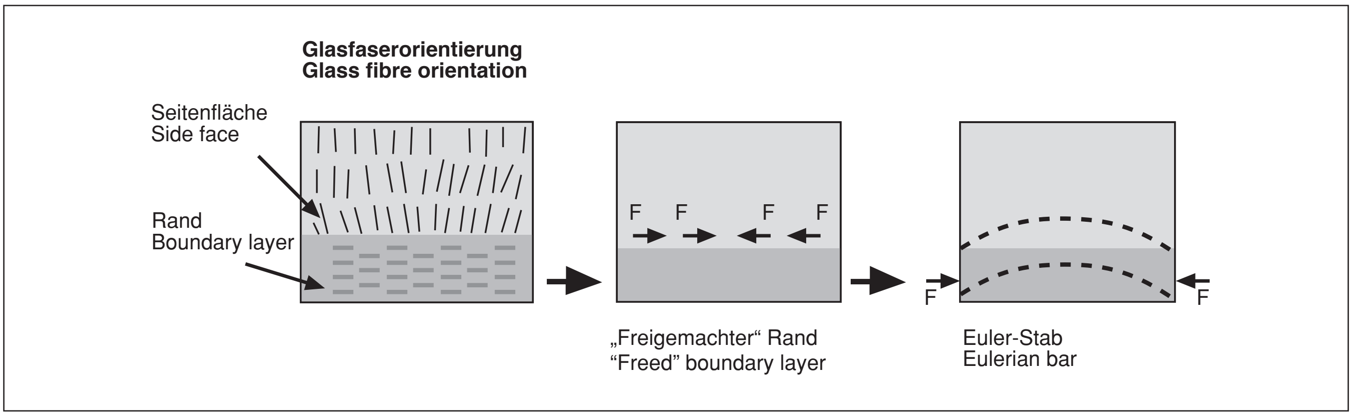

Fig. 9: Analogue to the “Eulerian bar”

The computational results (Figs. 7 and 8) indicate how deformation may be reduced: moving the cutting face to an end face (tunnel gate), increasing the wall thickness in the fed frontal surface. As a result, the melt spreads rapidly and evenly fills the lateral faces. Fig. 10 shows the calculated new filling of the molded article (left) and the calculated glass fiber orientation in the shear zone (right). The glass fibers along the lateral faces are now evenly oriented in a longitudinal direction. As a consequence, the maximum deformation value (Fig. 11) decreases by a factor of more than five compared to the starting situation (Fig. 9).

The illustrated example, along with many others, shows that the computation programs currently available make it possible to qualitatively pre-calculate the molded article deformation of injection molded glass fiber reinforced components. Comparisons with actually measured deformation values prove that this simulation affords satisfactory results despite the simplifications that the computations are based on. However, it is true of these calculations, too, that only continuous critical survey of the results, intricate knowledge of the material properties, and close practical orientation make shrinkage and deformation programs a tool that considerably facilitates the task of design engineers and helps reduce costs.

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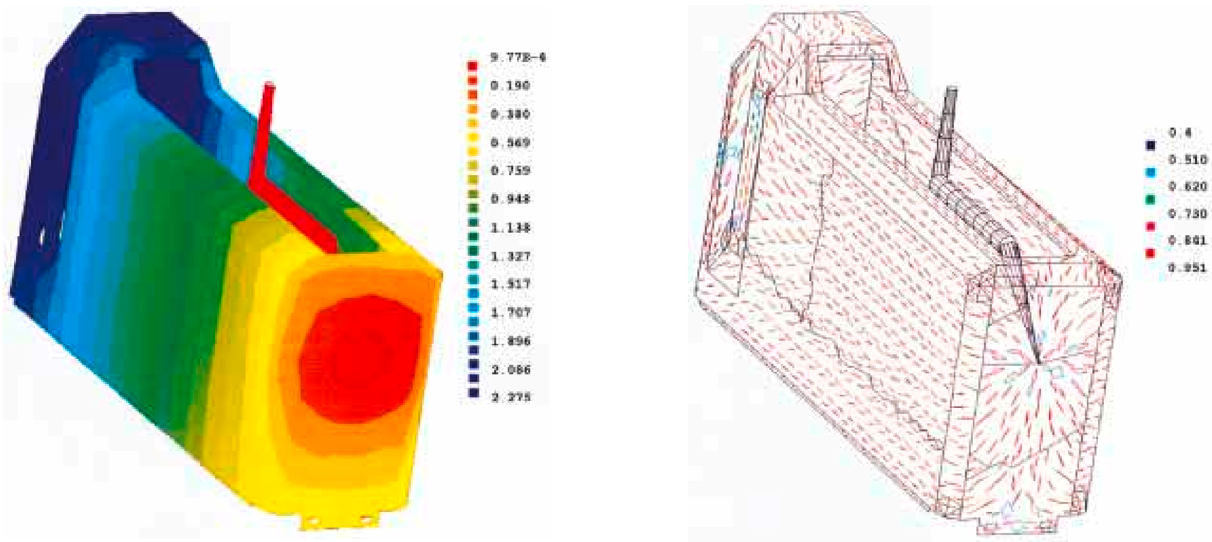

Fig. 10: Filling of the molded article (left) and glass fiber orientation (right) after mold change, computed according to Autodesk-Moldflow

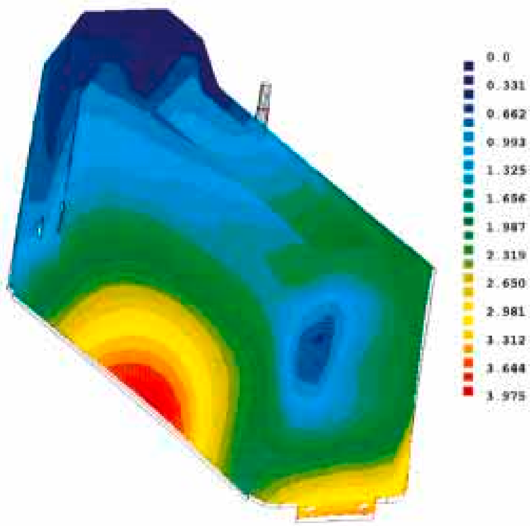

Fig. 11: Calculated deformation after mold changes computed according to Autodesk-Moldflow

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