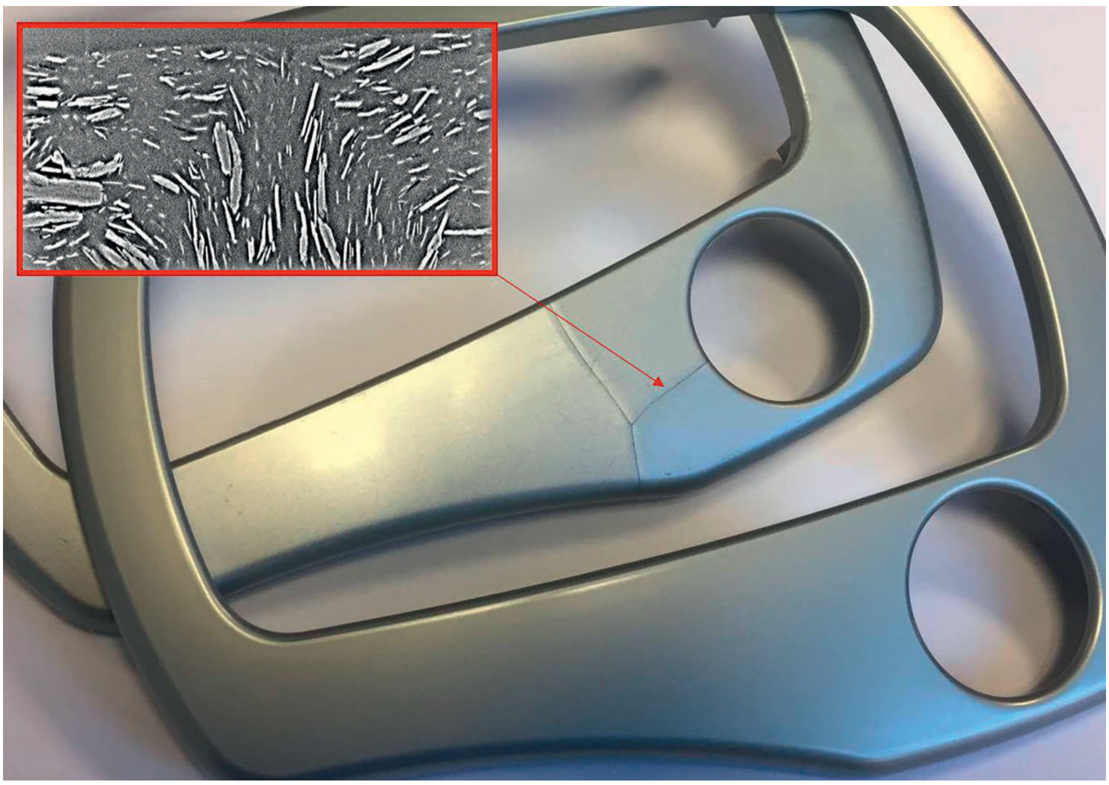
A Question of Orientation

How Thermally Conductive Fillers Affect the Weld-Line Strength

The selective integration of thermally conductive plastics into assemblies offers huge advantages in terms of freedom of design and technical functionality. The full potential of these materials is then available for the application, provided that the prerequisites have already been created in the product development phase. This also includes the design of the part regarding the formation of weld lines. The material used determines the effect on the weld-line strength.



Orientation of the filler boron nitride in the area of the weld line on the bezel of a navigation device (© KI Lüdenscheid)

When thermally conductive plastics are used in assemblies, the goal must be to fully exploit the potential of these materials with a view to the smart integration of functions. For many applications in the electronics sector, it is important for thermally conductive plastics also to be electrically insulating. To be able to utilize the advantage of these materials, however, for many applications, it is necessary to reconceive the conventional part development process. A "one-to-one" replacement of conventional metal heat-sink materials is not appropriate in many cases for reasons of cost.

Rather, the focus must be on the system concept, in which, e.g., a plastic housing must be made directly conductive, so that the use of a cooling element is eliminated and the heat can be dissipated directly via the housing. Furthermore, skillfully chosen production processes can significantly reduce costs and consumption of resources. An example of this is the manufacture of an electronic assembly by direct overmolding.

Top Priority in Parts Design

With the use of thermally conductive plastics, there is an increasing focus on applications-technology questions about processing such materials. Within a joint project at the Kunststoff-Institut Lüdenscheid, Germany, (topics: "Thermally conductive plastics 2"), the effect of thermally conductive plastics

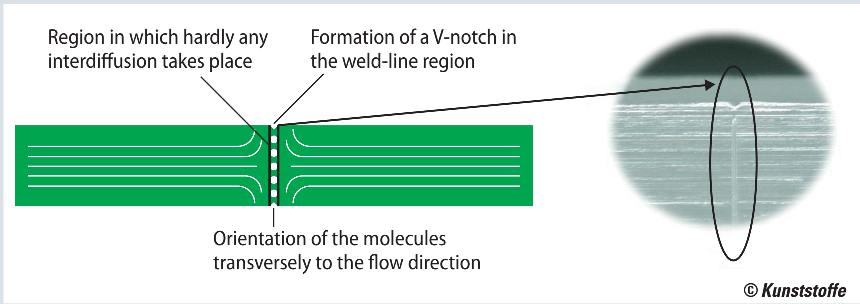


Fig. 1. How the development of a weld line affects the material structure (source: [1], TU Chemnitz)

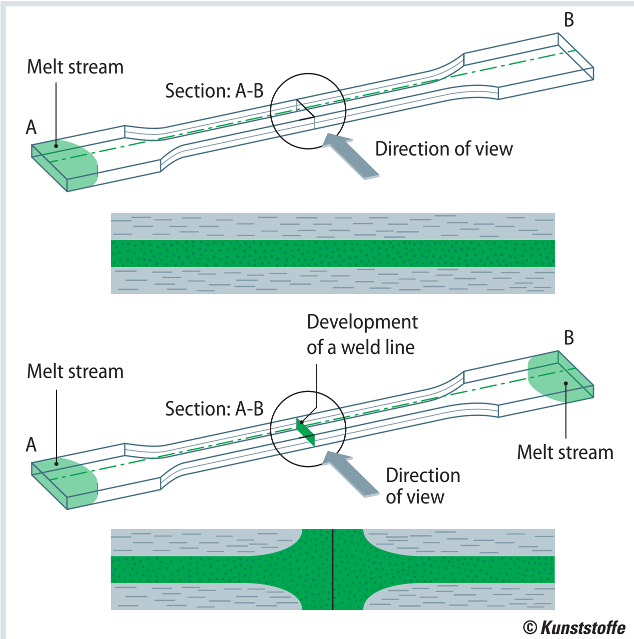


Fig. 2. If gating is from one side, the fibers in the outer layer are oriented in the flow direction (top). Gating from two sides (bottom) means that the fibers in the weld-seam region are oriented transversely to the flow direction (source: KI Lüdenscheid)

on the weld-line strength was investigated.

During the product development process, and thus also the plastics-oriented parts design, the formation of weld lines and flow seams must be taken into account. Weld lines arise in the part whenever two flow fronts meet. The main causes of the formation of weld seams are

- separation of the flow front by flow obstructions,
- openings,
- wall-thickness steps
- as well as the associated reuniting within the continuing progress of the flow front.

Weld lines are generally undesirable side effects during part filling, because they lead to mechanical and optical weaknesses in the part. The highest priority in the part design is consequently to avoid weld lines or to locate them in areas of the part that are not mechanically critical.

Weld lines cannot always be avoided, so that the material strength in these regions must be evaluated. The reason why there is limited strength in the center of the weld line is the poor interdiffusion of the macromolecules in the vicinity of the flow front. The macromolecules are oriented in the weld line transverse to the flow direction and a so-called V-notch arises on the part surface (**Fig. 1**).

The Fiber Orientation Is Interrupted in the Weld Line

If a plastic melt contains fillers, they are distributed according to the swelling flow in the mold. If the weld line in a tensile bar is considered, anisotropic fillers (fibers) are oriented transversely to the flow direction, so that they do not allow a strengthening effect if the weld line develops in the tension direction. The outer layers with longitudinally oriented fibers, which make a crucial contribution to increasing the strength, are interrupted in the vicinity of the weld line and, as in the core, are oriented transversely to the flow direction (**Fig. 2**).

If gating is from one side, an outer layer that is oriented entirely in the flow direction is produced, which increases the strength in the part. Due to the influence of the weld line, transverse orientation of the fibers occurs in the center of the tensile bar, which reduces the strength.

The comparison between an unfilled polyamide 66 and two glass fiber-reinforced PA66 materials illustrates the difference in loss of strength of the weld line (**Fig. 3**). It becomes clear that the glass fibers do not have a significant effect on the tensile strength in the weld-line region. The reinforcing agent only increases the tensile strength if it is oriented in the direction of the longitudinal axis (tension).

Differences in Thermally Conductive Fillers

Thermally conductive fillers show either strongly anisotropic or isotropic properties, depending on their geometry. These are apparent in both the mechanical characteristics and the thermal conductivity. A thermally conductive boron nitride platelet (with anisotropic properties) can increase the thermal conductivity in the orientation direction to 3 W/mK, even at a filler loading of 30 wt.%. The tensile strength is reduced by approx. 15 % compared to the starting material.

Aluminum oxide as filler generally has more spherical isotropic properties. The thermal conductivity at approx. 60 wt.% filler loading is thus increased to 1.5 W/mK. At the same time, the tensile strength is increased compared to the unfilled starting material.

A range of trials was conducted to show how the geometry of the thermally conductive filler influences the mechanical properties with regard to the weld-line strength. For the investigations, two different filler systems were assessed. The first filler system was an aluminum oxide with predominantly spherical isotropic properties, while the second was strongly anisotropic platelets based on hexagonal boron nitride.

Both filler systems were incorporated into a PA66 in the compounding process. For the studies, tensile bars according to DIN EN 527, type 1A, were used in the injection molding process, which were »

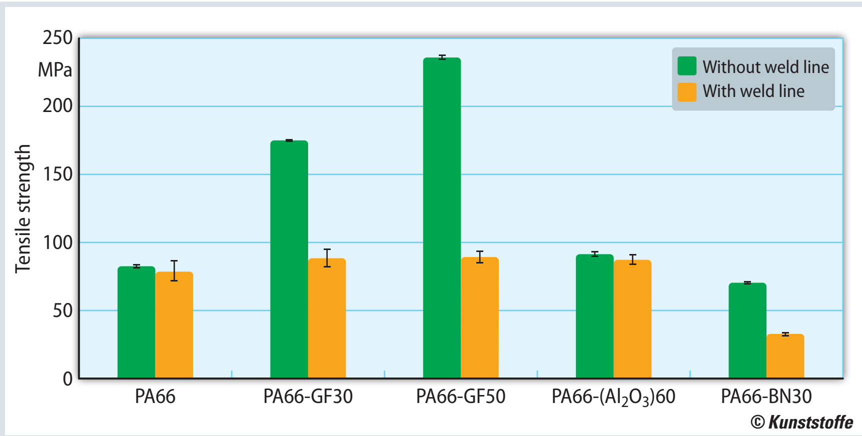


Fig. 3. Influence of the weld-line strength in the case of thermally conductive polyamides compared to glass fiber-reinforced materials thermally conductive fillers have different effects depending on their geometry (source: KI Lüdenscheid)

gated via a film gate. In the production of tensile bars with a weld line, the tensile bar was gated from both sides, so that, due to uniform mold filling, the flow fronts could flow together centrally in the middle of the tensile bar.

The results of the tensile strength studies show that the isotropic filler of the aluminum oxide hardly affects the weld-line strength even at high filler loadings (60 wt.%). In the case of the material filled with anisotropic material, a low filler loading (30 wt.%) already has a strong effect on the weld-line strength, similar to the case with glass-fiber filled PA66 (**Fig. 3**).

If the structure in the cross-section near the surface is considered by SEM analysis of the two materials, no change of orientation can be seen in the weld-line region of the aluminum oxide-filled material. In the weld line of the boron nitride-filled material, on the other hand, a changed orientation is clearly visible. Due to the flowing together of the melt, the platelets in the weld-line region are oriented transversely to the flow direction (**Fig. 4**). The longitudinal orientation of the platelets in the outer regions is interrupted by the flow conditions in the weld-line region, so that the strength is strongly influenced.

Summary

Depending on what thermally conductive filler system is used, the designer must pay attention to the development of weld lines when designing the molding. Another important point is how a changed orientation in the weld-line region affects the thermal conduction paths. A boron-nitride platelet has over 300 W/mK higher thermal conductivity in the orientation direction of the hexagonal structure, than transversely to this direction. In the part design, the heat dissipation behavior in this region should therefore also be taken into account.

Particles oriented transversely in a weld line represent a heat-flux barrier, so that the heat dissipation in these regions can be inhibited. However, the thermal conductivity through the material level is positively influenced, so that a better heat dissipation through the part wall can be expected in these regions. ■

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New Joint Project

In November 2019, the Kunststoff-Institut Lüdenscheid started a new joint project with the title "Thermally Conductive Plastics 3". The project includes the effects of flame-retardant modifications on the thermal and mechanical properties. On the other hand, the injection molding of 2-component thermoplastic/thermoplastic structures is to be investigated regarding thermally conductive plastics.

Service

References & Digital Version

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German Version

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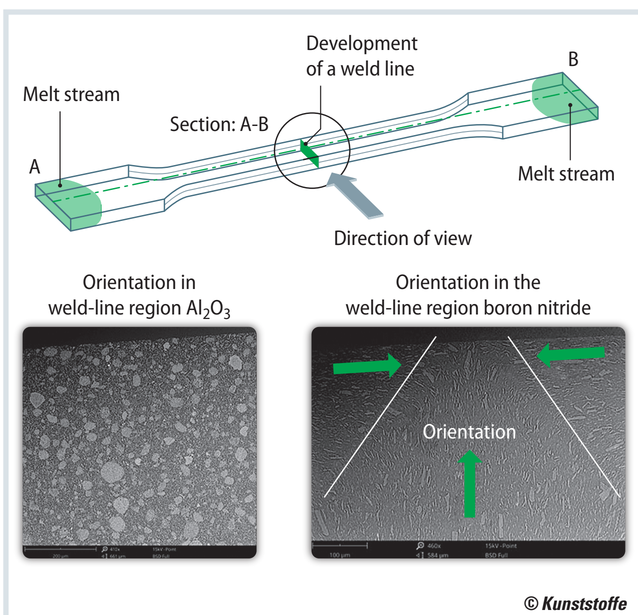

Fig. 4. SEM study on the filler orientation in the weld seam region Al_2O_3 (left) and boron nitride (right). In the weld-line area, the BN platelets are oriented transversely to the flow direction (source: KI Lüdenscheid)