# Molding on a Joining Element

## *Study of the Factors Influencing the Strength of the Bond between a Thermoplastic Composite and a Screw-in Blind Rivet*

The thermoplastic matrix of the composite is nowadays often provided with ribs and functional elements in the injection molding process. In the same way, joining elements can also be molded on. The screw-in blind rivet is one such joining element with adequate one-sided accessibility, high strength properties and good economic efficiency. The question is: what factors influence the strength of the bond between the semi-finished product and the molded-on blind rivet?

Mobility has always been one of man's most important needs. In view of climate change and the growing world population, mobility creates major challenges. If the many climate targets are to be met, energy-efficient mobility concepts based on renewable types of energy will be needed. An important factor in the energy efficiency of mobile systems is a reduction of the mass/weight. In this way, the necessary acceleration energy and the friction-induced resistance can also be reduced.

Multi-material construction methods allow cost-effective lightweight design. However, in order to combine different materials, suitable processes are needed to join them together. Plastics are noted for their low density, high geometric freedom and the constantly increasing material diversity with improved properties. For the mechanical joining of plastics, a particularly economical option has proved to be the direct screw-mounting method with high pull-out forces. Apart from that, there is the blind riveting method with one-sided accessibility and a sealing function [1–4].

The screw-in blind rivet method developed at Kunststofftechnik Paderborn (KTP), Germany, combines both joining methods. As a result, a variety of synergy effects are created. Screw-in blind riveting allows, for example, high strength and economic efficiency comparable with that of a direct screw connection, plus one-sided joinability and a sealing function. The screw-in blind rivet can be used as a separate joining element or, in the injection molding process, can be molded directly onto a plastic part. It consists of a screw-in tube and a shaft that connects the tube to the baseplate (or the part). In the thin-walled shaft there is a notch that initiates the buckling out of the shaft during the joining process [5].

The first step is to insert the blind rivet (which is positioned on one of the parts) into the drill hole of the other. Subsequently, a screw is screwed into the screw boss until the screw head makes contact. On further tightening the screw, the shaft buckles out at the notch between the baseplate and the screw-in tube (**Fig. 1**). Through the notch situated below the surface of the part being joined, the resultant bulge makes contact with the other part and ensures a secure, play-free connection [5].

### Three Molded-on Screw-in Blind Rivets

In terms of their lightweight construction potential, the most suitable plastics are fiber-reinforced types, especially thermoplastic composites. For these, new or modified joining processes are needed. They can be formed during heating or can be back-molded with ribs. However, the possibility also exists of molding on a screw-in blind rivet as a joining element. This creates a variety of advantages. The open fiber ends are overmolded and fixed with the new matrix material, and the screw bosses on the thermoplastic composite allow secure positioning during assembly.

In studies at the KTP, screw-in blind rivets were molded on to pieces of thermoplastic composite. During the course of the tests, the sample preparation of the thermoplastic composite was varied, »

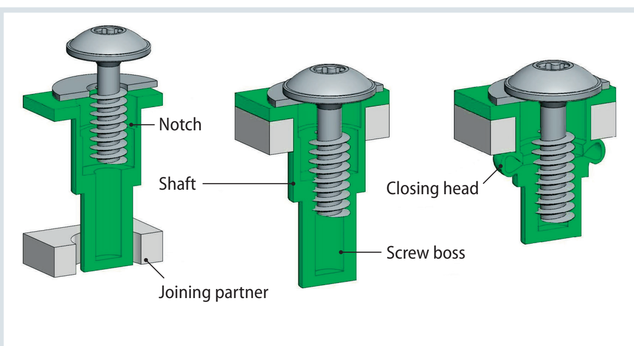



**Fig. 1.** The three steps of the joining process for a screw-in blind rivet connection Source: KTP

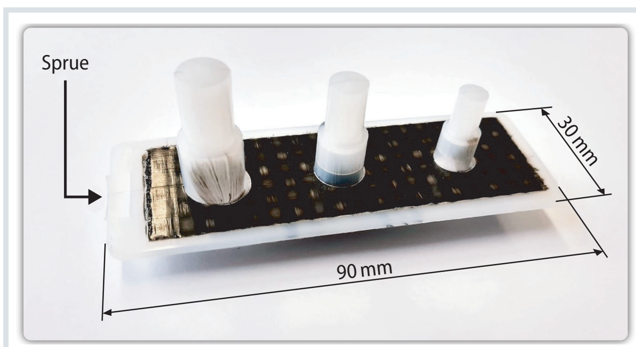



**Fig. 2.** The blind rivets are molded on through three drill holes in the thermoplastic composite with different diameters Source: KTP

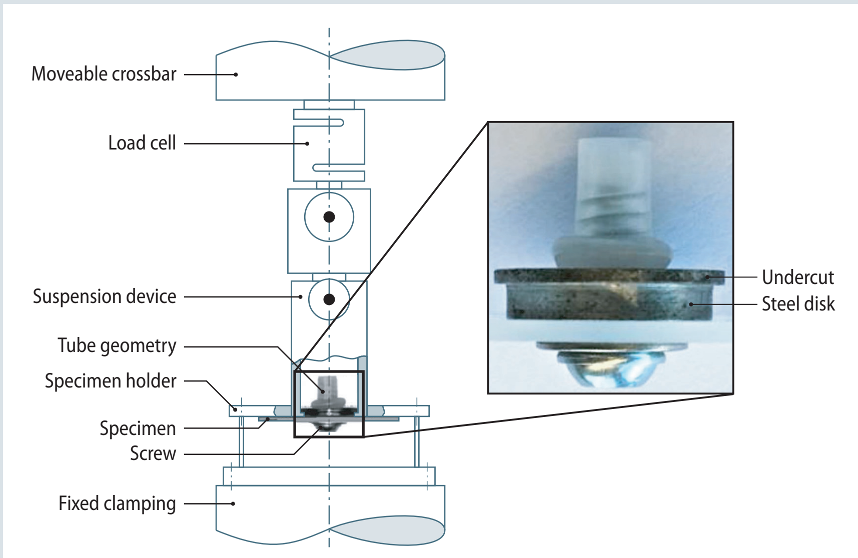


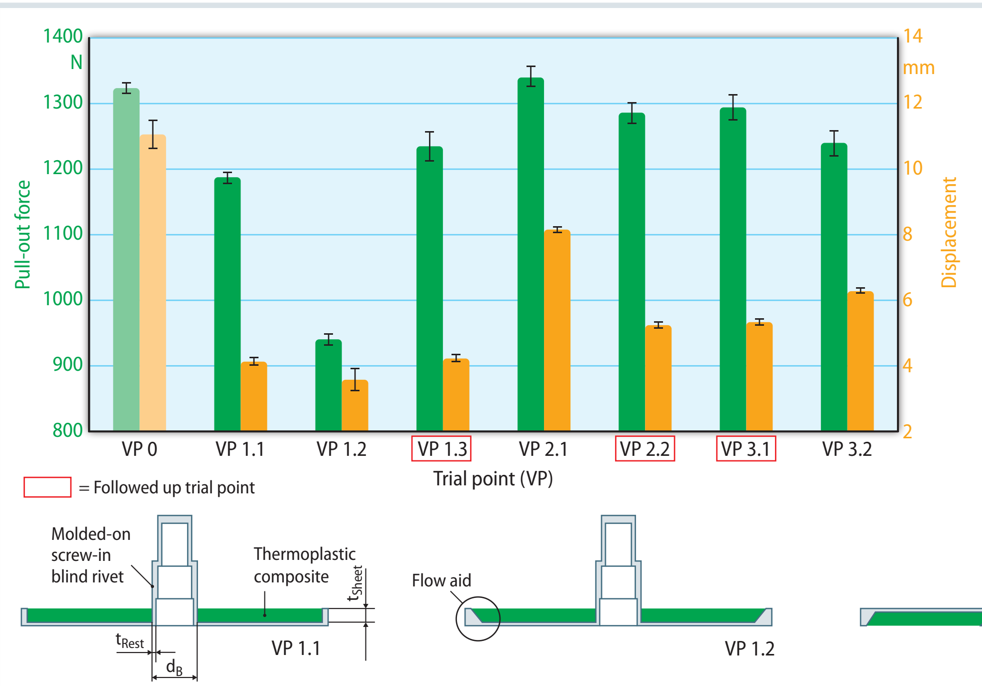

**Fig. 3.** Test set-up with joined screw-in blind rivet Source: KTP; graphic: © Hanser

as were the heating-up process by infrared lamp and, above all, the injection molding parameters. The strength of the bond between the blind rivet and the thermoplastic composite was evaluated with the aid of pull-out tests. The specimens were produced on an injection molding machine of the type Allrounder 420 C (manufacturer: Arburg), whereby three blind rivets of various diameters were integrated into the mold on a baseplate.

The thermoplastic composites (type: Tepex Dynalite; producer: Bond-Laminates) with a polypropylene matrix are built up from three layers of glass fibers in 0°/90° orientation and are available in thicknesses of 1.5 mm and 1 mm. They are inserted into the (2 mm thick) recess for the baseplate. The resultant gap replaces a specific gating point and, in this set-up, allows the melt to be fed to the screw boss (**Fig. 2**). To mold on the bosses to the baseplate, the thermoplastic composites must be cut to size (84 x 24 mm) to fit the mold. Holes are drilled (diameter $D_{S1}$ = 8 mm, $D_{S2}$ = 10 mm, $D_{S3}$ = 12 mm) at the later positions of the blind rivets. The prepared thermoplastic composites are suspended in the injection molding tool and heated via an infrared lamp. After the injection molding process with a polypropylene (type: Moplen HP400R from LyondellBasell), the thermoplastic composite with three molded-on blind rivets can be removed (**Fig. 2**). For the tensile test (testing velocity: 50 mm/min), the blind rivets are fastened with a screw suitable for plastic (Delta PT from Ejot) and with a steel disk at the other joining partner. The steel disk has an undercut for clamping. The baseplate of the blind rivet reinforced with thermoplastic composite is placed on a sample holder (steel plate with a 30 mm through-hole) (**Fig. 3**).

## *What Role is Played by the Geometry of the Thermoplastic Composite?*

The experimental plan was divided into various steps, and each step was carried out with the most suitable parameters from the previous step (**Fig. 4**). Screw-in blind rivets without thermoplastic composite (VP 0) served as the reference. First of all, the outer edge of the thermoplastic composite was varied: once without a chamfer, once with a chamfer on the rivet



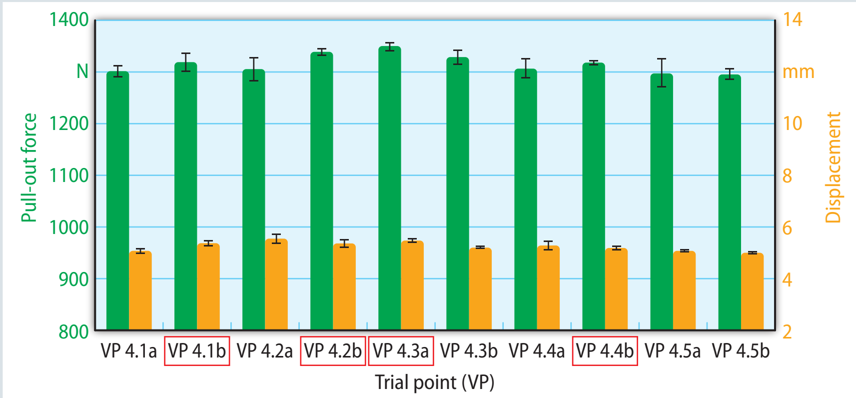

| VP | Description |
|---|---|
| VP 0 | Unamplified reference specimen |
| VP 1.1 | Without chamfer; thickness D = 1.5 mm; bore $d_B$ = 10 mm |
| VP 1.2 | VP 1.1 + flow aid on side facing away from rivet |
| VP 1.3 | VP 1.1 + Flow aid with chamfer on rivet side |
| VP 2.1 | VP 1.3 + D = 1 mm |
| VP 2.2 | VP 1.3 + 45° Chamfer on the hole |
| VP 3.1 | VP 2.2 + $d_B$ = 9 mm |
| VP 3.2 | VP 2.2 + $d_B$ = 12 mm |

**Fig. 4.** Results of varying the geometry: In the experimental plan (VP), each new step is based on the best parameters from the previous step. D: Thickness of the thermoplastic composite; $d_B$: Diameter of the drill hole Source: KTP; graphic: © Hanser

side, and once with a chamfer on the side away from the rivet (VP 1). Through the chamfer and the drill holes, fixing of the thermoplastic composite becomes superfluous. The chamfer also controls on which side of the thermoplastic composite the melt flows to the rivet.

The screw-in blind rivet molded onto the thermoplastic composite with a vertical edge showed slightly lower strength than the one without thermoplastic composite. On the other hand, there was a very distinct increase in the stiffness through the thermoplastic composite. The chamfer on the side of the thermoplastic composite facing the rivet attained the best mechanical strength data and was therefore pursued further (VP 1.3).

Furthermore, the thickness of the thermoplastic composite (VP 2.1) and the edge of the drill hole (VP 2.2) were varied. A thinner thermoplastic composite proved to be unsuitable because the displacement of the combination of thermoplastic composite and rivet declines significantly. A chamfer on the drill hole results in higher stiffness with comparable strength data.




| VP | Variation | VP a | VP b |
|---|---|---|---|
| VP 4.1 | Injection speed | 15 $cm^3/s$ | 35 $cm^3/s$ |
| VP 4.2 | Cylinder tmperature | 235 °C | 260 °C |
| VP 4.3 | Preheating of the composite sheet | 60 s | 120 s |
| VP 4.4 | Holding pressure | 400 bar | 500 bar |
| VP 4.5 | Mold temperature | 70 °C | 80 °C |

**Fig. 5.** Variation of the injection molding parameters: The influence on the bond between the thermoplastic composite and the blind rivet can be seen from the results Source: KTP; graphic: © Hanser

Finally, the diameter $d_B$ of the drill holes for immersion of the mold cores was changed from the original 10 mm to 9 mm (VP 3.1) and 12 mm (VP 3.2) (limited by the mold and part geometry). On reducing to 9 mm, the strength improved slightly.

For testing the process parameters, performed with the optimized geometry » parameters (VP 3.1), variations were made in the injection speed, cylinder temperature, preheating time of the thermoplastic composite, holding pressure and mold temperature (**Fig. 5**). The setting-up of the injection molding machine was made on the basis of the recommended processing parameters from the material manufacturer [6].

## *What Effect Do Different Process Parameters Have?*

The injection speed has a direct influence on the alignment of the molecule chains and the higher strength in the orientation direction. The raised cylinder temperature produces a higher temperature at the contact area between the melt and the thermoplastic composite. At the same time, the viscosity of the melt falls [7].

The contact surface between the melt and the insert is a weak point. By preheating the thermoplastic composite, the matrix is plasticized on the surface [8]. Use is made here of an IR lamp (200 W) from Heraeus at a distance of 25 mm from the thermoplastic composite.

The fiber fabric in the thermoplastic composite hinders shrinkage in the part, consequently leading to internal stresses. To avoid sink marks and delamination, a holding pressure must be maintained after the injection. This influences the resultant internal stresses [8].

A higher mold temperature reduces the temperature difference between the plastic melt and the mold wall, so that the cooling of the melt is slowed down. This raises the temperature at the contact surface to the thermoplastic composite, and improves the strength of the weld lines [7].

The studies (**Fig. 5**) showed that increasing the injection speed (VP 4.1b) and the melt temperature (VP 4.2b) has a positive influence on the bond between the thermoplastic composite and the blind rivet. Infrared preheating (VP 4.3) should, however, be limited. A short heating-up time produces better tensile strength data. A higher holding pressure (VP 4.4b) slightly improves the strength. As far as the mold temperature is concerned, no influence was established in the range covered by the tests.

Raising the melt temperature and injection speed leads to higher temperatures of the melt front (milky/transparent) when it reaches the thermoplastic composite. This results in plasticization of the thermoplastic matrix (black) of the thermoplastic composite, which visibly connects with the injected polypropylene. Furthermore, a better join is visible in the fracture pattern (**Fig. 6**). Finally, the best parameters were transferred to the rivets with 8 mm and 12 mm diameter. A comparison of the thermoplastic composite-reinforced screw-in blind rivets with their unreinforced counterparts showed that similar tensile strengths are achieved (**Fig. 6**). Consequently, adhesion between the thermoplastic composite and the blind rivet was good. At the same time, the rigidity of the bond was significantly increased. In the case of the screw-in blind rivets with a diameter of 12 mm, an increase in the tensile strength was immediately apparent. This finding was due to the fact that the unreinforced baseplate fails ahead of the rivet in the tensile test.

## *Outlook*

As the tests show, screw-in blind rivets can be molded on to thermoplastic composites without any loss of strength. With the test set-up used here, a significant stiffening effect was also seen. In future tests, the drill hole in the thermoplastic composite could be replaced by a cross-shaped cut in the fiber direction. In this case, the fibers of the preheated thermoplastic composite can be pulled into the foot of the boss. This should bring about a significant reinforcing effect under tensile shear load. ■

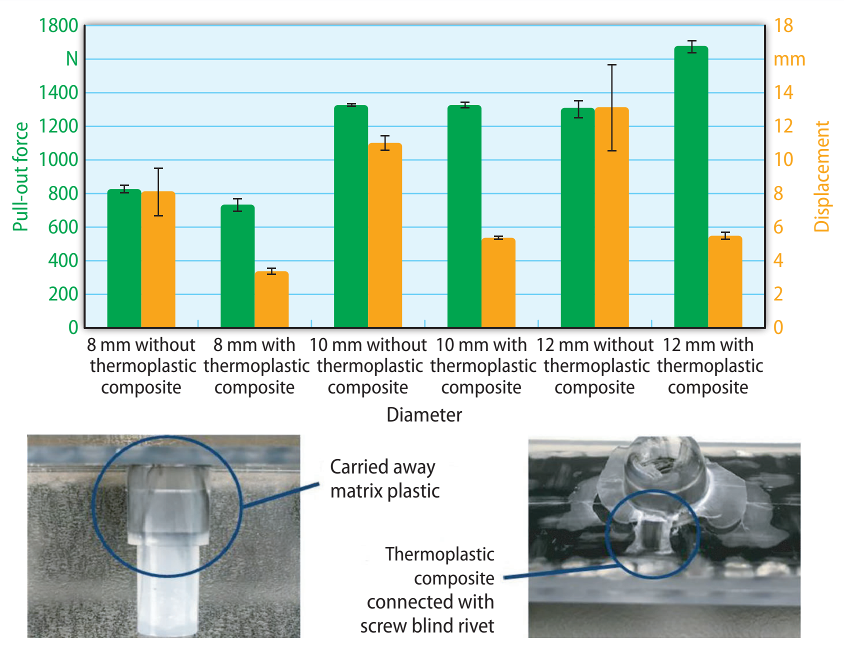



**Fig. 6.** Results of varying the diameter of the drill hole (top) and failure pattern (below); left: blind rivet with plasticized matrix plastic; right: blind rivet after failure Source: KTP; graphic: © Hanser

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