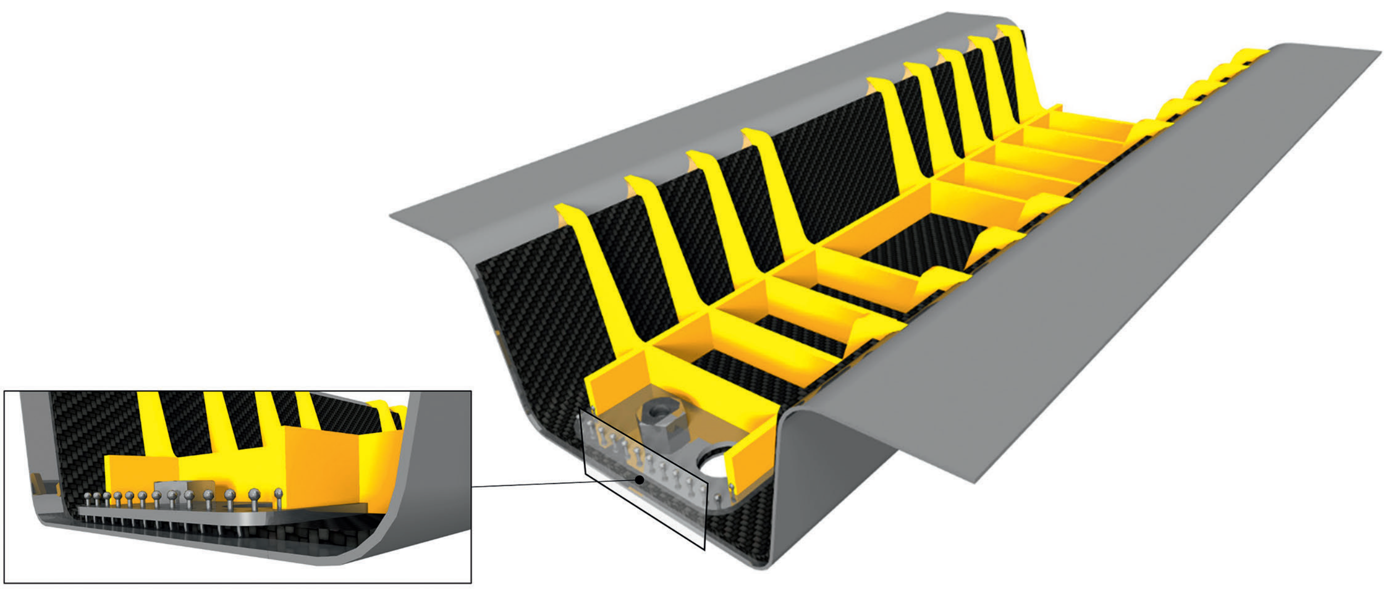
Reduced Settling Behavior in Multi Material Components

Structuring of Surface Ensures Reliable Anchoring of Thread Inserts in Organic Sheets

Threaded inserts ensure a secure connection of hybrid components. Under continuous load, effects can occur with thermoplastics due to pressure and temperature, which means that a durable screw connection is no longer guaranteed. Such effects can be prevented by thread inserts with a special surface structure.



Metal thread insert with surface structuring on both sides prevent settling behavior of thermoplastic polymers in multi-material components © IK, IWF

Conventional lightweight designs reach their limits in volume markets such as the automotive industry. In order to be able to achieve economically suitable weight savings, functional lightweight construction using multi-material design for so-called hybrid components made of metals and plastics is used. The advantage of this is the possibility of implementing improvements, such as the integration of functions or the creation of connection points, by combining materials and processes. Due to the combination of metallic materials with plastics, modified fastening concepts for the connection of add-on parts because of the different material properties are necessary.

Multi-material design can be used to reduce the weight of components, improve component performance through functional integration, optimize the production process and increase the cost-effectiveness of large series [1, 2]. The implementation of multi material design for structurally relevant automotive components can be divided into two basic principles (**Fig. 1**) [3]:

- Complex injection molded components with a high degree of freedom and integrated load bearing elements (inserts/onserts) as well as stiffeners such as profiles and corrugated metal sheets.
- Flat shell constructions based on metal sheets or endless fiber-reinforced plastic semi-finished products (laminates).

In addition functional elements such as thread inserts and structures such as ribs or clips in the form of fiber-reinforced plastics are applied to the shell structure by means of casting and compression molding (e.g. injection molding, extrusion and thermoforming). The component weight can be reduced by reducing the wall thickness of the semi-finished metal sheet and using high-strength steels and light metals [4]. In combination with the targeted use of fiber-reinforced plastics, the same or in some cases even better component performance can be achieved with reduced weight compared to the monolithic metal equivalent [5, 6].

Connecting attachments via thread structures formed in the plastic cannot comply with the requirements for mechanical properties and long-term resistance. For this reason, metallic components in the form of flat inserts or threaded inserts are often embedded in the plastic as load-bearing connection points during the application of the functional structure in the manufacturing process. The metal components are provided with undercuts such as beads, drill holes or surface structures [7]. These inserts are embedded with a molten thermoplastic or a resin mixture. After solidification of the melt or cross-linking of the resin, a mainly interlocking connection is created. This type of connection is usually used for screw connections directly on the functional side of plastic and hybrid components. In the case of screwing attachments through the composite material, the use of plastics in combination with metallic threaded inserts has the disadvantage of creeping under permanently loaded regarding to the visco-elastic behavior of plastics.

This problem can be easily identified in **Figure 1**. It shows a hybrid composite of sheet metal and an endless fiber-reinforced semi-finished plastic product with a thermoplastic matrix according to the second basic principle of multi-material design. In order to realize the screw connection in the hybrid composite, a metallic thread insert is placed on the laminate. This is screwed through the hybrid composite with a mounting part that the power flow resulting from the screwing force flows through the plastic component of the hybrid composite as well. When using a fiber composite semi-finished product with a thermoplastic matrix, a relaxation effect occurs as a result of the permanent compressive stresses in the plastic due to its visco-elastic properties and thus a flow of the matrix. Due to the reduction of stress in the plastic, there is a decrease in the pretensioning force of the screw connection. Permanently loaded mounted components in particular can therefore be subject to material-related settling effects, which lead to a change in the mounting position over the service life of the mounting part.

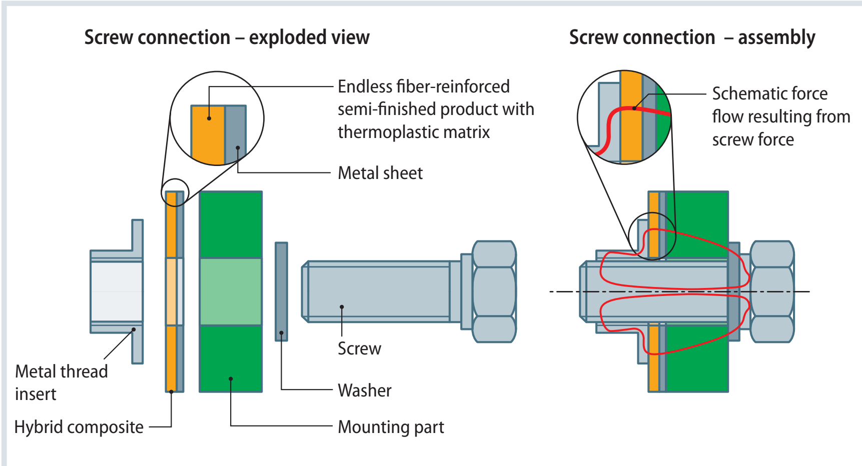


Fig. 1. Metal thread inserts in conventional hybrid composites without surface structuring lead to settling effects on the screw connection Source: IK, IWF, graphic: © Hanser

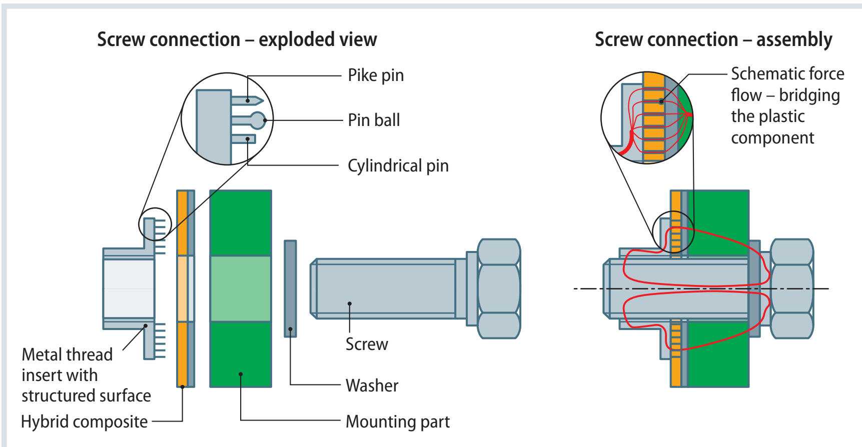


Fig. 2. Pins as a surface structure on metal thread inserts penetrate the tape layer and prevent settling effects of the screw connection Source: IK, IWF, graphic: © Hanser

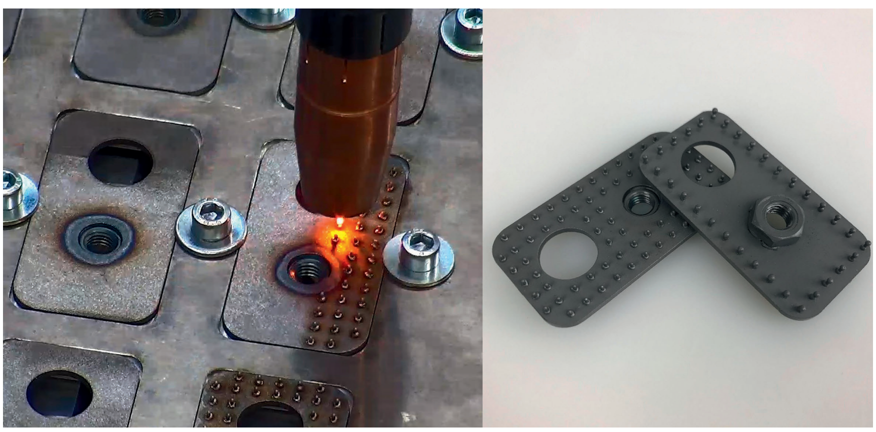


Fig. 3. CMT welding allows pins of defined length and with different head shapes to be attached to the thread inserts © IK, IWF

Bridging the Force Flow

In order to prevent the connection from settling and to enable the load effect of the screw connection to be better transferred to the hybrid composite, the fiber-reinforced plastic must bridge the force. The subject of the investigation in this case is a special surface structuring on the contact side of the thread insert to the semi-finished fiber-reinforces plastic »

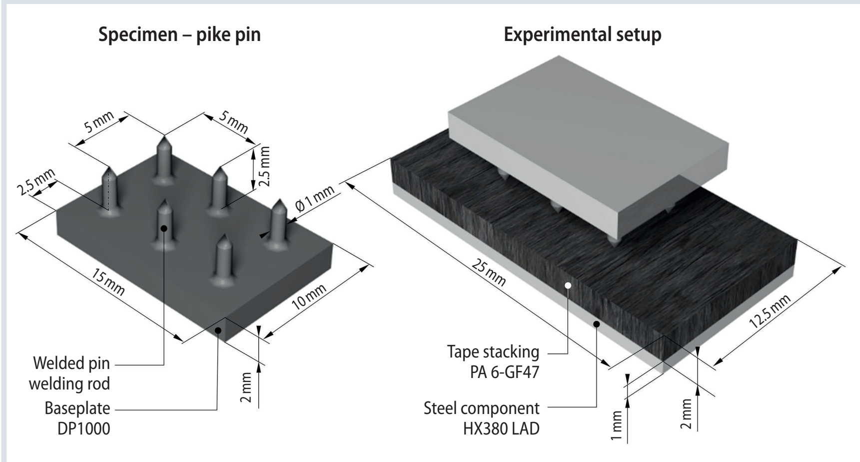


Fig. 4. Peak pins (left) are particularly suitable for textile semi-finished products. In the test, a glass fiber-reinforced PA6-tape fabric was penetrated with them © IK, IWF, graphic: © Hanser

product. The structure in the form of pin-shaped attachments (**Fig. 2**) penetrates the melted thermoplastic matrix of the semi-finished plastic product when the hybrid composite is processed and is supported on the metal side. The length of the structure is chosen about 25% larger than the thickness of the plastic component to be penetrated. As a result, the structure deforms on the metal side of the hybrid composite when pressed in and can form undercuts that lead to a interlocking connection. The support of the tightening forces, the tightening torque and the operating loads by the hybrid composite is thus ensured and the settling behavior of the connection is reduced.

Methods such as 3D printing, laser structuring, forming of the surface and welding can be used to form the surface structures on the thread insert [8–11]. The Cold Metal Transfer Welding (CMT) process is chosen for the thread insert described below. It represents a targeted possibility to implement the required structure in the form of pins on the surface. The advantage of the process is the possibility of robot-controlled application and thus a high repeatability with reproducible, defined dimensioning (length and tip shape) of the surface structure.

CMT welding is a further development of classic metal active gas (MAG) and metal inert gas (MIG) welding and is therefore an arc welding process. Its special feature is the active control of the filler metal during the welding process. A digital process control system detects the short circuit between workpiece and filler material during welding. By controlled retraction of the welding wire a stable welding process is guaranteed. Compared to the MIG process, it is characterized by improved drop separation and less heat input into the workpiece. The adjustment of the process parameters enables a part of the welding wire to be attached to the surface and cut off in a defined length. The length of the pin-shaped attachments produced in this way is between 0.8 and 3.0 mm. The pins can be designed as pike pin, cylindrical pin or pin ball by process adjustments [12].

Pins with spherical heads (pin ball) are suitable for connecting fiber-reinforced plastics and metals in order to form undercuts for a positive-locking connection [11]. For non-destructive penetration of materials, pike pins should be selected. Especially textile semi-finished products, such as endless fiber-reinforced laminates like organic sheets or tapes, can be penetrated with these similar to a needle without causing severe damage to the fibers. [13]

An automated welding process with a robot was used to manufacture the thread inserts (**Fig. 3**). The sample sheets were clamped in a fixed holder on the table in front of the robot for reproducible production of the pin structures. In order to investigate the penetration behavior of the pin structures into a tape layer, six pins with a tip were applied to a base plate made of a dual-phase steel (DP1000) (**Fig. 4, left**). These pin samples were pressed into a hybrid composite of a steel (HX380 LAD) and a tape fabric with a matrix of polyamide 6 (PA6) with a glass fiber content of 47% (**Fig. 4, right**).

The Authors

Dipl.-Ing. Benjamin Bader has been working as a research assistant at the Institute of Engineering Design (IK) at the Technische Universität (TU) Braunschweig, Germany, since 2015; b.bader@tu-braunschweig.de

Werner Berlin, M. Sc., has been working as a research assistant at the Institute for Machine Tools and Manufacturing Technology (IWF) at the TU Braunschweig since 2018; w.berlin@tu-braunschweig.de

Michael Demes, M. Sc., has been a research assistant at the IWF since 2015; m.demes@tu-braunschweig.de

Prof. Dr.-Ing. Klaus Dröder heads the IWF since 2012; k.dröder@tu-braunschweig.de

Prof. Dr.-Ing. Thomas Vietor heads the IK since 2009; t. vietor@tu-braunschweig.de

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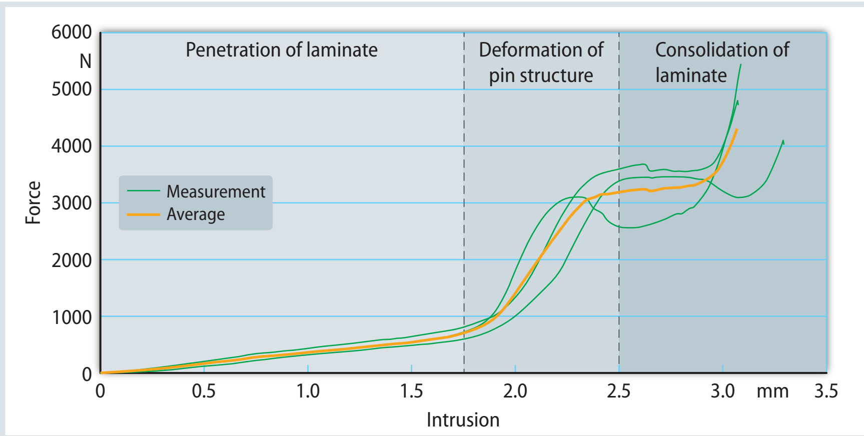

Fig. 5. Force-displacement characteristic when pressing the pin samples into the hybrid composite in accordance with DIN EN ISO 604 under the influence of temperature Source: IK, IWF, graphic: © Hanser

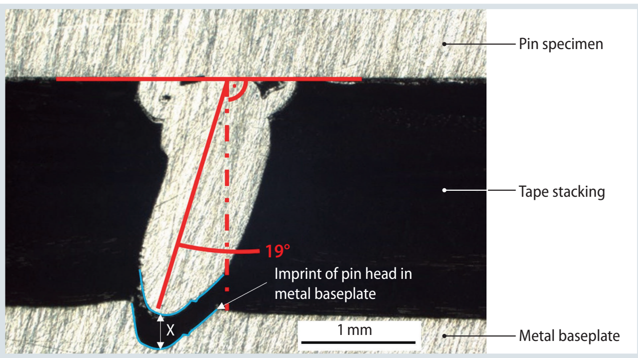

Fig. 6. The molded contour of the pin tip clearly shows that contact between the pin and steel base plate has occurred during the insertion process Source: IK, IWF, graphic: © Hanser

The penetration begins on the side of the plastic component of the hybrid composite. The matrix of the tape layer is melted by heating for 300 s at 220 °C in a plastic oven. The test was also carried out at 220 °C in order to maintain the molten condition of the matrix during the test. The selected temperature corresponds to the melting temperature of the matrix material PA6. The test is based on the pressure test for plastics according to the standard DIN EN ISO 604. A preload of 50 N was applied to ensure that all pins of the sample were in contact with the hybrid composite at the beginning of the experiment. Afterwards the sample was pressed 3.0 mm into the hybrid composite. The pin lengths of 2.5 mm are designed so that after penetration of the tape layer with a nominal thickness of 2.0 mm there is still a gap of 0.5 mm between the sample and the tape layer. This gap is closed in the further process. During this process, the pins deform due to the pressing forces applied.

In the course of the test, the force required for insertion was recorded. The force-displacement curves of the individual samples can then be combined to form an averaged curve in which an average value of the required penetration forces of all samples is assigned to each way point (**Fig. 5**).

Three main phases can be defined. In the first phase the pins penetrate the tape layer. With increasing penetration depth, the force increases almost linearly. This is due to an increasing displacement of the matrix and fibers during penetration. After about 1.75 mm the second phase begins. The distance travelled does not yet correspond to the thickness of the tape layer. Nevertheless, it can be assumed that an increasing elastic deformation of the pins is already occurring. This manifests itself in an increase in the gradient in the force-displacement diagram and can be explained by deviations from the nominal thickness of the tape layer, tolerances in the length of the individual pins and accumulations of fibers in front of the pins during penetration. The beginning of the third phase is characterized by the beginning of plastic deformation of the pin structures. Initially, a smaller increase can be observed in the force-displacement diagram. From about 3.0 mm penetration depth, increased compression of the tape layer begins, which further increases the force gradient. The maximum force at a travel distance of 3.0 mm is on average 3700 N.

The forming of an undercut at the plastically deformed pins was investigated by means of the preparation and microscopy of micrographs. **Figure 6** shows an example of such an image, in which the pin was bent by about 19° compared to its original orientation. The molded contour of the pin tips can be seen in the metal. This is a clear indication that the pin was in contact with the steel component of the hybrid composite during the press-fit process. The distance X (**Fig. 6**) is due to the recovery of the elastic components of the tape layer, which leads to the pin sample lifting off the steel base plate. This lift-off is reduced by the tightening torque of the screw due to elastic and plastic deformation of the plastics. If the tightening torques are too low, a gap filled with plastic remains between the pins and the metal component. This can lead to a reduction of the screwing forces due to viscoelastic flow of the plastic. A sufficiently high tightening torque, which leads to contact between pins and metal component, is necessary.

Minimizing Settling Effects

Settling effects occur in load-bearing screw connections in hybrid composites due to settling behavior of the plastic semi-finished product under load and temperature. The result is an undesirable change in the mounting position of the attachment part. With a metal thread insert with a special surface structure, the settling behavior can be minimized and the load transfer into the multi material structure can be improved. The thread inserts with surface structuring by different pin geometries penetrate the thermoplastic matrix of the semi-finished plastic product when the hybrid composite is pressed and are supported on the metal side. In this way the plastic component is bridged from the perspective of the power flow of the screw connection and the settling effect is reduced. A deformation of the pins during the pressing process in the semi-finished plastic product ensures a further improved load introduction through an additional positive fit. ■