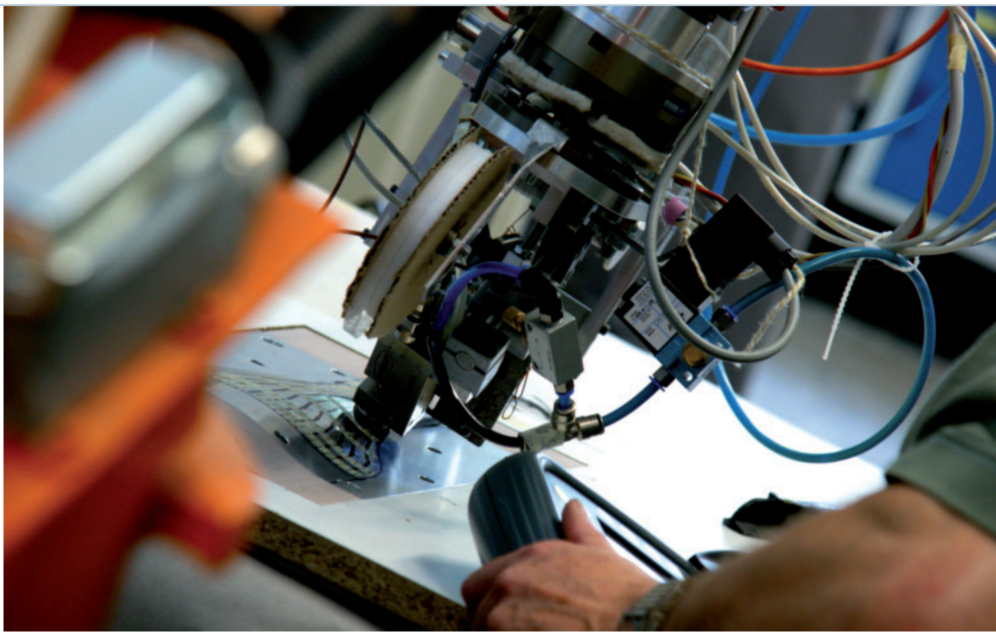

In the newly developed process, a robot lays up the bundled continuous fibers and fixes them with adhesive (photos: KVB)

Adhesive Fixing of Rovings Increases Load Bearing

Fiber Composites are continuing their advance as lightweight engineering materials. An important factor in the part design is the orientation of the fibers in the loading direction. However, the method of laying individual fiber rovings in the direction of force is almost never used. It is facilitated by a new process in which a robot tracks the lines of force and fixes the filaments with a cold adhesive system.

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Fiber composites, particularly carbon fiber-reinforced polymers, have a proven track record for extremely lightweight engineering [1, 2]. In preform technology, manufacture of fiber-reinforced components is subdivided into the processes of fiber lay-up and resin impregnation, and pressing, including curing. Depending on the method chosen, lay-up and impregnation take place in different sequences:

- Direct fiber lay-up with simultaneous resin impregnation in the mold (e.g. by winding and hand lamination),
- preparing a dry preform, inserting it into a mold and subsequent resin infiltration, or
- resin infiltration of the fibers prior to lamination and lay-up (prepreg method).

In the final step in each case, the component is pressed and cured.

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Effect on Part Properties

The production of flat, low-profile parts that must withstand flexural, tensile and compressive loads is the standard case and is sufficient for many requirements. The lay-up and impregnation of the fibers with resin can be performed in alternation, simultaneously or sequentially with the above-mentioned techniques [3, 4]. Subsequent pressing to the nominal thickness ensures precise geometries and a high fiber-volume fraction. Three-dimensional (3-D) parts can also be produced using textile fabrics and mats in many cases, however wrinkling and deviations of the fiber orientation from the loading direction are often unavoidable. This can be remedied with 3-D preforms, which are prefabricated as semifinished products and subsequently infiltrated with resin [5–7].

The fiber orientations in the laminate layers determine the strength and stiffness of the composite. If a component is optimally designed, the fibers are ten-

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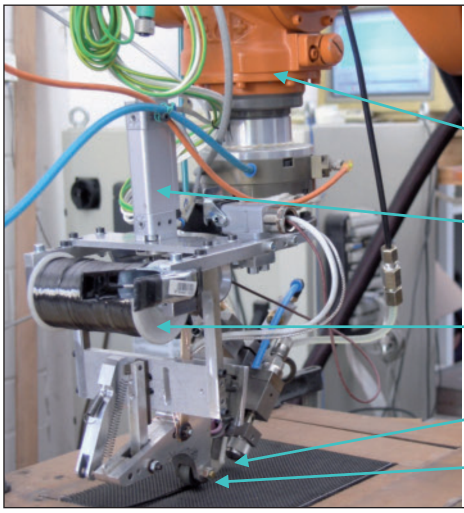

Fig. 1. In the cold-adhesive device, the roving is guided through a fiber-feed nozzle on the preform

sioned in the stressing direction; deviations of more than 3° from this often actually impair the properties. With multiaxial stressing states, the layer structure in the composite is often a compromise. Therefore, controlled lay-up of individual rovings is a necessary step in improving the exploitation of high-performance fibers.

Currently, preforms designed specifically for the loading case, with bundled continuous fibers, are produced using various stitching techniques, but do not present an optimum solution. Industrial methods include stitching and embroidery processes, in which either flat mats are stitched together or rovings are laid-up individually according to the loading and stitched onto the preform layer. The latter is known as tailored fiber placement (TFP) [8–12]. This contrasts with the fiber patch placement (FPP), in which the roving to be laid up is first coated with a thin layer of thermoplastic adhesive and cut into pieces [13]. Another possibility is to fix the bundled continuous fibers with the aid of thermoplastic filaments [14].

Designing Additional Reinforcement Layers According to the Stresses

In nature, it is common to find fiber-composite structures whose geometry and fiber reinforcement are optimized to the loads they have to withstand. Examples include trees, grasses and bone. Based on this example, the Institute of Design and Composite Structures (Institut für Konstruktion und Verbundbauweisen – KVB), Chemnitz, Germany, developed a novel process for producing 3-D preforms with extra reinforcement. The aim of the studies is to fix rovings by spot bonding and thereby produce stress-optimized preforms with low defects and a complex integral 3-D contour. The separate production steps of the preform production as mats and the manufacture of finished parts have been technologically restructured. This restructuring process comprises the individual steps of draping, positioning, impregnation, pressing, curing, demolding and secondary processing. In future, this should permit mass production with reproducible first-class quality.

In the newly developed process, a robot lays up the bundled continuous fibers in a limited number of layers and applies the fixing adhesive spots by means of a cold-adhesive system (Title photo). The system consists of

- a small pressure vessel containing the liquid adhesive,
- a thin, flexible and compact tube, which does not restrict the freedom of movement, and transports the adhesive, and
- a pneumatically operated spray head.

First, the roving is guided from the bobbin by a thread-feeding nozzle for lay-up on the substrate surface (Fig. 1). The nozzle moves along the path on which the roving is to be laid-up in the finished preform. A small adhesive spot is sprayed at the relevant points between the roving and component. A hot roller presses the fibers onto the substrate surface and effects rapid evaporation of the solvent (Fig. 2). When all the rovings have been fixed in orientation with the lines of force and the final preform has been built up, the component is infiltrated and pressed (Fig. 3).

A Comparison of Adhesive Systems

A sprayable resin-compatible adhesive is used for bonding. With some industrially available cold adhesives, however, the adhesive effect is so greatly reduced by the high solvent content that a long evaporation time is necessary for the roving to bond adequately to the substrate. In the

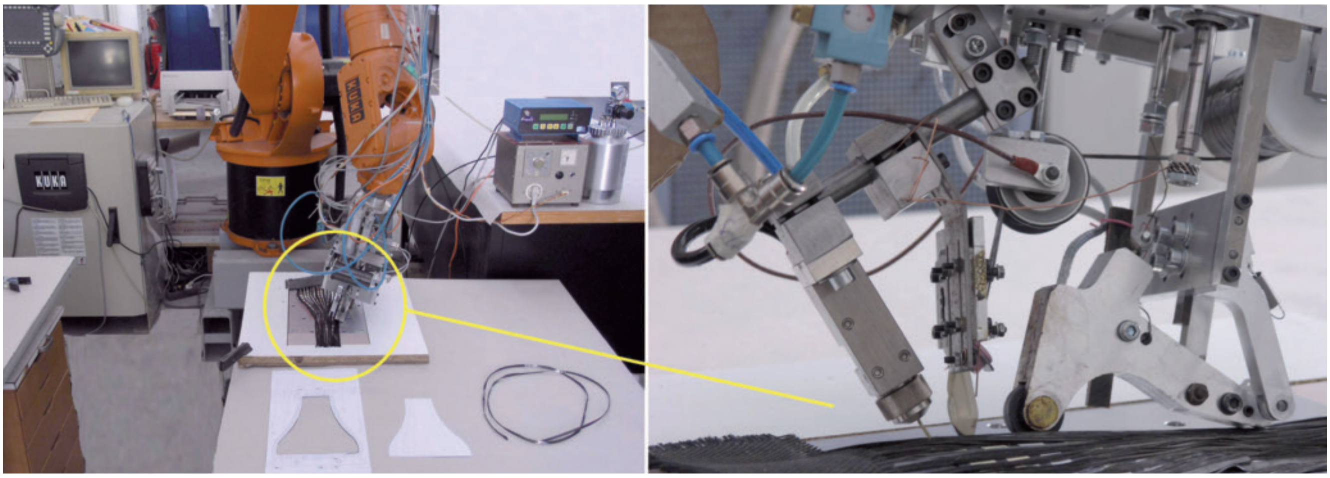

Fig. 2. The roving is laid-up in the swallowtail mold and fixed step-by-step by fiber placement, adhesive spraying and pressing

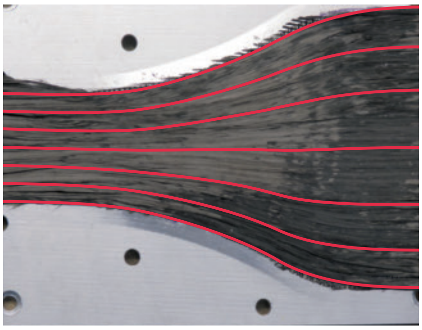

Fig. 3. In the left-hand figure, the rovings are positioned oriented to the schematic lines of force; beside them, the resin-infiltrated part can be seen in front and side view

Criterion	Adhesive fixing acc. to the R&D project	Stitching by TFP	Adhesive fixing by FPP
Number of roving layers	Max. five	Complete part can be produced from deposited rovings	Complete part can be produced from deposited rovings
Strength of the fixing	Rovings only tacked on	Roving firmly fixed	Roving firmly fixed
Precision of the roving orientation	Positional accuracy not less than 1 mm; rovings cannot be tensioned	About 0.3 mm acc. to manufacturer; rovings can be slightly tensioned	About 0.5 mm acc. to manufacturer; roving pieces are laid straight
3-D preforms	Parts can be three-dimensionally curved	Parts must generally have a flat basic structure	Parts can be three-dimensionally curved
Preform substrate	Laminate can be built up directly in the mold	Underside must be freely accessible for the stitching process	Laminate can be built up directly in the mold
Dimensions of the roving pieces	Width depending on availability, length unlimited; width determines minimum radius	Width depending on availability, length unlimited; width determines minimum radius	Of the order of 20 × 60 mm; radii can be realized with oblique/round cut edges

Table 1. Adhesive fixing of rovings is compared with the processes of TFP (tailored fiber placement) and FPP (fiber patch preform) according to production engineering aspects

cold-adhesive process, therefore, it is more suitable to use resin-compatible hot-melt adhesives, which are available as powders or granules and are fluidized with acetone for the process.

Hot-melt adhesive systems could be used instead of cold adhesive systems. However, hot-melt adhesives have the disadvantage that they cannot be so finely sprayed. In addition, after hot rolling, further cold rolling is necessary to prevent the rovings from lifting off before the adhesive has cooled sufficiently. The relatively large, compact adhesive spots increase the amount of adhesive in the final part, which results in local flow obstructions for the impregnating resin and leaves behind defects in the fiber composite in the form of air inclusions or adhesive accumulations. These defects in turn affect the part properties. The mobility of the robot head is greatly hampered by a thick, rigid and pressure-resistant adhesive feed tube, which has to be heated for hot-melt adhesion. Besides the above-described greater flexibility and lower adhesive content, another advantage of a cold-adhesive system is that the subsequent cold pressure roller is not needed.

As a result, the lay-up device on the robot head can have smaller dimensions, allowing it to be used more flexibly for working in curved 3-D geometries. This eliminates another disadvantage of the follow-up cold roller: despite the non-stick coating, it nevertheless tends to stick because of the incompletely hardened adhesive, and therefore lifts off the roving that has just been laid.

Summary

Table 1 compares the processes for preform production with stress-oriented fiber lay-up. Adhesive fixing of rovings is particularly suitable for introducing a limited number of additional reinforcing roving layers in the stress direction in the part – the preform continues to be produced traditionally to a certain extent, using mats and fabrics. The process permits three-dimensional lay-up without the need for additional space beneath the component for manufacturing stages such as stitching.

This bonding technology is especially suitable for high-strength lightweight components in machinery, plant, automotive and aircraft engineering. ■

REFERENCES

The list is available online at
www.kunststoffe-international.com/A007

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