# Integration and evaluation of mechanical and electrical joints in function-integrative textile reinforced thermoplastic composites

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## Abstract

*This paper presents the technological realization and experimental evaluation of adapted mechanic-electrical joints for function-integrative textile reinforced thermoplastic composites by means of blind riveting. For the necessary rivet holes a conventional drilling method and an adapted hole molding technology for thermoplastic composites are used. In regard to the hole molding process the textile-reinforcement will not be locally destroyed but bypassed around the hole. Furthermore, joints with molded and drilled holes are compared regarding to their mechanical and electrical behavior. Finally, the durability and quality of the conductive materials, integrated in textile reinforced thermoplastic composites, and the electrical contacts are evaluated.*

## 1 Introduction

Textile-reinforced polymers with thermoplastic matrix systems exhibit a great potential for the application in mass production of lightweight structures. They are characterized by highly-specific mechanical properties and manifold design possibilities in combination with economic and reproducible manufacturing processes [1-4]. In this connection textile-reinforced thermoplastic composites, developed in the frame of the Collaborative Research Centre SFB 639, show the possibility for material functionalization e.g. by the integration of conductive paths and sensor networks [5-9]. By the embedded components signal generation and processing is realizable in structural parts. Furthermore the transmission of electric energy inside the composite part becomes possible without additional electrical components outside of the structure. In regard to the signal- and energy transfer between such functionalized structures, specially adapted interfaces are necessary (see Figure 1).

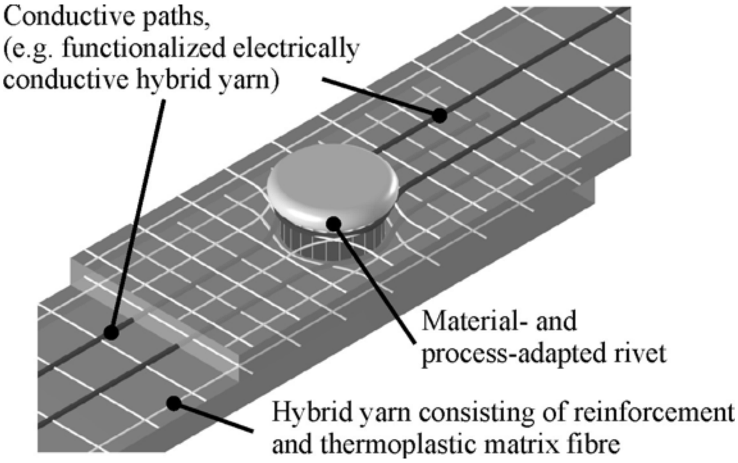


**Figure 1:** Schematic illustration of combined structural and electrical interface of joined functionalized thermoplastic composites

Besides mechanical requirements these interfaces also have to fulfill special thermo-mechanical demands of modern multi-material designs, such as robustness, the compensation of different coefficients of thermal expansion, and the avoidance of contact corrosion.

## 2 Description

The presented investigations deal with textile-reinforced thermoplastic composite parts with integrated conductors, which are already embedded during the consolidation process. The electrical contact between two integrated conductors in the composite parts will be realized by an adapted blind rivet technology. Therefore special blind rivets made of copper are used. For the blind rivet technology a previous hole-punching step is necessary to position and set the rivet. Concerning to the manufacturing of these holes a conventional drilling method and an adapted hole-molding technology, where the textile reinforcement will not be locally destroyed, like by drilling methods, but bypassed around the hole, were investigated. Previous investigations show that the hole-molding technology affects higher strengths, increased structural behavior in the case of initial failure, and higher deformation energy in comparison to drilling methods [10]. Regarding to the used hole forming technologies several variants of copper wire, copper mesh, and copper films were already investigated in initial studies to evaluate the ability for an appropriate design of the contact zones [10]. There, the copper mesh and copper film variants show the highest potential for a reproducible electric-mechanical joining zone, so that these material combinations are used in the latest investigations. Furthermore, initial investigations also showed that single riveted joints do not deliver constant electrical contacts due to the twistability of the joining zone. Therefore the contacts are additionally provided by a silver conductive varnish. In the following investigations the mechanical properties of the composites with integrated conductors are evaluated by tension tests and compared to textile-reinforced parts without embedded elements. There the influence of the embedded conductors to the mechanical properties of the textile reinforced thermoplastic composite is investigated. Furthermore, single-lap shear tests were performed to determine the maximum load capacity of the joining zone and the change of the electrical contact of selected joining variants. All mechanical tests are accompanied by an electrical measurement to determine the behavior of the electrical conductivity under mechanical load.

## 3 Manufacturing of test samples

The lay-up of the textile reinforced thermoplastic plates consists of 4 or 6 layers multi layered weft-knitted fabrics (MKF) made of glass and polypropylene. In the middle layer of the symmetrical lay-up the conductors are positioned and fixed by stitching with polyamide 6 (PA6) yarn. Two different types of conductors are used. The first variant is a copper film conductor. It consists of a 21 µm thick and 10 mm wide copper foil strip. The second type is a copper mesh structure. This is characterized by a width of 10 mm and a thickness of 150 µm. There the mesh consists of wires with a diameter of 62 µm and the repeat of the mesh is 166 µm. The conductors are lead out of the lay-up nearby the edge of the layers to enable a defined contact position for the power supply and the measuring devices. Furthermore, the MKF-layers with the integrated conductors are consolidated by a temperature of 200 °C and a pressure of 6 bar over a time of 30 minutes. The lay-up and a consolidated plate are shown in Figure 2.

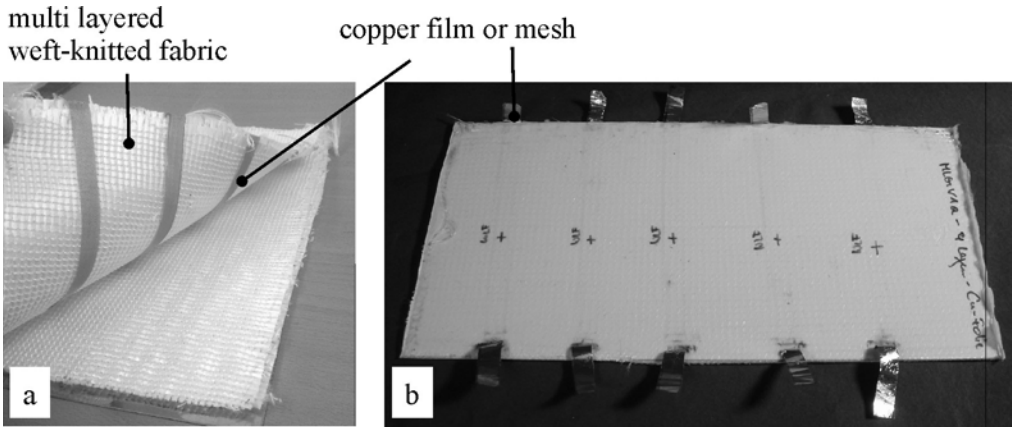


**Figure 2:** Lay up for the integration of conductors in the textile reinforced thermoplastic composite
a) Lay up with fixed copper mesh stripes
b) Consolidated plate with embedded copper film stripes

In the next step the consolidated plates are cut into several test samples by a water cooled saw. Regarding to the tension tests the samples are cut to stripes of 250 mm length and 25 mm width. For the single-lap shear tests stripes with a length of 150 mm and a width of 25 mm are cut. Furthermore these stripes have to be assembled and joined by blind rivets to single-lap specimens (see Figure 3).

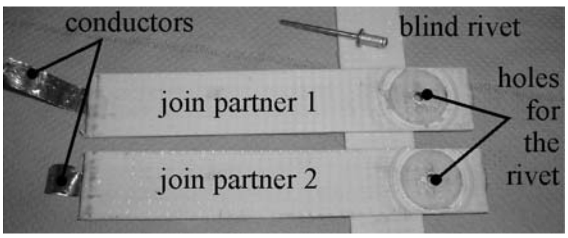


**Figure 3:** Built up of single-lap specimens

Regarding to the necessary rivet holes, one half of the holes are drilled by a drilling bit with a diameter of 3.8 mm. The other holes are formed by the novel hole-molding technology using a pin with a diameter of 4 mm. Figure 4 shows the schematic process for the hole-molding technology.

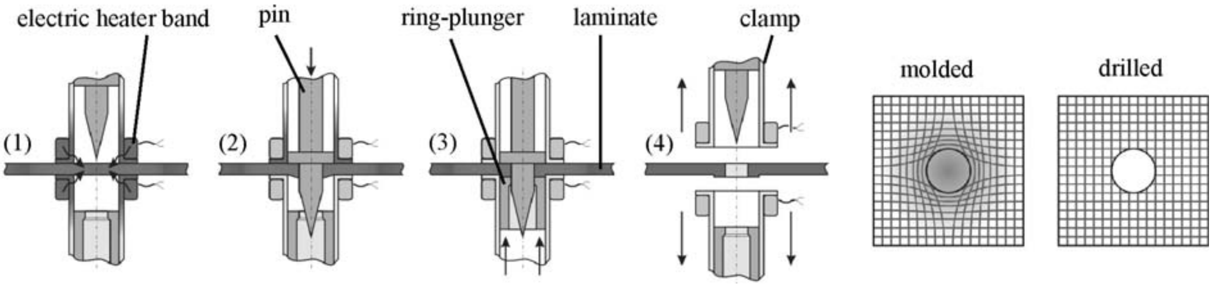


**Figure 4:** Schematic outline of the hole-molding technology and sketch of the fiber flow for drilled and molded holes [10]

At first, the process starts with local heating and melting of the joining zone using a ring shaped heater (1). Afterwards, a hole is molded by inserting a tapered pin into the molten laminate and shifting aside the reinforcement (2). In order to compact the laminates back side after fiber-reorientation, a ring-shaped plunger moves coaxially against the pin (3). Subsequent to cooling and solidification of the thermoplastic matrix, the notched part is demolded and led to assembly (4) [10]. Figure 4 also shows the different fiber flow around a hole in a textile-reinforced part caused by molding and drilling. Drilling interrupts the fibers and the hole-molding displaces the fibers around the hole.
After generating the holes the specimens are assembled to single-lap test specimens by copper blind rivets with a diameter of 4 mm and a shaft length of 8 mm (see also Figure 3). Regarding to the insufficient safety against the twistability of single blind rivet joints, further specimen variants with an additional silver varnish were investigated. The varnish is used to improve the mechanical contact and to enlarge the area of the electrical contact zone. To that effect, one half of the single-lap specimens are joined additionally by means of the silver varnish. Therefore, the shafts of the blind rivets and the inner circumference of the holes are coated by the liquid silver varnish and subsequently the samples are riveted.

## 4 Experimental set up

### *4.1 Tension tests*

The tension tests are performed based on DIN EN ISO 527 on a Zwick 1465 with a load cell of 50 kN. Concerning to the test set up, several sample arrangements are used. Figure 5 shows the configuration of the investigated specimens. The specification of the samples was selected according to the fiber orientation of the MKF and to the orientation of the integrated conductors in relation to the loading direction. There the nomenclature CUM means that copper mesh is used as conductive material and the designation CUF is applied for copper foil conductors. Each specimen is characterized by a length of 250 mm, a free clamping length of 125 mm, a width of 25 mm and a thickness of 3.26 mm. Simultaneous to the mechanical testing the samples with the specifications CUM 0°, CUM 45°, CUF 0° and CUM 45° are controlled by an electrical test set up. This is used to control the electric behavior under loading and to determine the order of failure, whether the MKF or the conductors are damaged first.

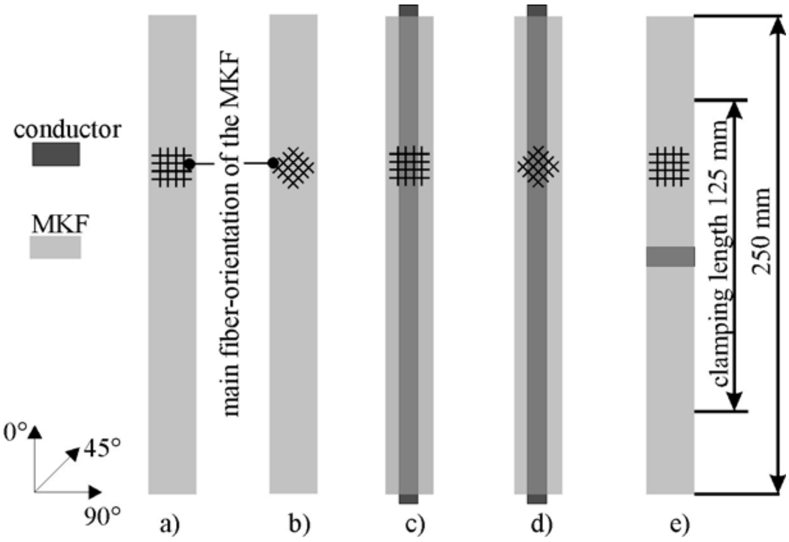


**Figure 5:** Test sample configurations for the tensile test

a) Unaffected MKF, specimen specification MKF 0°, MKF 90°
b) Unaffected MKF, specimen specification MKF 45°
c) MKF with integrated conductor, specimen specification CUM 0°, CUF 0°
d) MKF with integrated conductor, specimen specification CUM 45°, CUF 45°
e) MKF with integrated conductor, specimen specification CUM 90°, CUF 90°

*4.2 Single-lap shear tests*

Based on DVS 3480-1 single-lap shear tests are performed on a testing machine Zwick 1465 and a load cell of 50 kN. Figure 3 shows a representative single-lap specimen.

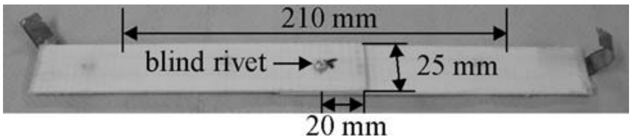


**Figure 6:** Single-lap shear specimen

These samples are characterized by an overall length of 260 mm, an overlap of 40 mm, and a width of 25 mm. The single joining partners have a thickness of 2 mm. The rivet is positioned 20 mm away from the edge of the shorter side and 12.5 mm from the edge of the longitudinal side of each join partner. In the tests a free clamping length of 210 mm was used. Figure 7 shows the test set up for the single-lap shear tests. Therefore, the specimens are clamped with hydraulic clamping jaws.

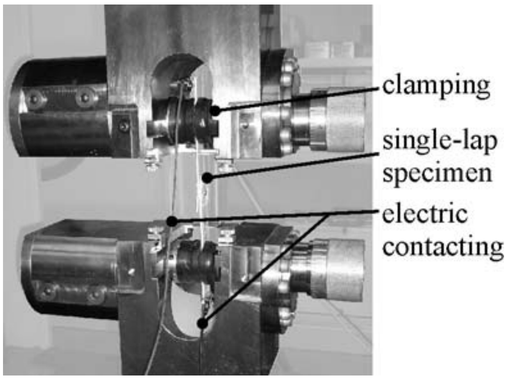


**Figure 7:** Single-lap shear tests - test set up

Outside of the jaws an electric measurement system is connected to the conductors to control the electric contact during the loading of the sample. Therefore, the electric test set up consists of a power source, a measuring board, and a lab view programme. Table 1 shows the investigated single-lap specimen configurations.

| sample specification | Conductor material | | Hole forming technology | | Additive |
|---|---|---|---|---|---|
| | Copper foil | Copper mesh | Drilling | Hole-molding | Silver varnish |
| CuM_B_xx | | X | X | | |
| CUM_WLF_xx | | X | | X | |
| CUM_B_SL_xx | | X | X | | X |
| CUM_WLF_SL_xx | | X | | X | X |
| CuF_B_xx | X | | X | | |
| CUF_WLF_xx | X | | | X | |
| CUF_B_SL_xx | X | | X | | X |
| CUF_WLF_SL_xx | X | | | X | X |

**Table 1:** Specimen configurations and specifications for single-lap shear tests

## 5 Results

### *5.1 Tension tests*

The tension tests show that the integrated conductors only marginally affect the mechanical properties of the composite in 0° and 90° orientation (see Figure 8 left). Compared to the MKF structures the specimens with integrated copper foils have similar mechanical properties. The samples with integrated copper mesh conductors show in 90° orientation even higher maximum stresses than the pure MKF composite. Regarding to the samples with 45 ° orientation the integrated copper conductors cause a reduction of the mechanical properties. There the maximum stress will be reduced to 83 % of the unaffected MKF for copper mesh and in the case of copper foil it is reduced up to 78% compared to the pure MKF. Furthermore, the accompanying electric measurements show that all integrated conductors are damaged only after the failure of the structure and the electric resistances are nearly constant over the whole testing time (see Figure 8 right).

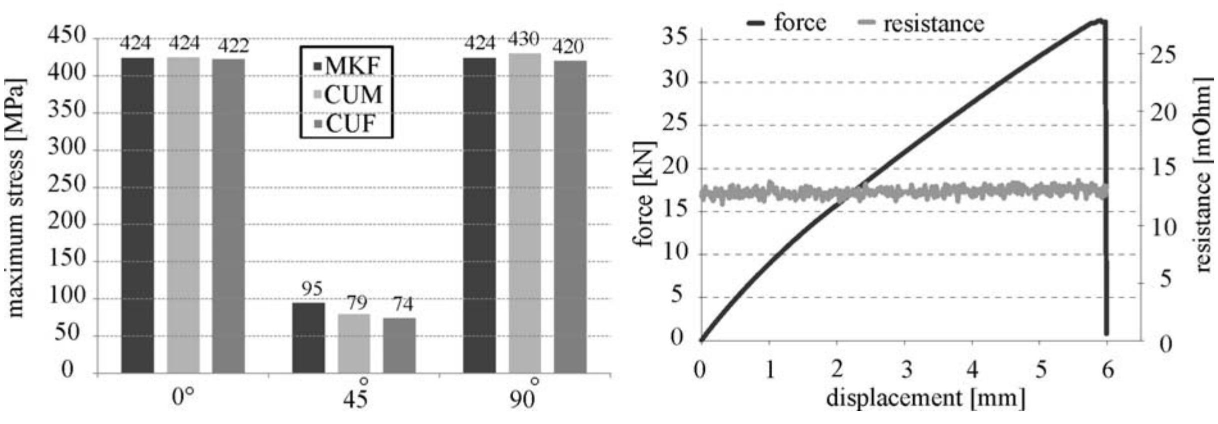


**Figure 8:** Comparison of the maximum stresses of the investigated specimen configurations (left) and a selected load-displacement-resistance-diagram from the electrical measurement (right)

### *5.2 Single-lap shear test*

In regard to the single-lap shear tests, the first failure occurs at the blind rivets. Common failures are shear failure of the rivet shaft or the pull through of the closing head. The rivets have hollow and thin-walled shafts. Therefore the change in stiffness from the composite to the rivet is relatively high, so that the resulting mechanical strengths of the jointed samples are relatively low. The electrical contacts were nearly constant over the whole testing time and remained until the total break-down of the jointed specimen (see Figure 9 right). Concerning to the comparison of the hole forming technologies, the samples with drilled holes show lower strengths, but less statistically spread than the specimens with molded holes. The additional silver varnish shows no significantly affect to the mechanical behaviour of the joints in these tension tests.

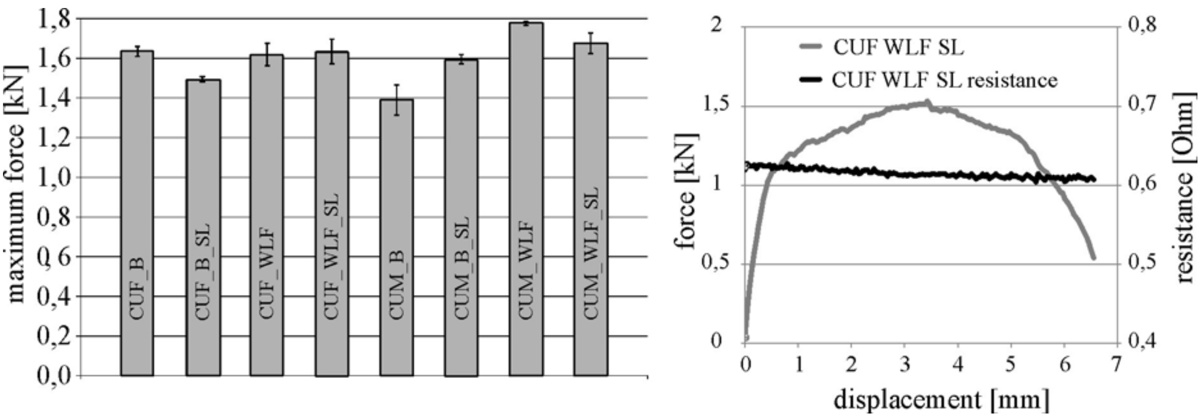


**Figure 9:** Results of the single-lap shear tests (Left: average maximum forces of the investigated joints; Right: exemplary force-displacement and resistance-displacement-diagram of a selected joint configuration)

## 6 Conclusions

The presented experimental investigations examine newly developed adapted joining techniques for function-integrative textile-reinforced thermoplastic components. Thus, blind riveting was selected as the basic joining technology. Here, the necessary rivet holes are manufactured by drilling and molding. In the performed studies the technologies for the hole-generation are compared, the integrated conductors are evaluated concerning structural degradation of the composite and selected blind rivet configurations are evaluated by mechanical and electrical testing. The experimental investigations show that the integrated conductors don’t affect the textile-reinforced composites in the main loading directions. Though, the specimen with a fiber orientation of 45 ° showed a degradation of the mechanical properties. The electric conductivity of each specimen was stable even after the failure of the composite structure. Furthermore, the tensile tests with single-lap specimens show that the electric resistance of the joint remains unaffected by the external load until the total mechanical failure of the specimen. Besides, adapted joints with molded holes show a higher ultimate load capacity and overall deformation energy than samples with drilled holes. In summary, the developed adapted joining technique allows for the realization of function-integrative assemblies made of textile-reinforced thermoplastics. On the basis of the presented results, progressive research is planned in order to improve the mechanical properties of adapted joints with molded holes. Therefore, mold tools will be re-designed and steel rivets with a copper coating will be used. Furthermore, the joints have to be investigated under cyclic loading.

## 7 Acknowledgement

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