THE FUTURE MOBILE REPAIR SYSTEM - A TECHNOLOGY DEMONSTRATOR FOR THE AUTOMATED REPAIR OF CARBON FIBRE REINFORCED PLASTICS

J. Holtmannspötter, J. de Freese, J. C. Meyer, M. Niedernhuber, F. Feucht

[1]WIWeB, Institutsweg 1, 85435 Erding, Germany
Email: JensHoltmannspoetter@Bundeswehr.org, Web Page: http://www.WIWeB-Erding.de

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Abstract

For structures made of carbon fibre reinforced plastics (CFRP) robust, fast, and reliable repair technologies are mandatory for economic usage. A key factor for the quality of bonded repairs is the scarfing and surface treatment process of the composite structures. Currently and for the past decades, most of the repair areas were simply prepared by manual grinding processes, which produce neither reliable nor robust surfaces for adhesive bonding.

In this paper, the possibilities and technical implementation of an automated milling process for the repair of composite structures are presented. The milling process has been developed to scarf the damaged area with high precision and to prepare the surfaces for adhesive bonding with a high reproducibility. The FMRS (Future Mobile Repair system) consists of a mobile 5-axes-milling unit and a control station. The mobile milling unit can be mounted on damaged aircraft structures by means of a vacuum suction system. An integrated laser-line scanner allows sampling of the complete surface with high accuracy. This change from manual production to automation tremendously improves the quality and durability of the repair and allows the creation of a uniform surface for adhesive bonding. Further integration of novel technologies is discussed and will further support and enhance the repair in the near future. Due to the high milling precision, new approaches for CFRP repair can be realized. Fibre-oriented repair scarfs are discussed with regard to minimisation of the repair area size.

1. Introduction

High performance fibre reinforced composites are increasingly used in light weight aerospace structures. The high tensile strength, the low weight, the favourable fatigue behaviour, and the ruggedness against outer influences (corrosion) have led to a significant increase in the use of carbon fibre reinforced composites. Besides various successful applications in military aviation, nowadays there are even two civil airliners (Boeing 787 and the Airbus A350) on the market that mainly consist of FRP materials.

For economic usage, analogous to recent metallic structures powerful and reliable repair technologies are mandatory. Adhesive bonding has already been applied for many years with great success in the repair of fibre-reinforced structures although it is still a challenge to establish reliable and robust adhesive bonding processes. Moreover, there is no non-destructive technique that can quantitatively test bonded structures. And, for repair processes on damaged aircrafts with used material and the presence of numerous contaminants the situation is even worse.

From the authors' point of view, the key factor for successful CFRP repairs is scarfing and surface preparation.

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2. Surface preparation - the key factor for reliable repairs

As a first step, cleaning is a must to avoid smearing and spreading of mobile contaminants on the surface. Over the past decades up to now, areas for repair are prepared by hand tools using sand paper or sanding discs. It is a simple method to remove thick layers of non-bondable, undefined surface layers. But the sanding processes are time consuming and highly dependent on the personal skill-level. The creation of a scarf by hand requires several hours. Visually exact stripping even of thin layers is possible. But it has to be taken into account, that grinding of polymers often does not lead to bondable surfaces and the ability to achieve satisfactory bond strength. Sanding therefore is a problematic process that is furthermore difficult to automate.
In preliminary studies, different surface preparation technologies like blasting, sanding, laser ablation and milling have been examined by surface analysis methods and destructive tests.

3. Automated milling

Milling is a process that allows material to be removed with high precision. In contrast to grinding and abrasive processes, milling is capable of reproducibly creating uniform surfaces at a high level of automation. Therefore it has been chosen for the automated repair. In order to produce CFRP surfaces suitable for adhesive bonding, i.e. without smearing and minimal interference to the fibre-matrix interfaces, the milling process needs to be optimized. Due to the material properties of CFRP and all types of composites in general, it is challenging to find a proper milling strategy to yield suitable surfaces. Because a composite comprises at least two different materials, the cutting conditions for the tool are constantly changing. Furthermore, the wear and tear of the milling tools is a challenge.

Figure 1. PM3 (left [1]) and FMRS (right) mounted on aircraft fuselage structures

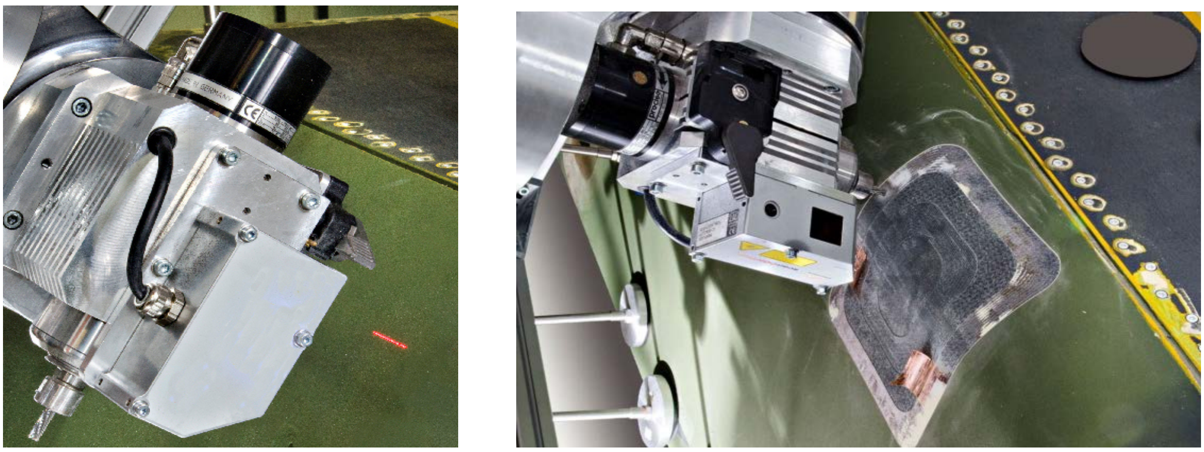

Figure 2. Laserscanning (left [1]) and milling of a rectangular scarf (right [1])

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In order to improve cost effectiveness and reliability, automated 5-axis milling tools for the repair area have been developed by the German Armed Forces in close co-operation with industrial partners that allow fast and reproducible creation of scarfs with highly bondable surfaces. The first prototype PM3 was build up in 2010. The actual mobile milling machine of the WIWeB, the Future Mobile Repair System (FMRS), was delivered in 2014 (figure 1). The frame structure of the FMRS and several other parts are made of CFRP to achieve sufficient stiffness for the milling process at low weight. By installation trials on real aircrafts, the adaptation capability was approved.
The mobile repair system consists of a mobile five axes-milling unit and a control station. The mobile milling unit can be mounted on damaged aircraft structures by means of a vacuum suction system. The entire repair process can be operated from a computer-based control centre using a graphical user interface. An integrated laser-line scanner allows sampling of the complete surface with high accuracy. After setting the process data and the type of repair (e.g. scarf geometry, layer thickness) a three axis milling program is produced. This three axis milling program is then adapted geometrically to the scanned surface and translated into machine code for the five axes kinematic.
The FMRS is a technology demonstrator that is used in a combined research program of the WIWeB to investigate possible improvements for CFRP repair. Additional technologies like ultrasonic non-destructive testing, a plasma torch for surface activation or a power ultrasound adhesive primer application can be adapted to the five axes kinematic.
The repeatable machining of laminates guarantees a defined geometry and more uniform surface quality and can also be used to realize complex and optimized repair geometries [2]. Currently used scarf repair patterns are of simple circular, rectangular or elliptical shapes with increasing dimensions towards the structure surface. With the recently developed automated milling systems, it has become possible to machine ply-wise stepped repairs with individual shapes into laminates.

4. Fibre-oriented repair

The idea of fibre-oriented repair geometries in aircraft composite structures aims to reduce the repair area by considering the orthotropic properties of reinforced plies. In Figure 3, a circular damage is used to explain the idea of fibre-oriented repair geometries.

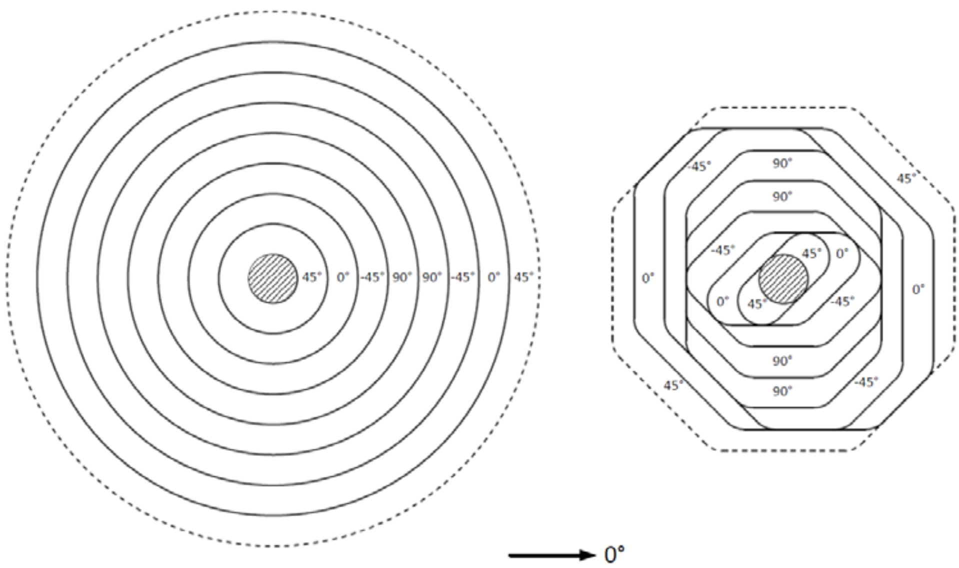

Figure 3. Graphical comparison between a fibre-oriented repair geometry on the right and a circular repair geometry on the left. Both repair geometries are based on a circular damage of 10 mm in diameter in the centre of the repair, a $(45/0/-45/90)_S$ lay-up and identical step lengths. The dotted outmost contour shows the top layer of the repair [2]

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As a first step, tensile tests of a stepped lap joint were done [2]. For the specimens with constant step lengths, an overlap of 6.25 mm was chosen for every step (scarfing ratio of 1:50). In fibre-oriented specimens, plies oriented in 0 degree direction had full overlap lengths of 6.25 mm, while plies oriented in +45 or -45 degrees had an overlap length of 4.42 mm. No overlaps were designed in plies with 90 degree fibre orientation. Carbon fibre UD reinforced epoxy prepreg Hexcel HexPly 8552/IM7 was used to manufacture quasi-isotropic laminates with a $(0°/45°/90°/-45°)_{2S}$ lay-up and a layer thickness of 0.125 mm. No adhesive was used to exclude effects from bonding processes.

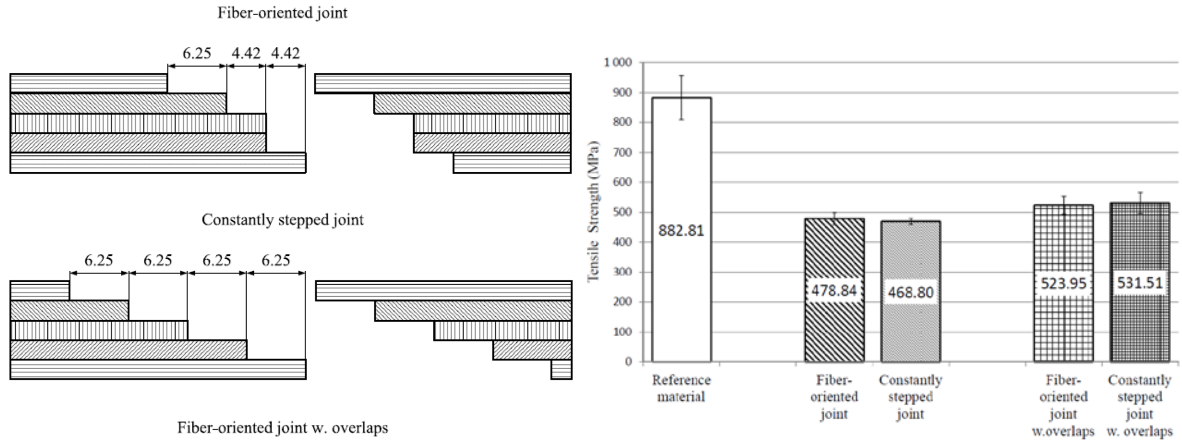

Figure 4 Schematic drawing of the step lengths in the investigated specimen series (left; all values in mm). For easier understanding, only the lowest four plies of the investigated laminates are displayed; Mean values of determined tensile strengths (right) of the particular series. Borders of two standard deviations are indicated around the mean values [2].

For fibre-oriented joint specimens with and without overlaps, similar mean tensile strengths were measured (figure 4). Reducing step lengths between UD plies with fibres not oriented in load direction, had no significant influence on the tensile strength of the stepped joints.

5. Conclusions

Automation of the CFRP repair helps to speed up the repair process significantly and to improve the quality of bonded joints and their reproducibility. Furthermore, automation might allow the realization of more efficient geometries for the repair of CFRP. By this, a reduction of repair geometries can be reached.

References

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