Repairing instead of Replacing

Process for Repairing CFRP Components without Machining

CFRP components are often in continuous use under harsh environmental conditions, for example in aircraft and motor vehicles. If any damage occurs, the CFRP structures are simply replaced by new components in most cases. This is mainly due to the high cost of established repair methods. With a newly developed process, defective CFRP structures can now be repaired locally much more easily.

The use of fiber-reinforced plastics (FRP) based on continuous fiber reinforcements is growing steadily [1]. This is mainly due to the desire for reduced pollutant and greenhouse gas emissions and increased energy efficiency combined with very good mechanical performance and increased cost-effectiveness, which has led to the a rising demand of lightweight solutions. With the widespread usage of carbon fiber-reinforced plastics (CFRP), including in the automotive and aerospace industries, the need for high-performance and on-demand repair concepts for FRP components is also increasing [2]. Damage to CFRP structures in need of repair has a variety of causes. The most common types of damage during the service life are material fatigue, excessive operating loads, impact or crash loads, damage during maintenance, contact corrosion and special load cases.

Repairing such damage without oversizing or changing wall thicknesses can be done by completely replacing the damaged CFRP components. However, this is not very sustainable and is associated with high costs due to the new parts required [3]. For this reason, various repair methods have been developed for special groups of components and individual cases, but these are often associated with considerable manual effort and thus insufficient reproducibility. These methods are predominantly based on a machining removal of the damaged area and the subsequent gluing or riveting of a new CFRP patch [4–7].

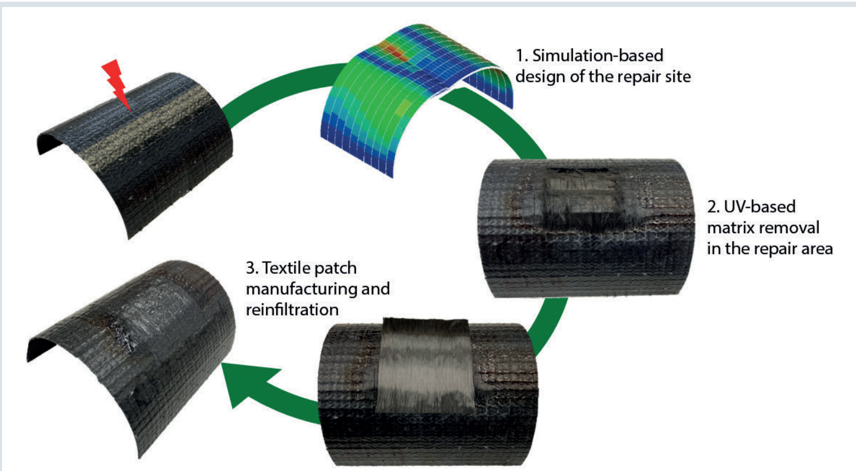

Fig. 1. Overview of the simulation-based repair method for CFRP components: the method enables targeted repair of the damaged area Source: ITM; graphic: © Hanser

Three Process Steps to the Repaired CFRP Component

A different principle underlies a process for repairing CFRP components developed at the Institute of Textile Machinery and High Performance Material Technology (ITM) at the TU Dresden, Germany. In this process, the use of inorganic semiconductor oxides (SCO) and targeted irradiation with ultraviolet (UV) light oxidatively degrades the matrix material in the damaged area and completely exposes the carbon fiber structure. The aim of the completed research project was to develop a flexibly applicable repair method for defective, multi-axially loaded, thin-walled CFRP components. It is based on three process steps (**Fig. 1**). First, a load-adapted textile patch is designed with simulation support. This is followed by local matrix removal in the area of the defect by means of targeted UV irradiation. The textile repair patch is then applied to the damaged area to replenish it, and finally reinfiltrated with a resin system.

Simulation as a Basis

For the load-compatible structural repair, a simulation model was created to design the textile repair patches. For this purpose, the composite structure was modeled from scrims. A meso model with shell elements was used to simulate the reinforcing fibers, with material modeling based on a three-layer laminate approach. For curved components, a drape model was created for this purpose. The composite was generated by applying the Domain Superposition Technique (DST) from coupling the textile model with a matrix model.

The simulation of the repair was done using a damaged CFRP sample. A parameter study with varying overlap lengths of the repair patch was performed and the necessary overlap was analyzed in both experiment and simulation to realize the best possible force flow via interlaminar shear between the individ-

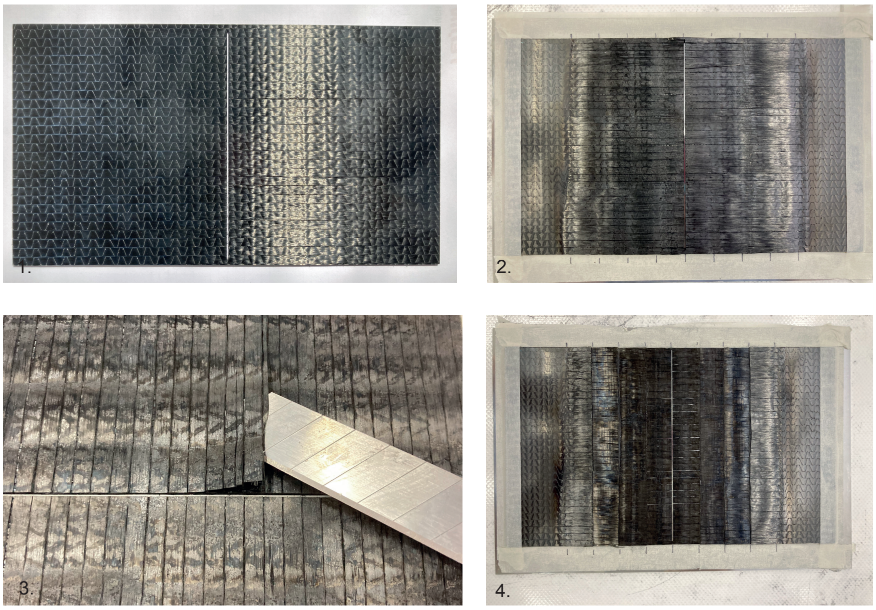

Fig. 2. In the process, the damaged area of the test specimen (1) is treated with a UV LED lamp (see Fig. 3). The fibers are then separated (3) in the repair area (2) thus exposed. The prepared repair area (4) is then cleaned, activated and prepared by an adhesion promoter for the insertion of the patch Source: ITM; graphic: © Hanser

ual layers. The simulation results show that higher the overlap length of the repair patch that higher is the tensile strength of the repaired composite. The model was validated by experimental studies showing that with optimum frictional connection of the patch to the as-built component, an almost complete restoration of the structural mechanical properties can be achieved.

Fig. 3. Matrix removal in the repair area is carried out with the help of an UV LED lamp. Compared to conventional processes, the manual effort is highly reduced, which ensures higher reproducibility © ITM

UV Light instead of Manual Ablation

Based on the simulation results, the local matrix removal in the repair area was carried out by activating semiconductor oxides (SCO) with a UV LED emitter. This process initiates a radical decomposition of the thermoset matrix polymer. For this process section, the process parameters were determined by evaluating the surface properties and by means of optical, mechanical and thermal analysis. Subsequently, a cleaning or activation and simultaneous re-sizing of the exposed carbon fibers was realized by means of a plasma torch. In this process, the differences in the fiber surface were leveled out by a specific treatment and introduction of an adhesion promoter and these were prepared for the subsequent repair process steps (**Fig. 2**).

A Semray 4103 UV LED emitter from Heraeus with an emitter area of 45 mm x 154 mm and a wavelength of 395 nm was used for the project (**Fig. 3**). This allowed almost complete exposure of the filaments in the damaged area [8]. However, in order to successfully perform complete, localized matrix degradation in the damaged area of thin-walled CFRP components, the irradiation parameters of power and irradiation area, as well as the installation space of the emitter, must be »

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Acknowledgement:
The IGF project 19946 BR of the Research Association Forschungskuratorium Textil e.V. was funded by the Federal Ministry for Economic Affairs and Energy via the AiF within the framework of the program for the promotion of joint industrial research (IGF) on the basis of a resolution of the German Bundestag. The author would like to thank the above-mentioned institutions for providing the financial resources and the companies of the Project Advisory Committee (PA) for their technical support and the provision of test material. The final report and further information are available at ITM.

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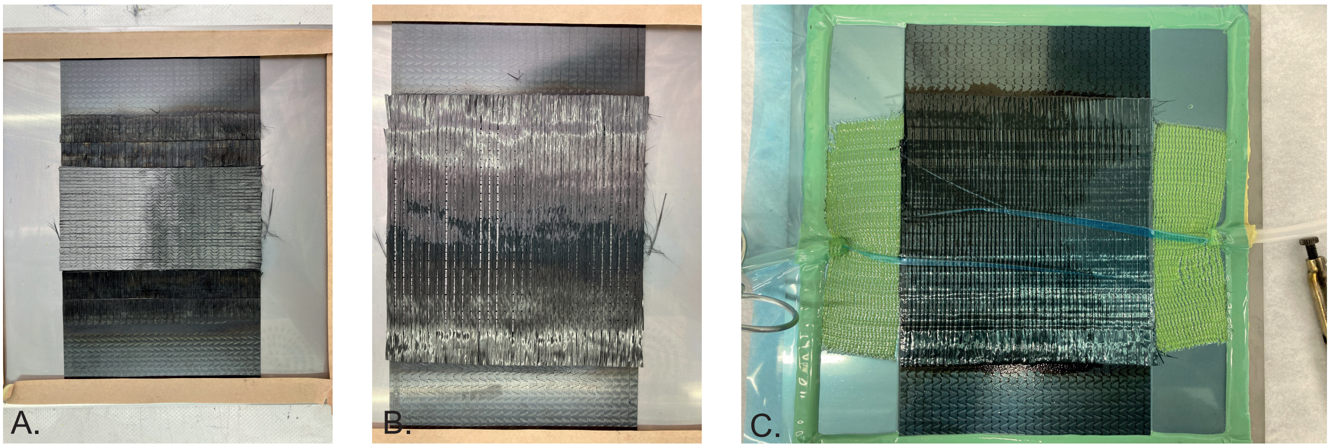

Fig. 4. For the repair, for example, a TFP patch is inserted into the prepared site (A – first patch part inserted, B – second patch part inserted). For the subsequent reinfiltration (C), a method based on the VARI process is used © ITM

adapted. In addition, there is still a need for research on the subsequent cleaning and re-sizing with the plasma torch. Insufficient adhesion between the exposed filaments in the component and the textile 2D repair patch results in reduced bonding properties. A possible solution is a two-step treatment with the plasma torch: in the first step, degraded matrix residues on the filaments are removed with compressed air, and in the second step, the filaments are resized with an adhesion promoter. The mediator EP 871 from Michelman was used for the investigations.

Tests with UD, TFP and MLG Patches

The thin-walled CFRP components (four layers of biaxially reinforced scrim [(0/90)2]s, thickness = 1.5 mm) with the repair area previously exposed and again coated with sizing (adhesion promoter) could be repaired in the third step using a textile 2D patch and reinfiltration with a resin system. The repair patches used in the project were blanks made of unidirectional layers (UD), tailored fiber placement (TFP) and multilayer knit (MLG). All of them were based on Toray T700SC 50 C 800 tex carbon fiber feedstock. They were designed load-adjusted according to the simulation results, machine-made, then characterized textile-physically (basis weight, yarn densities, thickness) and compared with the reference (removed fiber mass). After patch application, the repair site was refilled and consolidated with a repair matrix system using a vacuum-assisted resin infusion (VARI) method (**Fig. 4**). Different variants (RIMR 135; ER0051; ER5500) were used as resin system. After composite mechanical characterization, the original resin system from which the specimens were prepared was selected as the preferred variant due to the highest strength determined.

The investigations were successfully carried out on functional specimen of rising complexity with a component thickness of up to 2 mm. The practical suitability of the developed process was successfully tested on two thin-walled CFRP demonstrators. The flat composite panels were damaged in a defined manner by CNC milling, i.e. all fibers were cut in the direction of loading (0°), which caused a residual load-bearing capacity of 0 %. The specimens repaired with the aid of the process were characterized in tensile test according to DIN EN ISO 527–4. Irrespective of the textile manufacturing process of the repair patch, a breaking strength in the 0° direction of approx. 55 % of the undamaged CFRP reference material could be achieved (**Fig. 5**).

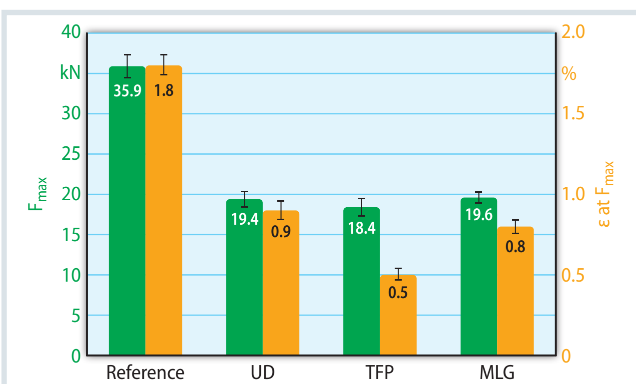

Fig. 5. Rupture force (F_{max}) and elongation at F_{max} for the different patch variants: the UD and MLG patches achieve the best values Source: ITM; graphic: © Hanser

Costs Reduced by 80 Percent

The developed approach thus represents a functioning repair procedure for simply curved, thin-walled CFRP components with a wall thickness of up to 2 mm. After repairing the previously completely damaged CFRP specimens, it was thus possible to restore a load-bearing capacity of more than 50 % while maintaining the same component thickness. Compared to the complete replacement of the CFRP component, costs are reduced by up to 80 %.

However, further research is required for the repair of complex, multi-curved and thick-walled 3D CFRP components to reach a load-bearing capacity of more than 50 % in tensile tests. For this purpose, simulation-based designed 3D textile patches with free thread ends and a sequential layer-by-layer 3D matrix degradation of the repair area with thus exposed threads for sufficient force transfer between patch and as-built component are mandatory. This is the subject of future research activities at ITM. ■