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REPAIR CONCEPT SUPPORTED BY LASER REMOVAL AND INDUCTIVE HEATING

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Abstract

With the increasing number of composite applications in aircrafts, it is essential to supply repair concepts with respect to the material properties. In addition to the carbon fiber reinforced composites with a thermoset matrix system, other matrix systems like high-performance thermoplastics have been continuously gaining market share. In comparison to other matrix systems, high-performance thermoplastics have advantages like their ability to reshape and to weld after the first molding process. These advantages can be used to develop new repair concepts.

The developing repair concept concentrates mainly on two steps between the detection of the damage and the post repair inspection. One of the steps is the scarfing out with the purpose to remove the damaged area. To simplify this step, the inclusion of a laser support to the repairing process was investigated. As a non-contact, thermal treatment, a UV Laser offers a ply-by-ply removal and can generate a precise stepped-lap repair geometry. With the help of these new possibilities, a load path conforming repair geometry can be developed. Another important step is the application of the repair patch by heating up the interface zone between the patch and the undamaged area. The necessary heat can be generated with the help of inductive heated metallic sheet.

The results of the investigations regarding the laser support and the inductive heating will be presented in this paper.

1 Introduction

In 2006, 1648 structural damages occurred on the 243 aircrafts in the Lufthansa fleet [1]. In 75 % of all cases, the damage was caused by mechanical effects, such as collision with ground servicing vehicles, jet bridges or runway debris. Lightning and bird strikes were mostly responsible for the remainder. In addition to these, hail strikes and overheating issues cause also damages. The different types of damage are pictured in FIGURE 1. A narrowbody aircraft suffers under structural damage statistically every 4600 flights, a widebody aircraft every 1000 flights on average.

a) Ground Service Vehicle b) Bird Strike c) Hail Strike
d) Lightning Strike e) Overheat f) Runway Debris

Figure 1 Aircraft damage scenarios [1]

The average aircraft downtime is 3.5 days and the mean downtime cost is $225000 per aircraft. For this reason, airlines, as well as OEMs, are trying to find ways to reduce these costs, without any compromises in the quality of the repair. New repair concepts need to be developed, which are optimally adapted to the needs of composite materials. These concepts should reduce the time and therefore save cost.

In this paper two new concepts are presented. The first concept simplifies the removal of the defected plies by using a laser system and the second one deal with a thermoplastic adapted sealing of the treated area.

1.1 Typical ongoing Repair Concept

The standardized steps of a common repair are described in the structural repair manual (SRM), which is issued and maintained by the OEMs. This manual contains the complete instructions to repair typical damages and is consulted, when the damage on a structural component is discovered. The repair process according to the SRM for hot bonded repairs starts with the localization of the damage. Its degree has to be assessed with the help of an applicable nondestructive testing method (NDT). Next step is to remove the defected material via eligible procedures. The structure of the repair depends on the damaged area and may have a complex 3-dimensional geometry. Regarding the geometrical requirements, the removals are scarfed manually. The difficulty by using a hand-held router is the imprecision of the tooling (FIGURE 2). In addition, well prepared chamfers or steps require a high level expertise of the servicing staff. There is a risk to create more damage and contamination because of hand-held router handling. To avoid these problems, the use of a laser system is examined.

Figure 2 Manual removing of defected plies

After the removal of the damaged plies, the patch must be integrated into the treated area. The preparation of the repair material includes the cutting of all single patch plies with their particular sizes and fiber orientations. After stacking the patch plies into the treated area, a vacuum bag can be installed directly on the patch (FIGURE 3). When the processing temperature is reached, it has to be kept constant in order to complete the cure cycle. For thermosets, normally the processing temperature is not more than 250°C. For this temperature range, heat blankets will be used to apply conventional repair processes. Some high-performance thermoplastics have melting temperatures over 300°C and processing temperatures up to 400°C. For this reason, an inductive heated metal sheet is the subject of the investigations to process on high-performance thermoplastics. A post-repair inspection must be carried out to ensure that the repaired parts can accomplish their function.

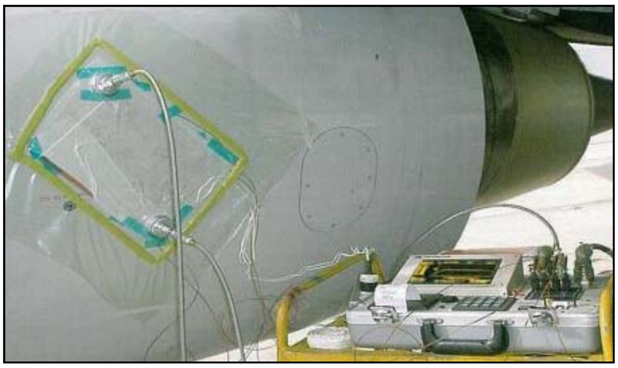

Figure 3 Vacuum bagging and heat blankets [2]

2 Laser Support to Generate a Precise Removal

A new repair technique must be reproducible, reliable and also cost- and time-effective. At the same time, damage on the structure around the repaired area should be avoided. The laser is a tool which can fulfill these requirements and take several tasks. As mentioned above, the defected plies can only be removed manually, which is imprecise and takes a long time. With the support of a laser system, a precise ply-by-ply removal and a complex, load path optimized repair geometry is possible. A variable radius and adaptable scarf angles of a stepped-lap joint can be realized. This technique promises very good peel stress and interlaminare tension shear strength.

According to SRM, typical step ratios range from 1:20 to 1:50 (1:20 panel edges; 1:30 lightly loaded parts; 1:50 high joint strength) [3]. With a step rate of 1:20 and a ply thickness of 0.125 mm, the length of one step is 2.5 mm. The definition of the step rate is also illustrated in FIGURE 4. In addition to the removal, the laser can be used to cut the patch plies according to their particular size and fiber orientation. If necessary, the laser can also be used for moisture or fluid removal and surface activation resp. preparation.

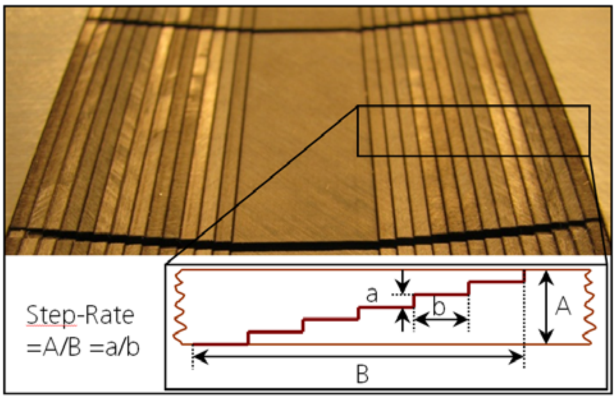

Figure 4 Definition of the Step-Rate

2.1 Laser Source

The processing of fiber composite materials using a laser system is currently subject of many investigations. The material used for the current investigation is carbon fiber reinforced Polyetheretherketone (PEEK), a high-performance thermoplastic with an excellent mechanical and chemical resistance. To generate a precise material removal, the means of success is an ultra-short pulse laser. The quality of the ablation process strongly depends on the used laser source, pulse duration and frequency.

The laser used for the investigation is a pulsed UV-Laser with a wavelength of 355 nm [4]. With the help of this wavelength, a high absorption for fibers as well as for the matrix material can be achieved. The pulse duration, in the range of nano seconds, transforms the average beam power of 23 W to pulse peak intensity in the GW/cm² regime. In order to minimize the influence of the fiber direction, the hatching direction alternates between 0°and 90° for every couple of ply. Several cycles, with a depth between 1 µm to 25 µm, can grind each ply very precisely and without any thermal damage. The time, the laser use to remove 1 cm² is 10 sec and for 1 cm³ 7 min [5].

2.2 Laser Machined Specimens - Experimental Investigations

To estimate the quality of the manufactured steps, the interlaminare tensile shear strength of laser machined and repaired specimens was measured according to Airbus QVA-Z10-46-34 resp. DIN 65148. The two groovings are located in the repaired area, which should ensure that the failure occurs between the parental laminate and the patch, in the stepped-lap joint. FIGURE 5 shows the geometry of a repaired specimen. As mentioned above, typical step ratios range from 1:20 to 1:50. To be able to repair also bended structures, nevertheless to meet the stiffness and strength requirements, it is important to minimize the step rate. Additionally, the area to repair will be smaller and the material to remove will be decreased. In order to have a first idea about the influence of the step rate to the interlaminare tensile shear strength, specimens with step ratios of 1:20 and 1:10 were manufactured and tested.

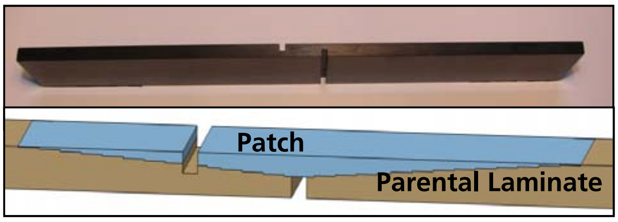

Figure 5 Repaired specimen modified according DIN 65148

The results and the analyses of these tests have shown no difference between the repaired and the reference specimens regarding the interlaminar tensile shear strength (FIGURE 6). That applied for repaired specimens with a step rate of 1:20 and also of 1:10. The average strength values of all specimens are in a range between 50 MPa and 60 MPa. These results lead to the conclusion that the machining by a laser-system and also

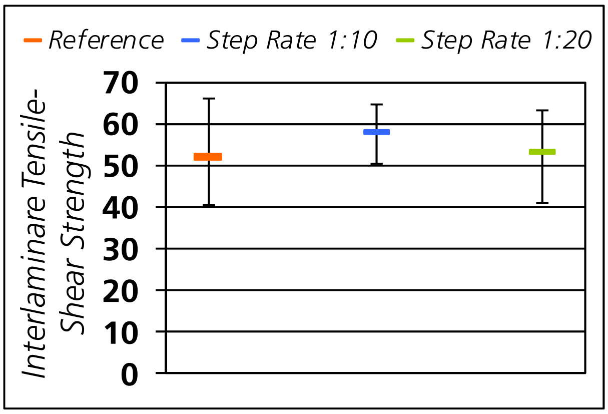

Figure 6 Interlaminare shear strength - reference and repaired specimens

the repair had no negative effect on the interlaminar tensile shear strength of the specimens. This conclusion can also be supported by the position of the point of fracture. In FIGURE 7, the point of fracture of different 1:20 specimens were compared. It can be observed, that the failure of the repaired specimens occurred in the middle laminate layer and also during the stepped-lap joint. Therefore, it can be argued, that due to the type of the failure, the interlaminar tensile shear strength did not decrease because of a stepped-lap joint.

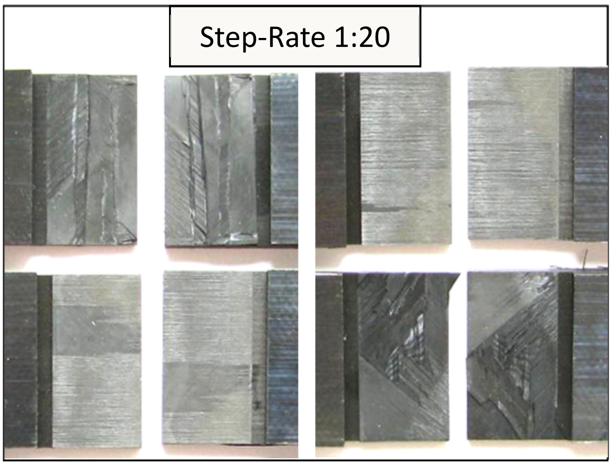

Figure 7 Point of Fracture

2.3 Further Investigations

Further studies aim to, if the removal can be accelerated with consistently high quality depending on different laser parameters. For this purpose, parameter studies are currently carried out. Furthermore, the effects of various parameters on the mechanical properties of a repaired structure are investigated. The aim is to make this step of the repair more time-efficient and therefore to decrease the costs. Looking further into the future, it should be possible to treat complex double-curved surfaces with the laser system and to have an automated repair process.

3 Practicable Heat Generation for the Repairing Process

The challenge to process high-performance thermoplastics is the high processing temperature. Heater blankets are used in the composite industry to bond and cure composite structures using vacuum bagging techniques, which have become standard in the industry. As mentioned above, temperatures for melting over 300°C and for processing up to 400°C are needed. Due to the material of heater blankets, made from fiberglass reinforced silicone rubber, temperatures are only permitted up to 260°C. A solution to avoid temperature problems is the use of other materials like metal and thermal resistant foil. One alternative to generate heat is electromagnetic induction.

3.1 Heat generation by inductive heated metallic sheets

To ensure a high quality joining between the patch plies and the parental laminate, two requirements are necessary; a defined pressure and temperature. In this concept, the heat is generated by an inductive heated metallic sheet. Induction heating is the process of heating an electrically conducting metallic sheet by electromagnetic induction. The experimental build-up will be explained as follows (FIGURE 8).

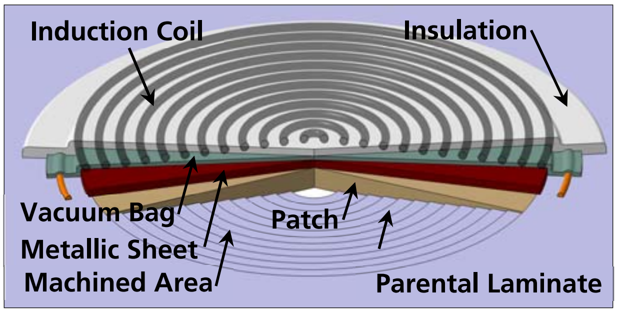

Figure 8 Heat generation by inductive heated metallic-sheets [6]

A temperature resistant foil must be placed subsequently between the patch and the metallic sheet after positioning the several patch plies into the processed area. This foil prevents the sticking of the patch to the plate. To compact the patch plies, pressure is necessary, which can be generated by a vacuum bag. Glass fiber mats are used as an additional layer to insulate the laminate. Completing the setup, the induction coil must be added above the metallic sheet to generate an electromagnetic field. After reaching the processing temperature and pressure, the conditions have to be kept constant in order to complete the consolidation cycle. The matrix will be melted and the patch plies joint together with the parental laminate.

3.2 Experimental Results

With the first investigations, it was to demonstrate, that this approach can provide a high quality joining between patch and parental laminate. To establish realistic results for the first specimen plates, laser machined plates were used. A halved repaired specimen plate is shown in FIGURE 9. The repaired area is marked with blue lines. At the bottom image, no steps or shifting are observable on the cutting edge. To achieve a high joining quality through the parental laminate and the patch, it is essential to generate a controlled heat. To be able to ensure a good consolidation, the temperature on each side of the specimen plate was measured during the entire test. The front side, which is heated directly by the metallic sheet, should not be warmer than 400°C, otherwise degradation effect appears. With to low temperatures, the matrix would not melt completely and the patch plies could not combine with the parental laminate. Until the back side of the specimen plate reaches at least a temperature of approximately 390°C, the metallic sheet should be heated continuously. Once this temperature is reached, the heat generation should be turned off. A longer period of heat generation causes deformation and thermal damage on the structure around the repaired area. As can be seen in FIGURE 10, the heating of the metallic sheet is homogeneous at both sides of the specimen plate. The green lines mark the field with a good processability temperature, for PEEK in the range between 385°C and 395°C. In further experiments, one of the aims is to reduce the process time, especially the soaking time to the back side of the laminate.

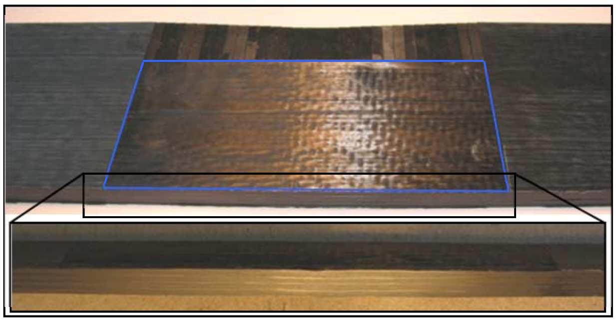

Figure 9 Repaired plate with a step rate of 1:20

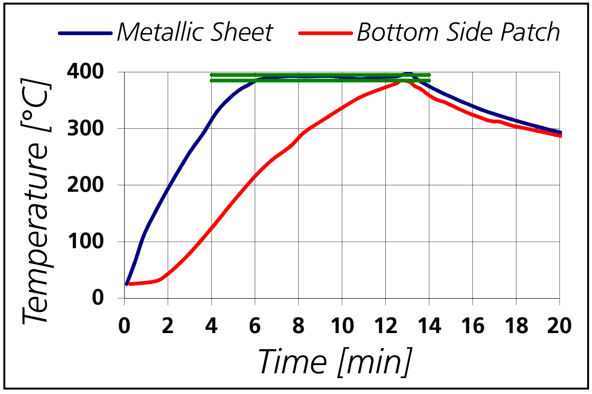

Figure 10 Heating Cycle of Patch Consolidation

4 Conclusion

The suitable adaption of existing repair processes to the requirements of CF-thermoplastics requires the development of new repair concepts, which might enable an almost fully restoration of the previous strength and function. Due to the removal of the damaged plies by using a UV-laser-system, the tedious and imprecise grinding by hand can be substituted. The support and integration of the laser-system in the repair concept will allow a reproducible, effective and precise repair. In addition to the simplification of the removal, current studies focus on the technical feasibility of the heating up of the specimens with an inductive heated metallic sheet. The studies have shown that homogeneous heating can be realized. The optimization of this concept will be the content of the further investigations.

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