STRUCTURAL ADHESIVE BONDING OF AIRCRAFT STRUCTURES - THE NECESSITY FOR RELIABLE AND ROBUST PROCESSES

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Abstract

The use of adhesive bonding for fabrication and repair of structures made of carbon fiber reinforced plastics (CFRP) is of great interest, to further reduce the overall number of parts and weight. The Achilles heel of adhesive bonds is the adhesion itself. There is and there will probably be no non-destructive testing method (NDT) to test the quality of the adhesion achieved within a bond. In consequence, aircraft manufacturers are neglecting to use the weight saving potential of adhesive bonding. This contribution will give an example of a highly reliable (and therefore robust) adhesive bonding process. From the author's point of view, the key element of reliable adhesive bonding is proper surface treatment. The proposed process is based on a combination of a peel ply and an atmospheric pressure plasma jet treatment. Furthermore, difficulties in destructive testing of adhesive bonded CFRP samples are discussed.

1. Introduction

Peel-plies are widely used for the fabrication of CFRP structures. They have some important advantages. First, they sponge up the surplus resin during manufacturing. Afterward they cover the surface during non-destructive testing of the fabricated structures, handling and for storage. They can be removed instantaneous prior to adhesive bonding to create "fresh and bondable" surfaces.

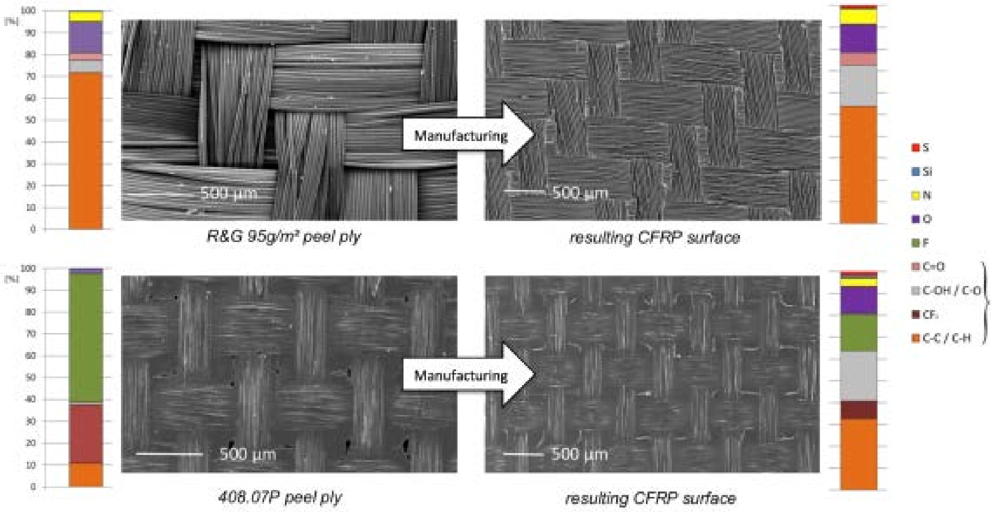

Figure 1. Topography (SEM images) and surface chemistry (via XPS) of the used peel plies is transferred due to the manufacturing process from the peel plies onto the CFRP surfaces [1].

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In reality, common peel-plies are coated with release agents to avoid fiber pull out during peel-ply removal. This leads to contaminated surfaces [1], low bond strength and inhibits a reliable use of adhesive bonding for safety relevant structural applications. Figure 1 exemplary shows CFRP surfaces produced with two different peel plies. The CFRP specimens were made from a prepreg material (Hexcel 8552/IM7 with epoxy matrix) in an autoclave process. They were manufactured to form a quasi-isotropic layup of 2 mm in thickness. In neither case a surface suitable for a reliable adhesive bonding was created.Hence, using peel-plies is a method to create reproducible, but contaminated surfaces. Only in combination with a surface treatment process it is possible to establish reproducible surfaces. Especially plasma processes are very interesting because they allow to create a well-defined surface chemistry and topography on the nanometer scale.

Our research shows that, the combination of peel-ply and subsequent plasma treatment allows the creation of a reproducible surface on nanometer scale even in industrial processes. In order to accomplish this reliable surface treatment, extensive research activities on plasma composition and effectiveness on CFRP surfaces [2] in combination with intensive optimization of peel plies were necessary. To test the strength and the durability of the adhesive bonds, suitable destructive tests have to be performed to test especially the interface.

2. Use of peel plies and atmospheric pressure plasma jet for surface modification

Atmospheric pressure plasma jets (APPJ) are often used to treat a surface line by line to modify the entire area intended for bonding. Using compressed air as process gas and a manipulator to move the nozzle, it is a keen technology that can be integrated into an automated process chain. Depending on the process parameters (nozzle-substrate distance, movement speed etc.) the intensity of the APPJ-treatment can be varied.

Scanning Electron Microscopy (SEM), Laser Scanning Microscopy (LSM) and Atomic Force Microscopy (AFM) are used to measure topography changes qualitatively and quantitatively. Contact Angle Measurement and X-Ray Photoelectron Spectroscopy (XPS) allow investigations on the chemical composition of the very top atomic layers of CFRP surfaces. Figure 2 shows how a CFRP surface (Hexcel 8552/IM7 manufactured with a fluorine based release foil) is changed by an APPJ-treatment.

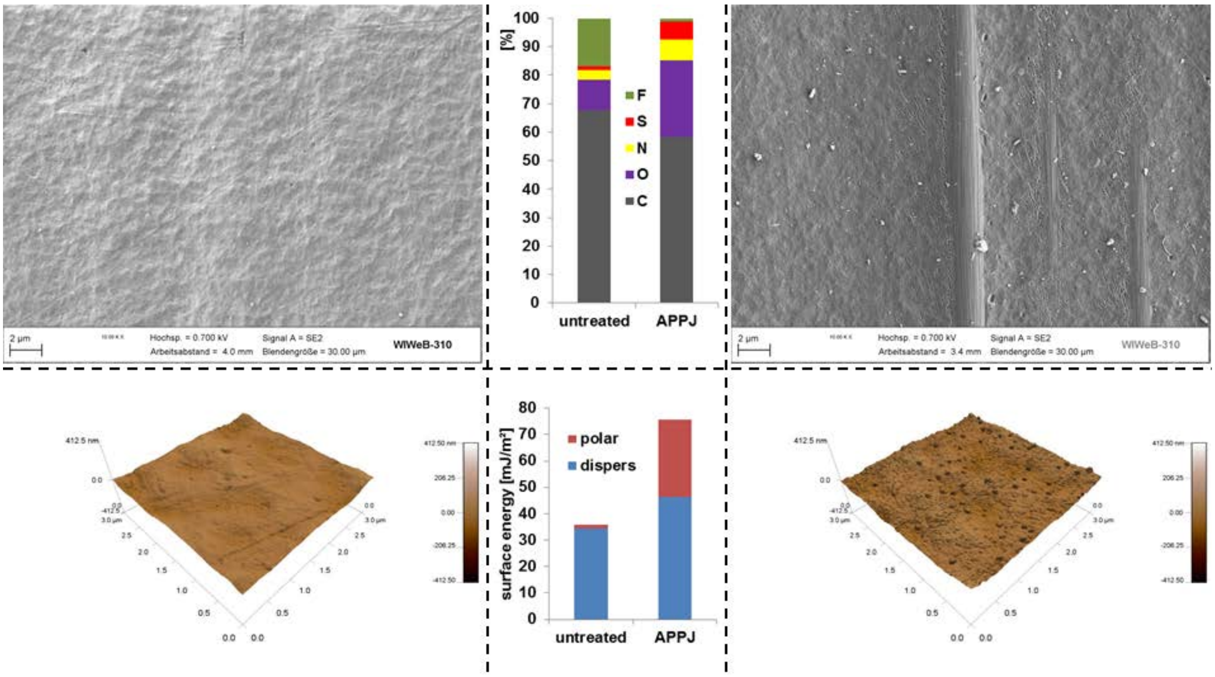

Figure 2: Differences between an untreated (left) and APPJ- treated (right) CFRP- surface. Changes in topography can be seen in SEM (top) and especially in AFM (bottom) images. Chemical modification can be seen in the surface free energy (middle, bottom) and XPS- results (middle, top).

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The topography on the micrometer scale, created by the peel ply used, is affected very little while on the nanometer scale a much rougher surface with an increased surface area is created. The chemical modification is distinguished by the removal of release agents residuals and the attachment of oxygen containing functional groups.

An improvement in bonding strength through APPJ- treatment can be achieved within a wide range of process parameters, avoiding interfacial failure, for different types of peel plies and release foils as well. For a variety of fluorine-based peel plies a change in failure mode from interfacial to cohesive/ laminate failure accompanied with increased bonding strength can be observed after APPJ- treatment, even if the fluorine is not totally removed [5].

Detailed investigation has been carried out to improve the understanding of the plasma-surface-interaction. Thus not only areal treated specimen are investigated but single line treatments as well [2]. If a fluorine-based peel ply (or release foil) is used in the manufacturing process, the fluorine-carbon ratio and the oxygen-carbon-ratio determined via XPS can be used to indicate the cleaning and activation effect on the surface as shown in Figure 3. Dependent on the used process parameters differences in intensity and width can be shown. Comparing these results with analysis of the plasma itself allow control of the process control that is independent of the used APPJ-system and thus transferable to different systems.

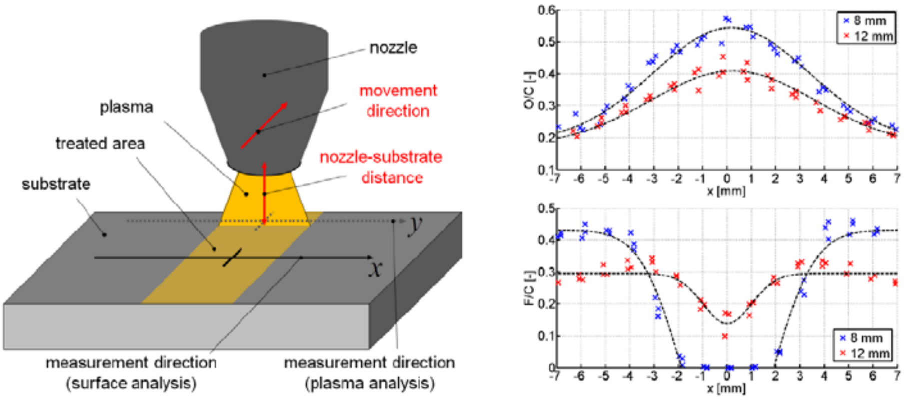

Figure 3: Single line APPJ-treatment of a specimen (left) and distribution of the O/C-ratio (right, top) and the F/C-ratio (right, bottom) for a nozzle-substrate distance of 8 mm (blue) and 12 mm (red) [2].

3. Destructive Testing of bonded CFRP samples

Due to the lack of non-destructive testing methods, destructive tests have to be undertaken. For CFRP, various destructive test setups exist. Double cantilever beam (DCB), floating roller peel, and single lap shear specimens are commonly used to qualify processes and to quantify adhesion strength. Despite the lack of stress concentration for the boundary layer in these destructive test methods, there is always the problem of the limited laminate strength within CFRP. The high strength adhesives exceed the strength of the CFRP fiber-matrix interface. Therefore it is difficult to test the quality of the adhesion and to compare different surface treatments.

One example is to vary the joint length of single lap shear specimens. With an decreasing joint length, the stress distribution is more uniform. Figure 4 shows the lap shear shrength of APPJ treated single lap shear specimens with various joint length (6,25 mm, 12,5 mm, 25 mm). A decreasing joint length results in an increase of lap shear strength from 22 MPa (25 mm) up to 50 MPa (6,25 mm). In addition, these joint length variation results in a change of the fracture pattern from a light fibre tear (6,25 mm) to a cohesive failure in the adhesive. So with a more uniform stress distribution at a joint length of 6,25 mm it is possible to generate high strength bondings with a cohesive fracture pattern. Now the shear stresses determine the failure behavior and the adhesive bond can be tested up to 50 MPa.

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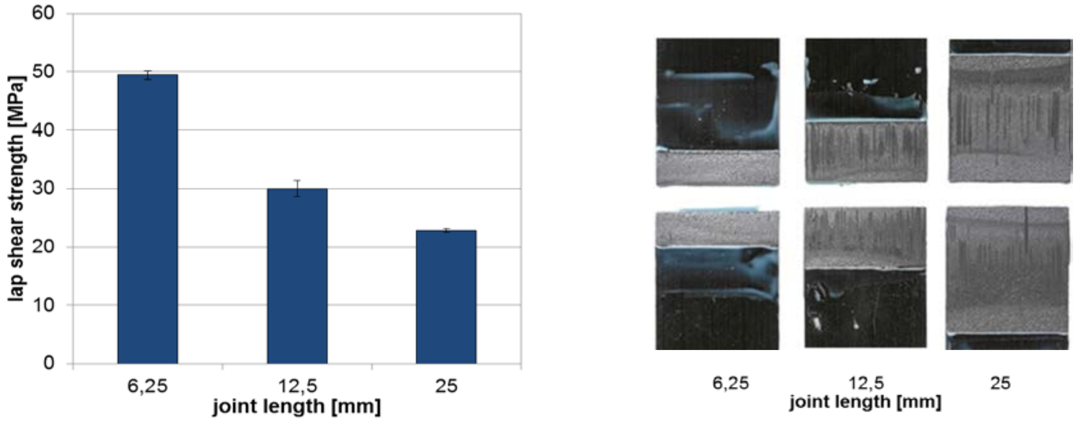

Figure 4. Lap shear strength and fracture surfaces of APPJ-treated single lap shear specimens with various joint length.

For structural applications, also the longtime durability of the adhesion has to be guaranteed. To obtain a statement about the longterm stability of a bonded joint hydrothermal aging tests are necessary. For aging tests of APPJ-treated single lap shear specimens, again the fiber-matrix adhesion is the archilles heel of the adhesive joint. The fiber-matrix adhesion decreases while hydrothermal aging (85°C, 85 % r.H., 1000 h). This causes a laminate failure of CFRP after aging (Figure 5). It is therefore not possible to get any information about the quality of adhesion.

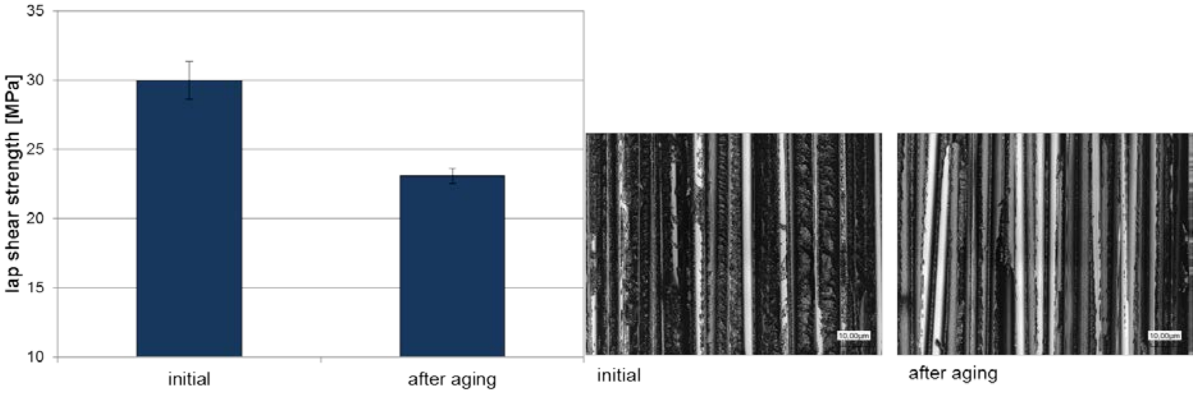

Figure 5. Lap shear strength and fracture surfaces of single lap shear specimens before and after hydrothermal aging (85°C, 85 % r.H., 1000 h) [4]

To determine the stability of the adhesion generated by different surface treatments a different way of testing is proposed: To exclude the fiber matrix adhesion, by using adhesivly bonded pure matrix resin samples.

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5. Conclusions

The use of structural adhesive bonding of CFRP is a challenge. For proper surface-adhesive interaction surfaces have to be prepared in a defined way. By using a combination of peel-plies and atmospheric pressure plasma jet this goal can be reached in an industrial environment. Therefore, the effectiveness of the peel ply and the plasma treatment can be understood on the nanometer scale. Plasma composition and peel-plies have to be optimized to establish a reliable adhesive bonding process with a maximized process window. Destructive tests are necessary and must be able to test the strength and durability of the generated adhesion.

The applicability is shown within the “FFS” (Fortschrittliche Flugzeug Strukturen) project, a close co-operation of WIWeB, DLR, and AIRBUS D&S in which an airbrake of a combat aircraft is rebuild with structural adhesive bonds and certified for military airworthiness.

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