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Surface treatment of CFRP: influence on single lap joint performances

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ABSTRACT

Nowadays composite materials play a leading role in structural design, particularly in aeronautics and automotive. In these industries, to reduce the weight of the components maintaining the same performance is most required. With this in mind, the use of structural adhesives allows to maximize the specific strength of assembled parts. To have a thorough knowledge of the various influencing parameters is necessary in order to design bonded components. In particular, surface treatments play a key role in joint strength. Understanding the best combinations of adherend - adhesion surface - adhesive allows designing bonded components more easily and reliably. This work analyses the influence of surface treatment of CFRP adherends on mechanical strength and breaking morphology. In particular, SLJ (Single Lap Joints) specimens were made with both film and paste adhesives. It has been noted that the combination between adhesive and surface treatment influenced the failure morphology and mechanical strength.

1. Introduction

The use of structural adhesives entails advantages such as a more uniform distribution of joint stresses and the possibility of coupling components avoiding machining operations on the same. In this way, it results in cost reduction and elimination of drilling which, especially for CFRP materials, can be the cause of nucleation and growth of defects, as stated by Budhe et al. [1] and Sorrentino et al. [2–4]. Nevertheless, the performance of the glued joint is a function of many factors such as the geometry of the same, the materials the adherends are made of and their surface preparation, the chemical compatibility between adhesive and adherend, the type of adhesive used and the surface cleaning. Li et al. [5] found that thick single-lap joints present slight nonlinearity in the load displacement curve, due to the bending effect caused by eccentric loading, while Sargent [6] identified an increase of peel strength with adherend roughness. Banea et al. [7] found an influence of the adherend material on the joint strength for large overlaps, while for shorter overlaps that influence was not noteworthy.

The mechanical strength of the joint is given by the chemical bonds between the adhesive compounds and the atoms on the adherend surface during the polymerization of the adhesive itself: for this reason, it is important that the adhesive has a certain chemical affinity with the substrate to be glued so as to allow the joint to demonstrate an adequate mechanical resistance and a longer adhesion life. For example, Molitor and Young [8] stated that bondings of thermosetting CFRP laminates to titanium alloys exhibit a higher adhesion stability over time than bondings of CFRP thermoplastic laminates.

Besides chemical compatibility, the joint resistance is also related to the geometry of the joint itself. In fact, the joint geometry depends on the stress state that will be established in the bonded joint. In particular, the geometry allows to identify the critical points in which the damage can occur: for example, Moreira and Nunes [9] said that in the single lap joints the presence of a bending moment significantly increases the peel component, leading to an apparent joint resistances very different from other geometries. Langella et al. [10] found that the adherend shear deformation influenced the stress state of the adhesive layer.

SLJs are very common in the industry field because of their standardization and ease of implementation. However, the results obtained from their use are influenced by a number of parameters that are hard to be uniquely related to each other as the overlap length, the adhesive thickness and ductility and the surface preparation of the adherends. Da Silva et al. [11] carried out some experimental tests and defined a simple relation for the SLJ design. Nevertheless, lap shear tests are very useful when a comparison among the effects of these parameters is needed.

The surface to be bonded must have certain characteristics: it must be devoid of contaminants and possess a high roughness. Molitor et al. [12] and Encinas et al. [13] stated that all the surface treatments used for increasing the strength and the duration of a bonded joint have in common the need to increase the adherends surface energy, understood as roughness and chemical reactivity. In fact, surface treatments play a primary role on the durability of the glued joint. Armstrong [14] found that these treatments must also be chosen according to the stress condition with which the joint is stressed.

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The abrasive techniques have the advantage of removing most of the contaminants present on the adherends surface. Abrasion is the most commonly used method because of the ease of realize, especially when repairing unbounded joints. However, according to Wingfield [15],surface treatment must be such as to avoid defects or delamination which may be detrimental to joint strength. In particular, the materials to be treated can be more or less susceptible to abrasion damage, so in some cases to use less invasive techniques is preferable, such as the peel ply. Peel plies selected for use must not deposit contaminants on the surfaces to be bonded[16]. Kanerva and Saarela [17] found that the use of the peel ply, over and above the achievement of a more uniform surface, also involves a reduction in costs associated with the elimination of the mechanical abrasion phase.

The aim of this work is to study the influence of adherend surface treatment on the mechanical strength of single lap joints. The choice of this type of joint is due to the simplicity of realization combined with the ability to perform comparisons aimed at determining the influence of the various factors investigated. The surface treatments chosen for this purpose are sanding, grit blasting and peel ply. This analysis was carried out on three different adhesives, belonging to two different types: paste and film.

2. Materials and methods

The bonded joints were made according to ASTM D1002 and ASTM D5868. The specimens consist of two laminates of 25.4 mm x 101.6 mm x 2.54 mm, while the overlap length is 25.4 mm long, with a nominal glue thickness of 0.76 mm (Fig. 1).

The prepreg ply selected for the production of laminates has a thickness of about 0.33 mm in uncured state and is produced by SAATI S.p.A.; the matrix consists of the epoxy resin ER450, while the reinforcement consists of the carbon fibres CC289 with 5 H satin weave: each weft yarn is over four warp yarns before interlacing under a warp one. The warp has the same direction of the specimen axis, while the weft is obviously rotated 90 °. The stacking sequence were $[(0°,90°)]_8$ where (0°,90°) is one layer of fabric.

For specimens realization, 3 laminates of the dimensions of 495 mm x 265.2 mm are stratified, then compacted with the vacuum bag and then cured in autoclave; the cure process consists in a heat rate of 2 °C/min for 55 min and a dwell at 135 °C for 2 hours at 7 bar pressure.

Once these laminates were made, they were cut with a band saw to obtain the six smaller laminates, which were glued in pairs to obtain 3 different assemblies, one for each type of adhesive. In total, 45 specimens were made, that are five for each adhesive-surface treatment combination (Table 1).

Sanding was carried out manually, using a P80 sandpaper as abrasive agent; the operation was carried out on a work bench with suction system to minimize dust generated during processing steps.

The grit blasting treatment was carried out using a sandblasting machine to isolate the working environment from the outside. For the treatment was used only clean grit: in fact, the previously used grit can leave contamination on treated surface. At the end of the process, the laminates underwent a first step of cleaning by compressed air, with the aim of eliminating most of the abrasive agent and processing residues remaining on the surface to be glued.

Table 1
Experimental plan.

Factors	# Level	Levels
Adhesive	3	AF 163-2K, EA 9309NA, EA 934NA
Surface Treatments	3	Sanding, Grit Blasting, Peel Ply
Replications	5	

The peel ply used in this work was the 51789 produced by the Precision Fabric Group and it was made of nylon fibres woven together. The operations carried out to obtain the surface finish with the peel ply simply consist of stratifying it on the laminate before cure and removing it just before the bonding step.

After the surface treatments were carried out, the bonding zones were cleaned with acetone and subsequently bonded.

The adhesives identified for the tests were the EA 934NA AERO paste adhesive manufactured by Loctite (also known as Hysol EA 934NA), the EA 9309NA paste adhesive manufactured by Hysol and the AF 163-2 K film adhesive produced by 3 M Scotch- Weld. The general characteristics of the adhesives are given in Table 2.

Loctite EA 934NA AERO is a two-component thixotropic paste, consisting of a gray paste (part A) and an amber colour liquid activator (part B), in weight ratio of 100 for part A and 33 for part B. The polymerization reaction occurred at room temperature for seven days.

Similarly to EA 934NA AERO, Hysol EA 9309NA is composed of two separate parts, a translucent beige paste (part A) and a red liquid agent, suitable for hardening (part B); these must be mixed accurately according to the weight ratio of 100 (part A) and 23 (part B), respectively. Also for this adhesive, the polymerization reaction took place at room temperature for seven days.

The AF 163-2 K is part of the AF 163-2 adhesive film family: this includes various adhesives that have a support in a variety of materials. The chosen adhesive had a thickness of about 0.24 mm and it had a carrier inside that gives it more traction resistance. The polymerization reaction was carried out in autoclave according to the technical data sheet.

In order to guarantee the final geometry of the joint specimens, a special equipment was used for bonding (Fig. 2).

The machine used for testing is an INSTRON 3382 with a maximum capacity of 100kN. The test conditions were carried out according to ASTM D5868 with a set speed of 1.3 mm/min.

3. Results and discussions

The analysis of the results was quite complex as it took into account, besides the surface treatment of adhesives, a series of factors such as

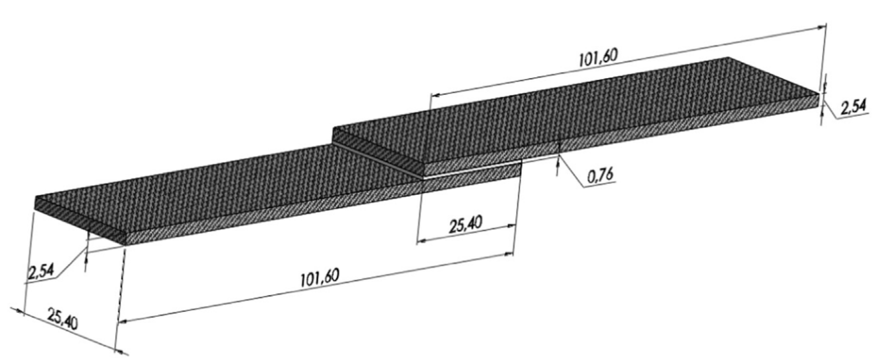

Fig. 1. CAD of single-lap joint specimen with related dimensions.