FABRICATION OF ADHESIVELY-BONDED CFRP T-JOINTS FOR STIFFENER PULL-OFF TESTS

João Vieira Cardoso[1], **J. Nunes Pereira**[1], **Abílio P. Silva**1(*)

[1]Centre for Mechanical and Aerospace Science and Technologies (C-MAST-UBI), Universidade da Beira Interior, Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal
(*)*Email:* abilio@ubi.pt

ABSTRACT

Adhesively bonded joints have been increasingly applied in primary aerostructures, mainly due to their numerous advantages over riveted or fastened joints. More specifically, bonded T-joints made from carbon fibre reinforced plastics (CFRP) are commonly found as stiffening members (stiffeners, or stringers) on wing panels and fuselage sections. However, aluminium stiffeners can yet be considered a safer and more conservative solution, since composite T-joints face delamination problems that typically initiate at the central noodle of the stiffener - the part where the three arms of the stiffener come together.

In order to better comprehend the failure mechanisms and sequence of these joints, Stiffener-Pull-Off Tests (SPOT) were experimentally conducted on a two CFRP adherends (SEAL® Texipreg HS 160 REM) - skin and stiffener - adhesively bonded with a structural film adhesive (EA451 U150). These specimens were fabricated following a novel fabrication plan, which left open the possibility of re-engineering the noodle region with the scope of increasing the through-thickness strength of the bonded joint. This can be achieved by eliminating the problem of the twisted fibres at the noodle that occur during the cure stage when no filler material is used.

Keywords: Adhesive bonding, T-joint, Structural adhesive, Skin-to-stiffener connection

INTRODUCTION

Composite materials, namely carbon fibre reinforced plastics (CFRP), are being increasingly used in many diverse engineering applications. Particularly in the aerospace industry, they have become the main structural materials for aircraft structures, mainly because composite materials offer superior specific strength and stiffness when compared to the traditional metals [1].

However, in order to fully exploit the weight-savings potential of composite materials in full-scale structures, a suitable joining technology must be implemented. While riveting and fasting have been the most conventional methods for joining aircraft structures, adhesion is attracting increasing interest as a direct alternative to these mechanical methods [2]. Especially in composites, adhesive bonding offers numerous advantages over riveting or fastening, which break the fibres and hence create local defects and stress concentrations around the holes, both of which reduce the overall structural integrity and performance of the composite laminate [2].

In aircraft applications, skin-to-stiffener joints are very common in fuselage panels and wings, with stiffeners being adhesively bonded to skin sections. However, due to lack of suitable material models and failure criteria on these bonded composite structures, they are often "overdesigned" and/or required to include fasteners as an additional safety precaution [1,3,4]. This results in highly inefficient structures which were found to be outperformed by the aluminium equivalents [1].

Due to the impossibility to test different design concepts and materials at a full-scale, the Stiffener Pull-Off Test (SPOT) is one of the sub-components tests which simulates out-of-plane loading in skin-to-stiffener joints, such as internal pressure of the fuselage skin and low pressure zone of leading edges [1]. These tests have been extensively used to evaluate skin-to-stiffener joints, however, there is still the need for an effective and relatively easy method of improving the through-thickness strength of the joint, especially at the noodle region - where the failure usually initiates. Consequently, this work aims to conceive a novel fabrication method that avoids the twisted fibres at the noodle that occur during the cure stage when no filler material is used.

The SPOT specimens consisted on two CFRP adherends: an inverted T-shaped stiffener (Fig. 1a) and a rectangular skin; with the stiffener being adhesively bonded to the skin at its mid length (Fig. 1b). The fabrication process for these complex specimens is not standardized, and consequently entails the elaboration of a unique and carefully though planning, which will now be explained.

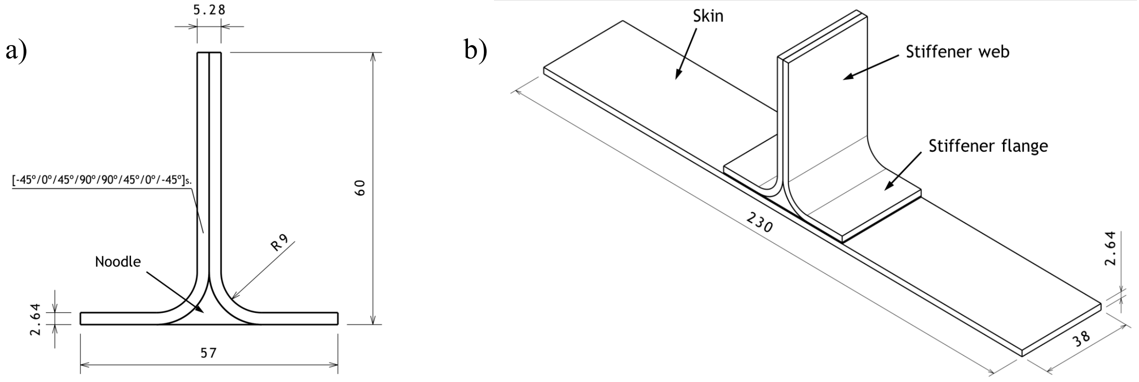

Fig. 1. Specimens dimensions: a) Stiffener; b) Stiffener bonded to skin.

PROCEDURE

To fabricate the CFRP stiffener and skin, separate stages (secondary bonding) were used to cure the specimens, thus preventing any release of moisture between the adhesive and the skin or stiffener, in order to increase the strength of the joint [5]. The adherend material consisted of a modified epoxy resin reinforced with high strength carbon fibres (prepreg) in the form of a unidirectional tape (0.164 mm thick), being its commercial name SEAL® Texipreg HS 160 REM. The adhesive was a structural epoxy adhesive film, EA451 U150 (unsupported).

The process carried to fabricate the adhesive joint can be summarized as follows:

1. The prepreg roller was removed from the freezer, and allowed to partially thaw for approximately half an hour (at room temperature).

2. 16 plies (300×300 mm) were cut out for the skin, and 32 plies (380×100 mm) were cut for the stiffener. The plies were cut using an x-act and taking into account the four possible orientations (0º, 90º, 45º and -45º).

3. Each layer was placed upon a tool, which was covered with a Teflon® sheet (Release 234 TFP-1) for releasing, and on top of it, a polyester peel-ply to provide a clean and active surface for secondary bonding. A metal plate was used as a tool for the skin; while for the stiffener, the plies were laid up on the convex size of two L-shaped metal parts.
The plies were laid up according to the stacking sequence, which was the same for the skin and the stiffener: [-45º/0º/45º/90º/90º/45º/0º/-45º]s.

4. During lay-up, the plies were slightly heated with the use of a heating gun for better adhesion, and after each layer, the air bubbles were removed using a spatula. Additionally, the stiffener laminates were debulked after the first ply and every subsequent 3 plies. This procedure consisted on covering the prepreg laminate with a perforated release film and a breather ply, applying vacuum for approximately 5 minutes before subsequent lay-up. Debulking ensures that there is a homogeneous consolidation; that air is removed from between the prepreg layers before final curing; and helps the prepreg to conform to the tool shape, especially in the corner.

5. Following the final debulking process, the two L shaped laminates were put back to back, and the region between (noodle) was filled with either unidirectional plies, adhesive film rolled into the cavity, or left empty (with or without an additional tool). Then the three parts of the tool were put together and slightly tightened using six screws (Fig. 2).

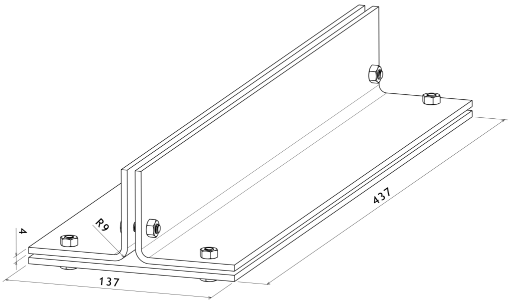

Fig. 2. Stiffener's tool.

6. The laminate (or tool, in the case of the stiffener) was entirely covered by a layer of polyester breather (Airweave® N10) for providing airflow under vacuum, and the complete setup was then placed inside a bagging film (Stretchlon® 700) as schematized in Fig. 3a) and Fig. 3b) for both the skin and the stiffener, respectively.

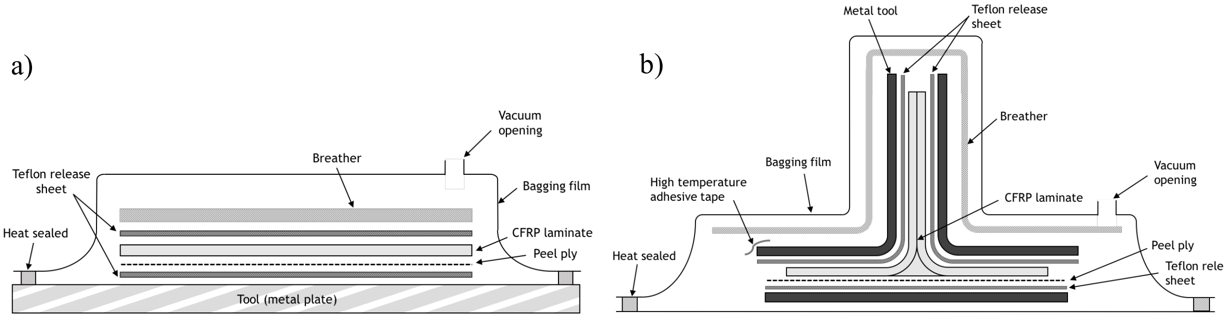

Fig. 3. Curing setup: a) Skin's setup; b) Stiffener's setup.

7. The vacuum bag was subjected to a thermal cycle inside the autoclave according to the manufacturer's instructions. After 1 h of curing at 125 ºC and 5 bar, the laminate was left to cool down overnight. The peel ply was left on the laminate in order to preserve the surface from any contamination that could result in inferior bonding. The final skin specimens were cut out using a water jet cutter, while the stiffener specimens were manually cut by mechanical means and then rectified to the final dimensions using a surface grinder machine.

8. Prior to the adhesive cure cycle, the adherends were dried for 24 h at 50 ºC to avoid any release of moisture from the CFRP specimens. The peel ply was removed from the parts, and additionally, the bonding surfaces were sanded with 240 grit silicon carbide sandpaper, followed by an acetone cleaning to remove the abrasion products. 3 layers of adhesive film were cured between the adherends for 1 h at 120 ºC, while using weights on the stiffener flanges to apply pressure.

RESULTS AND FUTURE WORK

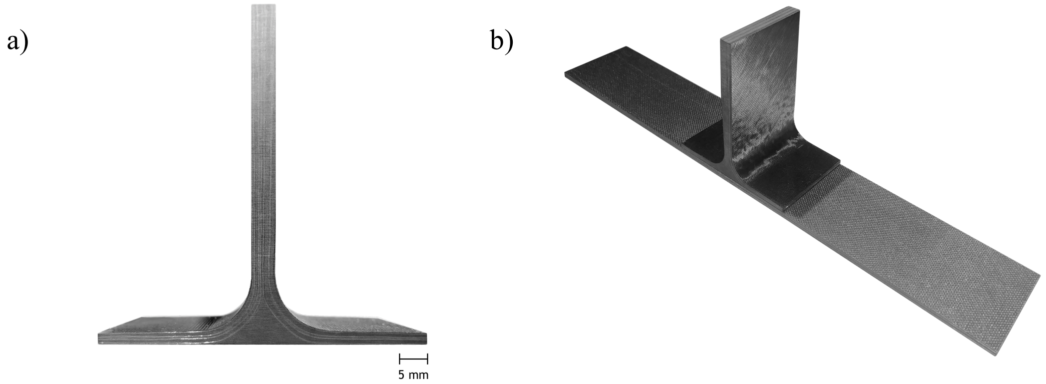

Fig. 4. Cured specimens: a) Stiffener filled with 0º fibres; b) Stiffener bonded to skin.

The CFRP skin-to-stiffener bonded joint was successfully produced. No twisting of fibres was observed when unidirectional fibres were used to fill the noodle (Fig. 4a), and bonding between the skin and the stiffener was visually satisfactory. Further work will focus on redesigning the noodle region, experimentally evaluating the best possible combination of parameters, conceiving novel ideas and methods which will hopefully give the best performance of these composite bonded joints (Fig. 4b).

ACKNOWLEDGMENTS

This work has been supported by the project Centro-01-0145-FEDER-000017 - EMaDeS - Energy, Materials and Sustainable Development, co-financed by the Portugal 2020 Program (PT 2020), within the Regional Operational Program of the Center (CENTRO 2020) and the European Union through the European Regional Development Fund (ERDF).

REFERENCES

[1] S. Teixeira de Freitas e J. Sinke, “Failure analysis of adhesively-bonded skin-to-stiffener joints: Metal–metal vs. composite–metal,” vol. 56, pp. 2-13, 2015.

[2] G. Scarselli, C. Corcione, F. Nicassio e A. Maffezzoli, “Adhesive joints with improved mechanical properties for aerospace applications,” *International Journal of Adhesion and Adhesives,* vol. 75, pp. 174-180, 2017.

[3] W. Broughton, L. Crocker e M. Gower, “Design Requirements for Bonded and Bolted Composite Structures,” National Physical Laboratory, Teddington, 2002.

[4] B. M.D. e d. S. L.F.M., “Adhesively bonded joints in composite materials: An overview,” *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications,* vol. 223, nº 1, 2009.

[5] S. Budhea, M. Baneaa, S. de Barrosa e d. S. L.F.M., “An updated review of adhesively bonded joints in composite materials,” *International Journal of Adhesion and Adhesives,* vol. 72, p. 30–42, 2017.