Implementation of a new method for robotic repair operations on composite structures

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Abstract

Composite materials nowadays are used in a wide range of applications in aerospace, marine, automotive, surface transport and sports equipment markets. For example, all aircraft's composite parts have the potential to incur damage and therefore require repairs. These shocks can impact the mechanical behavior of the structure in a different ways: adversely, irretrievable and, in some cases, in a scalable damage. It is therefore essential to intervene quickly on these parts to make the appropriate repairs without immobilizing the aircraft for too long.
The scarfing repair operation involves machining or grinding away successive ply layers from the skin to create a tapered or stepped dish scarf profile around the damaged area. After the scarf profile is machined, the composite part is restored by applying multiple ply layers with the correct thickness and orientation to replace the damaged area. Once all the ply layers are replaced, the surface is heated under a vacuum to bond the new material. The final skin is ground smoothed to retrieve the original design of the part. Currently, the scarfing operations are performed manually. These operations involve high costs due to the precision, heath precautions and a lack of repeatability. In these circumstances, the use of automated solutions for the composite repair process could bring accuracy, repeatability and reduce the repair's time. The objective of this study is to provide a methodology for an automated repair process of composite parts, representative of primary aircraft structures.

Keywords: Robotic machining, Composite repair, Repair of structural composite parts, machining process.

1 Introduction

Composite materials nowadays are used in a wide range of applications in aerospace, marine, automotive, surface transport and sports equipment markets [1]. For example, all aircraft's composite parts have the potential to incur damage and therefore require repairs. These shocks can impact the mechanical behavior of the structure in a different ways: adversely, irretrievable and, in some cases, in a scalable damage. It is therefore essential to intervene quickly on these parts to make the appropriate repairs without immobilizing the aircraft for too long.

There are two main repair techniques, and these are referred to as scarf and lap (see figure 1). In the scarf technique the repair material is inserted into the laminate in place of the material removed due to the damage. In the lap technique the repair material is applied either on one or on both sides of the laminate over the damaged area. [2]

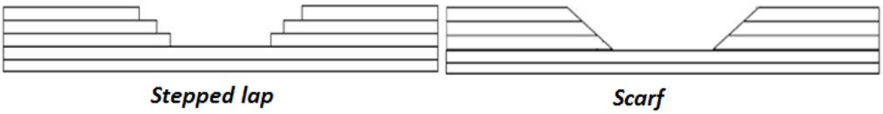

Fig. 1.Stepped lap and Scarf main repair techniques

To perform and automated this repair operations on CFRP components, a lightweight, portable manipulator with a collaborative robot has been designed and developed during the project “COPERBOT”.

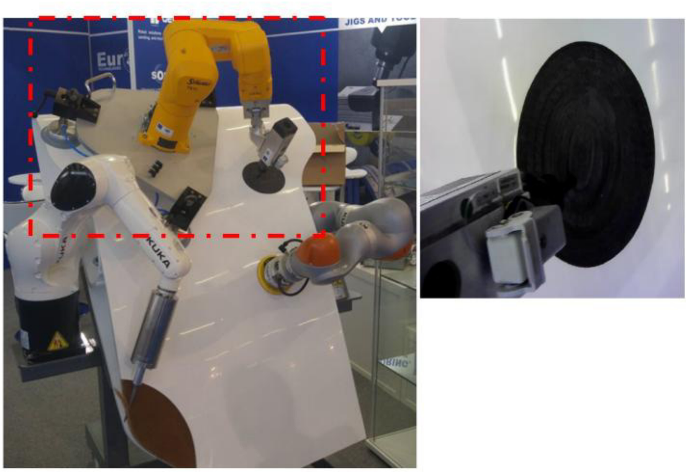

Fig. 2 Robotic solution developed for composite materials reparation in the project COPERBOT

The aim of this project is the development of an integrated process chain for a fast, low price, automated and reproducible repair of high performance fiber composite structures with a collaborative robot.

This platform will be mountable on aircraft structures even in-field, which allows for repairs without disassembly of the part itself. Consequently, a faster, more reliable and fully automated composite repair method is possible for the aeronautical and nautical industry. The objective of this article is to propose a new method to automate repair process of composite parts, for example monolithic CFRP laminate plates representative of primary aircraft structures.

This article is based on industrial examples from the collaborative “COPERBOT” project.

1 Development of a robotic repair method for composite structure.

Repair range of an impact on a composite structure consisted of the steps listed below:

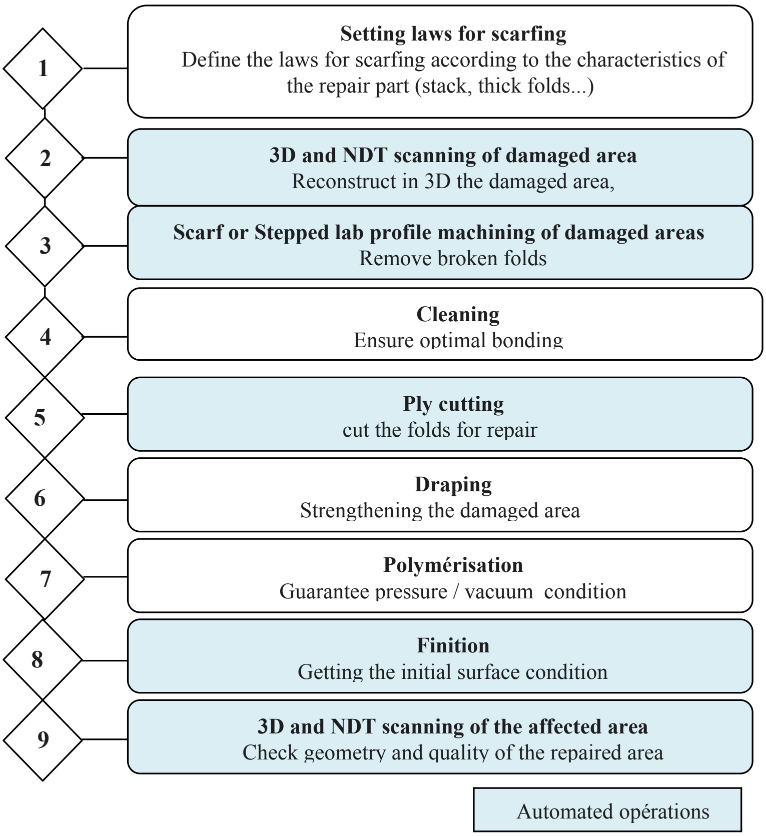

Fig. 3 Reparation range of an impact on a composite structure

The work carried out in the project COPERBOT are limited for the moment to repair tests on monolithic composite prepreg Hexply 8552 - AGP280-5H with a draping plan [0,45,0,45,0,0, 45,0,45,0].This type of plate is representative of materials, thicknesses and stacking sequences found in primary aircraft structures such as the radome of aircraft.

2 Surface generation by 3d-scanning

Most composite structures present in an airplane such as radome has curved shapes. It is therefore necessary to make a 3d scanning of the surface in the area to be repaired in order to recover the normal to the surface to adjust the trajectory machining.

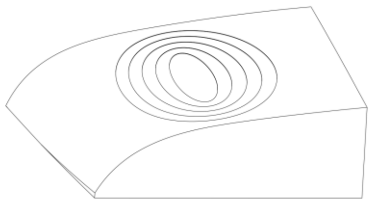

Fig. 4. Example of a stepped lap on convex part.

The first step in our robotic repair method is to reconstruct the surface to prepare the stepped lap trajectory of the damaged area with an onboard laser sensor on the 6th axis of the robot. The method adopted to reconstruct the surface is scanning the surface with the robot following a regular mesh defined by three points by the operator. By combining the position of the robot and the information given by a distance sensor (a line laser), we can then reconstruct the damaged area surface. Three typical examples are shown in fig 5:

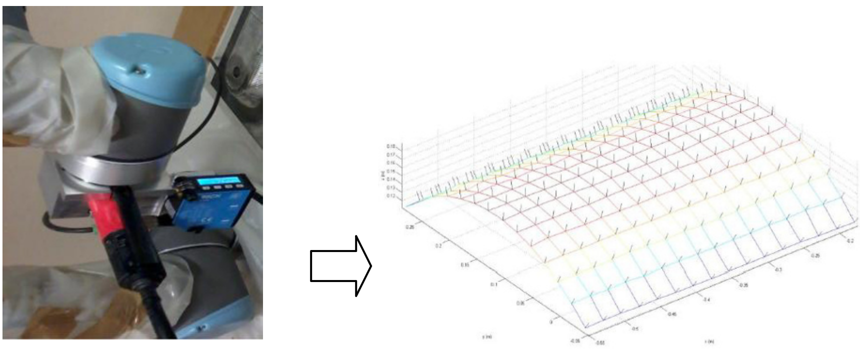

Fig. 5. Surface reconstructed by laser sensor fixed on a robot

3 3D Scarf calculation and milling trajectory.

From the recovered data on the reconstructed surface, machine path trajectories are calculated to create the appropriate geometry scarf on the surface. This patch needs to be draped mathematically on the surface, otherwise it wouldn't fit later in the scarf especially for parts with a smaller radius. [2] [5] Based on this 3D scarf definition the final milling trajectory is calculated taking into account different cutter types (shank or radius) as well as the stability of the part during the milling process. Two typical trajectories are shown in fig 6:

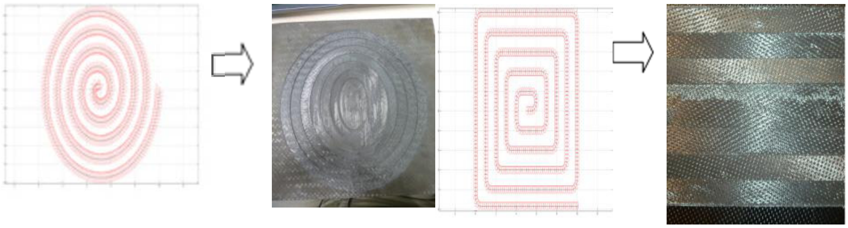

Fig. 6 Two trajectories for a stepped lap.

4 Stepped lap milling

To evaluate the optimum conditions of different repair materials, two types of tools, and three types of material were used. Repairs were made by the stepped lap techniques. [9] The cutting conditions selected are listed in the table below:

Tools:	PCD Ø 10mm	Carbide tool Ø 10mm
Rotation speed	19250 tr/min	12 000 tr/min
Cutting speed	604.45 m/min	376.8 m/min
Feed per revolution	0.25 mm/rev	0.25mm/rev
Cutting depth	0.10 mm	0.10 mm
Width of each step.	20 mm	20 mm

Fig. 7 Cutting conditions selected for tests.

Results of tests recommend to use a polycrystalline diamond tool (PCD) for machining of stepped lap. This type of cutter is designed to withstand the abrasive properties of composite material.

Fig 8 Stepped lab composite part produced by the robot

To limit the defects created by the machining forces, two types of parameters were tested to determine the most suitable for our application: on one side, those associated with the tool, those related the cutting conditions (feed per revolution, cutting speed, direction of the fibers in relation to the feed rate ...) [2]. The machining paths that were chosen with a view to study subsequently the influence of fiber orientation on the cutting forces [5].

5 Metrological controls of surfaces obtained by stepping in to optimize the process conditions.

Optical 3D measurement has controlled the removed pleat depths and the surface roughness obtained by machining robots on our test plates.

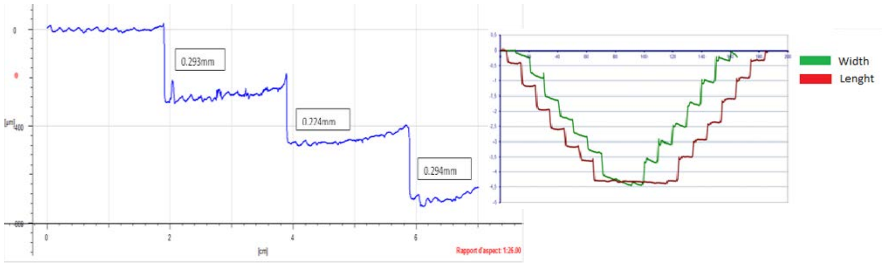

Fig 9 Metrological controls realized of stepped lap in composite part produced by the robot

Micrographic examination of the surface topography and the profile control review by a coordinate measuring machine on machined steps show an accuracy of a tenth of the depth machined on each floor for each of the two tests. Robotic scarfing made by the technical steps with PCD tool enables a low roughness (Ra of approximately 21) and without the presence of delamination floors contour levels.

Fig 10. Analyzing surface quality obtained by PCD tool.

The tests have shown that the quality of the automatic repair is at least as good as for a repair manually executed by skilled repairmen.

Even for simple repairs the robotic scarfing process has shown to be two times more efficient than a manual process.

6 Conclusions

This article points a scientific view about the problematic of composites repairs and proposes excavation solutions achieving normalized using robot.

Through testing we found that the PCD tools associated with certain operating conditions allow achieving the desired quality level for the preparation of the repair area. The approach of 3D surface scan and projection paths were validated by measuring the qualities of realized scarf. Analysis of scarfing tests checks on robot allows to consider robotic solutions finalized type “ cobot “ for repair of composite parts on ship or airplane by interventions directly on the sites or exploitation zones.

However, additional tests must be conducted to validate the proposed methodology, and the mechanical characterization of the interface repaired and analysis of the structural strength of the repair by testing expense and fatigue of different specimens repaired.

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8 References

1. B.FURET – B. JOLIVEL – D. LE BORGNE, "Milling and drilling of composite materials for the aeronautics", Revue internationale JEC Composites N°18, June-July 2005
2 A. EDWIN- E.LESTER, "Automated Scarfing and Surface Finishing Apparatus for Complex Contour Composite Structures", American Society of Mechanical Engineers, Manufacturing Engineering Division, MED 05/2011; 6.
3.S.GOULEAU–S. GARNIER–B.FURET, « Perçage d’empilages multi-matériaux : composites et métalliques », Mécanique et Industries, 2007, vol. 8, No. 5, p. 463-469.
4.A.MONDELIN–B.FURET– J. RECH, « Characterisation of friction properties between a laminated carbon fibres reinforced polymer and a monocrystalline diamond under dry or lubricated conditions », Tribology International Vol. 43, p. 1665-1673, 2010.
5. B.MANN, C.REICH, « Automated repair of fiber composite structures based on 3d-scanning and robotized milling» Deutscher Luft- und Raumfahrtkongress, 2012.
6.C.DUMAS, S. CARO, M. CHERIF, S. GARNIER, M. RITOU, B. FURET, “ Joint stiffness identification of industrial serial robots ”, Robotica, 2011. (2011-08-08), pp. 1-20, [hal-00633095].
7.C.DUMAS, A. BOUDELIER, S. CARO, B. FURET, S. GARNIER, M. RITOU, “ Development of a robotic cell for trimming of composite parts”, Mechanics & Industry 12, 487–494 (2011), DOI: 10.1051/meca/2011103
8.A.BOUDELIER, M.RITOU, S.GARNIER, B.FURET, “Optimization of Process Parameters in CFRP Machining with Diamond Abrasive Cutters”, Advanced Materials Research (Volume 223), 774-783 (2011), DOI: 10.402/www.scientific.net/AMR.223.774
9.BAKER, A.A., A Proposed Approach for Certification of Bonded Composite Repairs to Flight-Critical Airframe Structure, Applied Composite Materials, DOI 10.1007/s10443-010-9161-z
10.WHITTINGHAM, B., BAKER, A.A., HARMAN, A. AND BITTON, D., Micrographic studies on adhesively bonded scarf repairs to thick composite aircraft structure, Composites: Part A 40 (2009), pp. 1419–1432
11.GUNNION, A.J. AND HERSZBERG, I., Parametric study of scarf joints in composite structures, Composite Structures, Volume 75, Issues 1-4, September 2006, pp. 364-376
12.C.BONNET- G.POULACHON-J.RECH-Y.GIRARD-J.P COSTES, “ CFRP drilling: Fundamental study of local feed force and consequences on hole exit damage “ International Journal of Machine Tools and Manufacture, 2015, 94, pp.57-64.