LASER ULTRASONICS INSPECTIONS OF AERONAUTICAL COMPONENTS VALIDATED BY COMPUTED TOMOGRAPHY

Esmeralda CUEVAS AGUADO[1], Carlos GALLEGUILLOS[2], Covadonga GARCÍA RAMOS[1], Fernando LASAGNI[2]

[1] Aeronautical NDT Technologies TECNATOM S.A; Avda. Montes de Oca, 1 28703 San Sebastián de los Reyes, Madrid, Spain. Phone: +34 91 208 46 18; e-mail: ecuevas@tecnatom.es

[2] Materials & Processes department, Center for Advanced Aerospace Technologies (CATEC), C/Wilbur y Orville Wright 17-19-21, E-41309 La Rinconada, Seville, Spain. Phone +34 954 179 002, e-mail: flasagni@catec.aero

Abstract. Repeatability, traceability, recording, independence of the operator and optimization of the inspection times are the main requirements in Non Destructive Inspection of Aeronautical components. In order to ensure them, laser ultrasonic inspection can offer many advantages compared with manual techniques. Laser ultrasonic technology combines two lasers in order to perform the inspection of the part: a short-pulsed laser for generation (CO2 laser, < 100ns) and a long-pulsed high power detection laser (Nd:YAG, >500W) coupled to a high-bandwidth optical interferometer to measure the ultrasound. Other elements of the laser ultrasound system include a high-speed optical scanner to index the inspection point, and a real-time control system to synchronize the scanner, lasers, and measurement acquisition hardware. Ultrasound is generated within the top surface of the composite without physical contact or water couplants; the induced ultrasonic wave will always propagate perpendicular to the surface thereby enabling testing of parts with substantial geometric complexity. In addition to these characteristics, the inspection part distance from the scanning head can work from 1,5 to 2.1 meters. In this study, aeronautical components have been inspected with Laser Ultrasonics, and the obtained results are validated by Computed Tomography, where a quantitative analysis for the characterization of void content (at selected region) is presented. Furthermore, radiographic analysis of main indication is addressed. In this way, the inspection of aeronautical complex component by Laser Ultrasonic technology is demonstrated.

Introduction

RTM (Resin Transfer Moulding) design and manufacturing process is also present within composite structures, taking advantage of the integration benefit provided by this technology. Complex geometries are obtained with a very good surface finish as well as accurate dimensional tolerances. These characteristics are provided by obtaining the final product inside a closed mould, where fabrics are stacked in the interior of such a manufacturing tooling. The fabrics are laid-up in a dry format, usually covered by a polymeric product used as a binder. After closing the mould, a degree of vacuum is attained, enabling the injection of a liquid resin, heated previously to reach a suitable low viscosity condition.

Because of these complex geometries obtained, a flexible Non Destructive Method like Laser Ultrasonics is proposed, taking advantage of non-contact inspection, no need of special tooling for different configuration and also distance to the inspected part. [1]
The Figure 1 shows a representative structure of curved panels stiffened by RTM parts, co-bonded to the skin. Due to the manufacturing process, the RTM process constitutes a good selection to obtain a non-hollow beam with a complex shape that includes the crosses between stiffeners.

Figure 1. Curved panel stiffened by RTM detail parts

1. Laser Inspection

1.1 Laser Technology

Laser ultrasonic (LUS) technology combines two lasers in order to perform the inspection of the part: a high peak power pulsed laser for generation (TEA CO2) and a detection laser (Nd YAG). Other components that are also involved in the process are an optical interferometer, a photo detector, a digitizer and a module control to synchronize laser shots and measurement acquisition. See Figure 2 [Cuevas 2015]

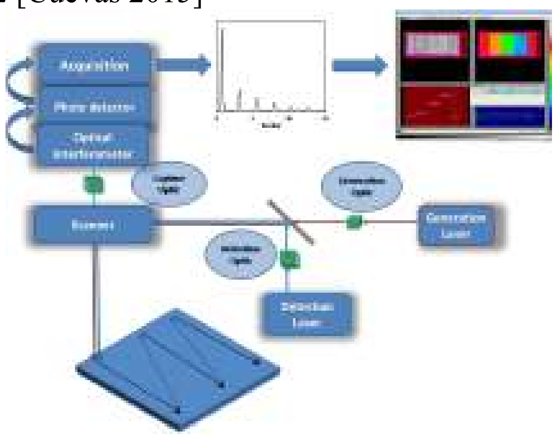

Figure 2. Schema LUS Inspection

The laser ultrasonic system is integrated in the Rabit inspection cell ensuring not only software and hardware integration but also safety requirements.
Depending of the parts to be inspected and the optimization of their inspection time, three different alternatives are described below:

Figure 3. tecnaLUS developed within LUS-TEAM project.

Figure 4. tecnaPLUS over linear track

1.2 Laser Inspection Benefits

Laser Ultrasonic is one of the most innovative technology in the field of non-destructive testing. Tecnatom proposal using Laser Ultrasonic Technology combined with Rabit one has both the advantages of laser Ultrasonic inspection and the ones from integrated systems.

Advantages of Laser Ultrasonic Technology are listed below:

- Optimization of laser system for composites inspection
- No need of couplant
- High tolerance relative to the incidence angle of the laser beam with the part (± 35º) and to the distance from the scanning optical on head
- Ability to detect defects up to 40 mm depth
- Productivity: Reducing inspection times. This reduction is bigger for complex shape components.

Advantages from Rabit technology (Robotic systems) are listed below:

- Integrated system with powerful HW-SW technology that enables the integration of the complete inspection process: learning of part geometry, CAD reconstruction and Automatic Trajectory generation, simulation and post-processing of the generated trajectories for final validation, integrated inspection process from definition of the parameters to the evaluation process including management of robot movements and also safety components.

- Flexibility: incorporating different solutions to increase its performances: Robot over track, Robot holding the parts.

2. Tomography

X-Ray Computed Tomography (XCT) is the most suitable method for the study of the internal structure of materials with a high degree of detail, and without the need of destroying the object. This technique can be applied to the characterization of many materials such as composites, metals and polymers.

During a tomographic evaluation, it is possible to evaluate defects, inclusions, damage, or the internal structure. Studies including metrological analysis and reverse engineer are also feasible, due to the potential of the technique to reveal the internal structure and surface of the inspected parts.

The technique [2] is based on irradiating the object under study using an X-ray cone beam, while a detector collects radiation passing through the object. During the inspection, the part is rotated 360° under controlled conditions, and producing several projections for each angular position. For the case of large components, reduced angle inspections can be also performed. Large computing capacity is required for the generation and reconstruction of the recorded information. Results can be displayed in cross-sections, or as a three dimensional views.

Inspection has been performed by means of a XCT system, model “VJT-225 μ-CT”, manufactured by VJ Technologies (Figure 5). The last includes the following technical characteristics: (x1) X-Ray tube 225KV @ 30 mA, 4,500W, (x1) GE 2048 x 2048 pixels, (x1) Shielded vault of 4,000 x 3,032 x 2,827 mm (lwh), Volex and VGStudio softwares for reconstruction and analysis, respectively.

Testing parameters for the different XCT tests on samples were determined as: Voltage [KV] = 140; Current [μA] =150; Nr of projections =1,200; Voxel size[μm] = 66.3; Exposure time [ms] = 2

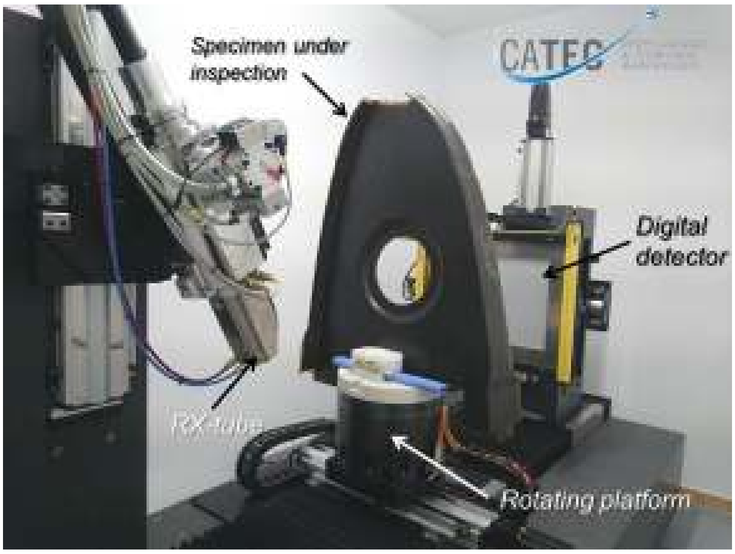

Figure 5. View of computed tomography system at CATEC facilities.

3. Results

3.1. Part's description

The specimen has been inspected by means of Laser Ultrasonics and validated using Computed Tomography technology. The part consist on a Leading Edge, manufactured in carbon fiber (CFRP Carbon Fiber Reinforced Polymer) by RTM process. Table 1 shows the Leading Edge dimensions while Figures 6 & 7present a general view of the component and set-up within inspection cell, respectively.

Table 1. Part Dimensions

<table>
<tr><th>View</th><th>Length (mm)</th><th>Height (mm)</th><th>Thickness (mm)</th></tr>
<tr><td>A</td><td>1017</td><td>115 to 174</td><td rowspan="2">3,3 to 7,5</td></tr>
<tr><td>B</td><td>762</td><td>114</td></tr>
</table>

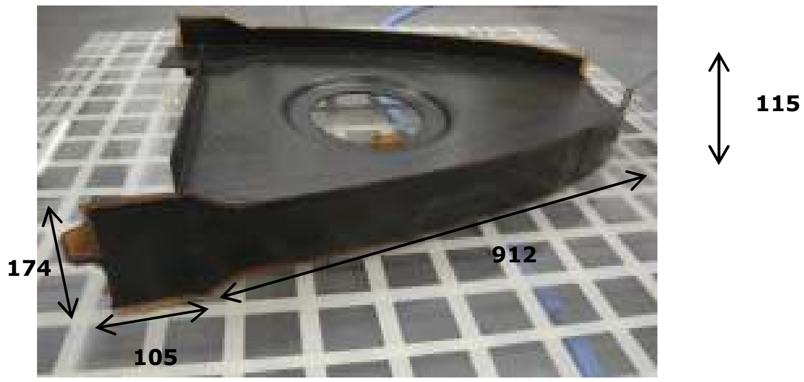

Figure 6. View A of Leading Edge

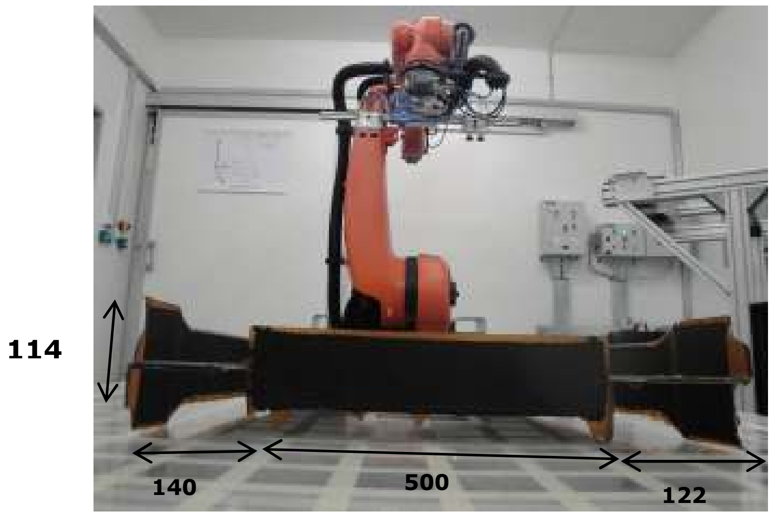

Figure 7. View B of Leading Edge

3.2 Inspection Results

Laser Ultrasonic gives very good results after the inspection of such part, with complex geometry, where conventional ultrasonics in an automated way results a very difficult task. The last is related with the requirement of several and different probes in order to fulfill the required geometries. tecnaLUS is detecting porosity, this can be identified in Amplitud C Scan (Figure 8), where the amplitude drops, and also in Time of Flight (ToF) C Scan, where the indication can be located.

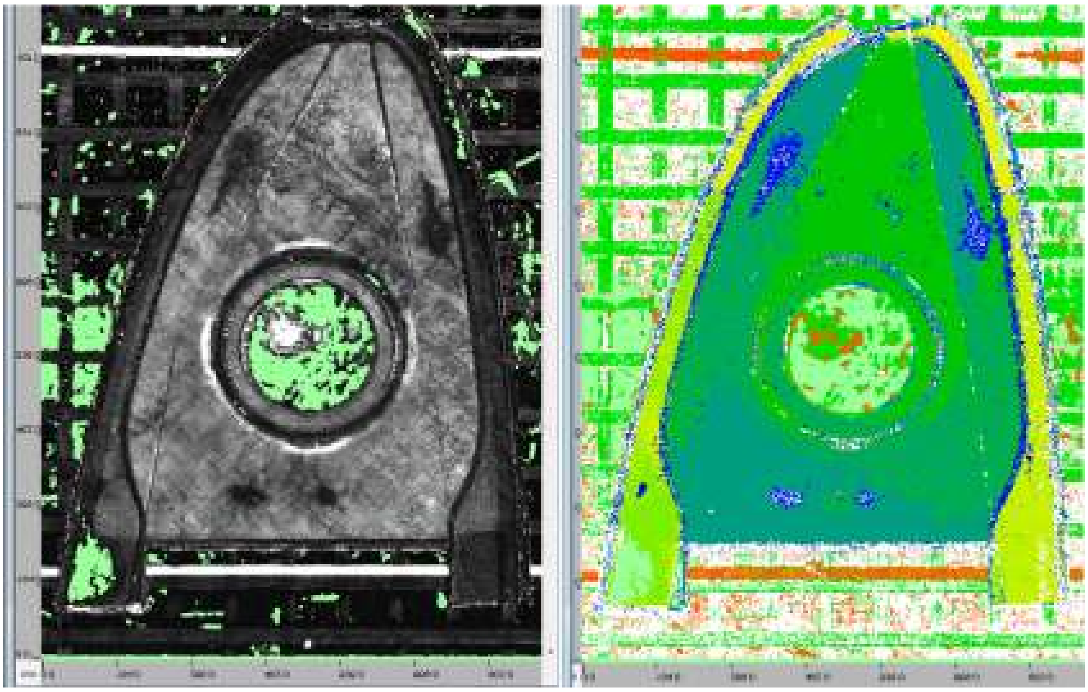

Figure 8. tecnaLUS Inspection results of Leading Edge

After detection of attenuated zones, a tomographic study has been performed using digital radiograph and computed tomography. Figure 9a illustrates a general view of the part with superposed radiographs. Fig. 9b and c show magnified sections with porosity indication, in agreement with LUS inspections. For quantification, a tomographic quantitative analysis has been carried out by tomography. The Region of Interest (RoI) is depicted in Fig. 10c. Cross-sections are presented in Figures 10a and b, with an overall void content of 0.75%. An histogram with void distribution is shown in Fig. 10d, where a high concentration of voids $<0.04\ mm^3$ is observed (by 45% in number). Also, a considerably number of pores (aprox. 10%) larger than $0.2\ mm^3$ is as well observed.

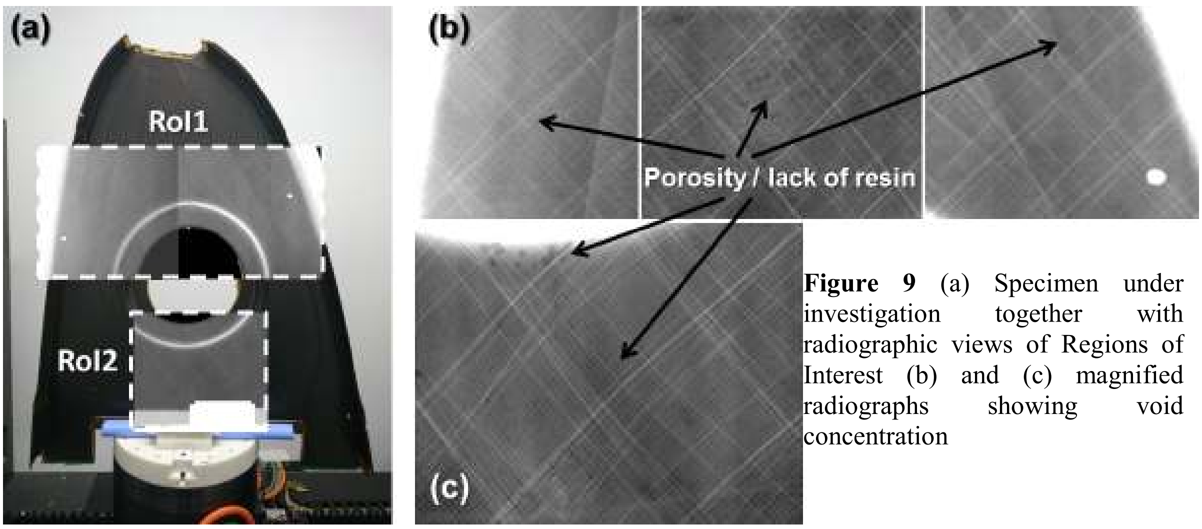

Figure 9 (a) Specimen under investigation together with radiographic views of Regions of Interest (b) and (c) magnified radiographs showing void concentration

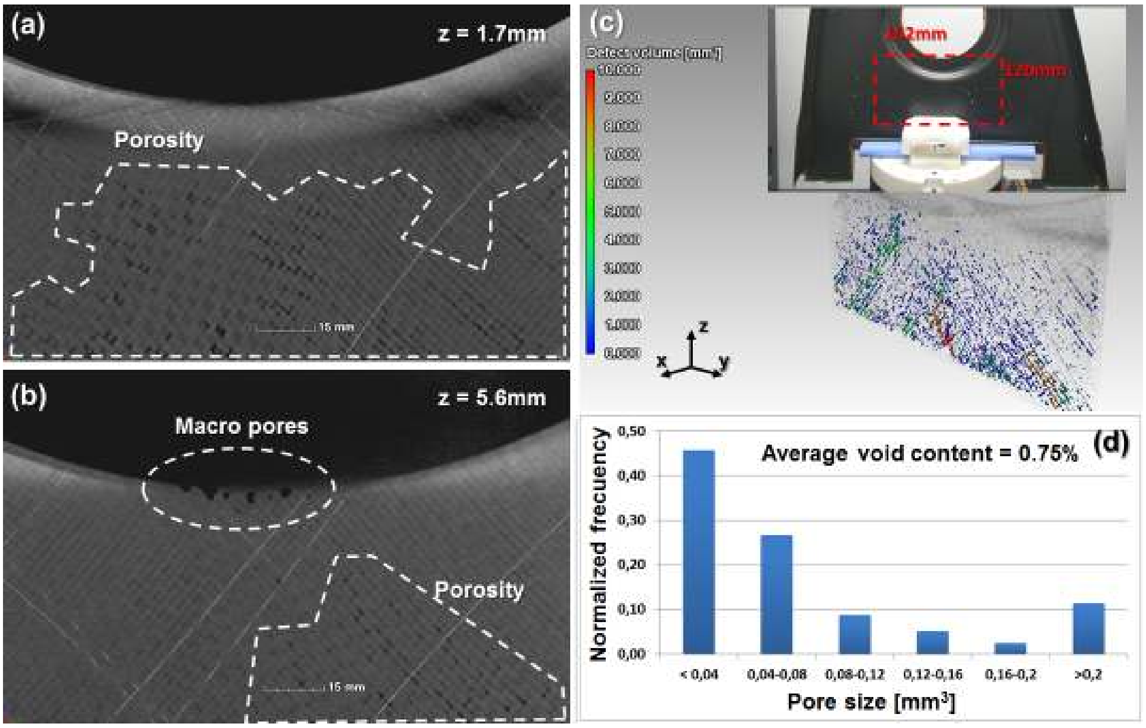

Figure 10. Tomographic investigations on target part: cross sections at (a) 1.7 and (b) 5.6mm thickness position with indication of porosity; (c) 3D representation of detected porosity and Region of Interest (RoI); and (d) histogram with pore size distribution.

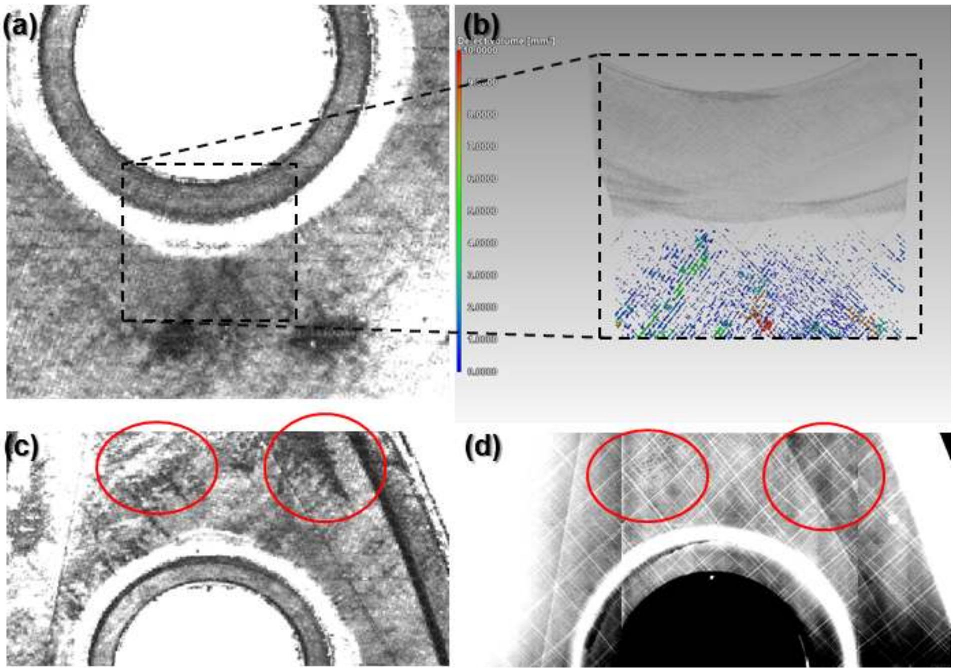

Figure 11. Comparison results views from high void content areas: (a) LUT C-Scan and (b) 3D tomographic representation of RoI with void content by 0.75%; (c) LUT C-Scan and (d) Digital radiograph of RoI with porosity accumulation (see red circles). All results shows very good correlation.

Finally, Figure 11 shows a good agreement between tomographic and LUS inspections, where attenuated zones corresponds to porosity concentration zones by 0.7-1.0%.

4. Conclusions

Non Destructive inspection of ccomponents with complex geometries are carried out mostly in manual mode with the consequent dependence on the operator, not having register of the inspection and increasing inspection time and costs.

Integration of Robotic Systems and Rabit Technology with laser Ultrasonic Inspection, is the most appropriate solution for the inspection of detailed parts with complex geometry, increasing productivity rates and also quality of the manufacturing process, including in this one the Inspection stage. These results have been confirmed by tomographic and radiographic evaluation, where a clear correlation at attenuated areas of UT signal are observed and related to concentration of porosity (0.7 – 1.0%).

References

[1] E. Cuevas, C García, L. Rubio: Laser Ultrasonics Inspections of Aeronautical Components with High Cadence and Geometrical Variations, Manufactured by RTM: Resin Transfer Moulding. 4th International Symposium on Laser Ultrasonic & Advanced Sensing, Evanston, Illinois, USA, June 2015

[2] F. Lasagni, A. Lasagni: Fabrication and Characterization in the Micro-Nano Range: New trends for two and three dimensional structures, Springer-Verlag GmbH Berlin Heidelberg, ISBN 978-3-642-17781-1, 2011, Chapter 6 B. Harrer and J. Kastner: "X-Ray Microtomography: Characterisation of Structures and Defect Analysis"