Advances in the implementation of a UT contactless inspection system in the manufacturing process of thermoplastic components for aeronautical use, within the framework of the H2020-DOMMINIO project.

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Abstract

In recent decades, the aeronautical industry has undergone a drastic transformation in the manufacturing philosophy in response to the growth of aircraft production (by 60% in the last 10 years), due to the increase in passenger transport demand. Although the pandemic has contracted the sector 66% during the last years 2020-2021, it is expected normalization by 2024. The transition to the use of more advanced composite materials, together with the increase in aircraft performance and the rate of productivity is a challenge. Also, the necessity to produce effective structures and components using ecological materials and technologies have been increased, with the consequence of reducing cost, weight and fuel consumption. The DOMMINIO project from the European H2020 program, aims to develop new integrated design methodologies and knowledge based on manufacturing and optimization for the production of new multifunctional fuselage parts. This technology is applied manufacturing by Laser ATL (**A**utomatic **T**ape **L**ayout) technique, using the automated deposit of thermoplastic tapes on a mold. Additionally, the DOMMINIO project deals with ensuring the quality of the components during the manufacturing process by a novel non-destructive control based on Ultrasound contactless technologies. To this end, DASEL has developed non-contact transducers that are coupled to the technological process of layer deposition, performing a non-contact quality control. This paper presents the results of the first year of the project, emphasizing the detection of delamination or lack of consolidation in real time.

KEYWORDS: Aircraft Ultrasonic NDT, thermoplastic plate elements, Lamb waves, Air contactless ultrasonic technology.

1. Introduction

Domminio is an EU funded collaborative research project focused on the development of an innovative digital methodology to design, manufacture, maintain and pre certify multifunctional and intelligent airframe parts [1].

This project uses thermoplastic matrix composite materials, processed with an ATL (Automated Tape Laying) process (Figure 1). This is based on the in-situ consolidation of composite material in tape format, which is consolidated layer by layer applying pressure (with a compacting roller) and temperature (by means of a laser source). Then the ideas to deposit layers sequentially, obtaining a consolidation between them, so that at the end of the lamination process the part is finished, without the need to carry out a subsequent curing cycle [2].

In this process, defects may appear that can affect the behavior of the part in the service. The most common defects are porosity, delaminations and foreign objects that may fall during the laminating process, or other defects derived from the tolerances of the ATL equipment, such as gaps or overlaps between tapes or wrinkles in the tapes [3]. Since this process does not require further processing, these defects could be detected during the lamination process. This is one of the fundamental tasks sought by the DOMMINIO project.

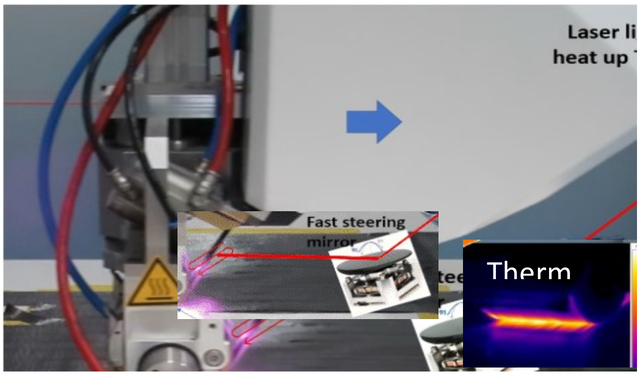

Figure 1. ATL system for the formation of thermoplastic plate.

As a part of the project Domminio, it includes a development of an ultrasonic contactless inspection system for the online quality control of the previous manufacturing of thermoplastic aeronautic components. This specific part in the project is considered as the fundamental objective presented in this congress. The UT contactless technique is based on ultrasonic air transducers that, according to the low frequency and relatively low thickness of the aeronautic components, should produce Lamb waves. This is a kind of guided waves that present the dispersion phenomena where the phase and group velocities depend on frequency and thickness. In this work, it is also considered the use of standard high frequency ultrasonic technique based on phase array for testing final thermoplastic components in order to complement the previous technology.

2. Theoretical model

2.1 Lamb wave propagation

Lamb wave isone of the guided waves presented on plates (Shear Vertical, or SV) [4] [5]. This elastic wave mode appears when the wavelength is less than the thickness plate. In this case, the phase velocity (and then the group velocity) depend on the frequency and thickness of the plate. In Figure 1, it shows one example of the dispersion curves for a material considered in the work, where it is shown two fundamental modes: antisymmetrical and symmetrical modes.

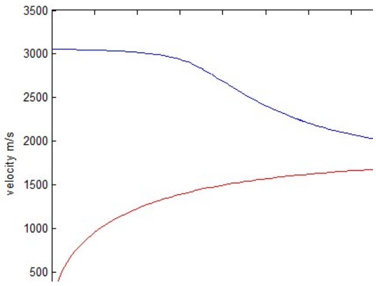

Figure 2. Dispersion curves for a 2 mm thickness plate. Blue is the symmetrical mode. Red is the antisymmetrical mode.

2.2 Lamb wave pulse excitation.

Figure 3, shows a diagram of the experimental setup used, for the excitation of Lamb waves. A first transmitter transducers T_x excites a longitudinal wave in the air surrounding the plate. The incident angle is obtained from the following Snell expression:

$$\boldsymbol{sin(\alpha)} = \frac{\boldsymbol{C_{air}}}{\boldsymbol{C}} \qquad (1)$$

Where Cair is the velocity of longitudinal waves in air (360 m/s). The value of C is obtained from dispersion curves. In this work it is used the antisymmetrical mode (Figure 2, red curve) with a given frequency as expressed below. Then (1) is a necessary condition for the excitation of a desired Lamb mode (that assume a “refraction” angle of 90^0).

The Lamb wave mode propagates through the plate and produce a leakage phenomenon in the air that can be detected with a second receiver transducer R_x. In a pulse excitation at T_x, it is possible to obtain an RF signal over R_x, according to Figure 3. This is the fundamental implementation of the contactless technique developed for testing this material.

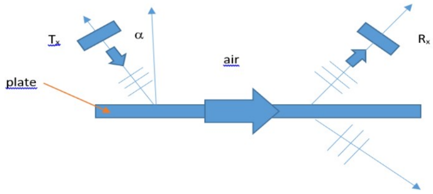

Figure 3. Diagram of the UT contactless inspection system. Tx=transmitter, Rx=receiver.

3. Material and Method.

It is shown on Figure 4, the basic configuration of both transducers developed for this project. Both of this transducer have a central frequency of 250 KHz. An angle around 10 to 15 was used in order to obtain a desired antisymmetrical Lamb wave mode. Both transducers move as a whole with fixed distances over all the plate. Then it is possible to obtain RF signal at each position and then a C-Scan picture, with details of a possible defect according to the amplitude changes of Lamb wave mode.

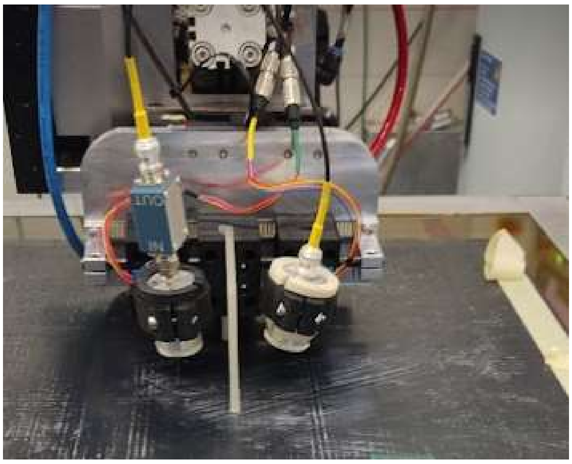

Figure. 4. Experimental configuration with the two transducers Tx and Rx with a central frequency of 250 KHz

The next Figure 4 shows two of the samples used in the experiments of the Domminio project. On the left side there is a classic thermoplastic plate that is used as reference. On the right, there is a thermoplastic sample developed using the ATL technique. The idea is to compare the new ATL process with the classic one. Both samples were tested with pulse echo phase array technique (5 MHz) and the ultrasonic contactless technology using antisymmetrical Lamb wave mode.

Figure 4. Left Thermplastic sample made with compression molding. Right Thermoplastic sample made by Laser ATL process.

4. Results.

The Figure 5 shows the results for the first reference thermoplastic sample. Two images, the B-Scan from phased array or PA (left) and Contactless Lamb wave C-mode are displayed. Both images are considered as reference to the case of ATL technology. The PA shows a clear bottom echo of the sample made by this reference technology. Assuming this sample as a flawless sample, the C-mode is taken also as a reference for the next ATL image.

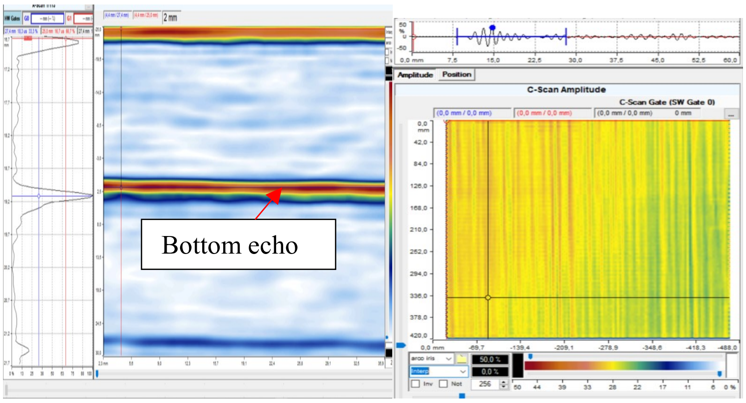

Figure 5. Images examples from thermoplastic reference sample obtained from standard procedure. Left B-mode phased array image. Right. C-Mode Contactless Lamb wave mode.

On the other side, Figure 6 shows the first results obtained from an ATL sample with the same technologies as the previous case. In this case, the results show two fundamental aspects. First in the PA B-Scan it is not possible to obtain at the bottom echo as in the previous case. The C-Scan Lamb wave mode, also shows non uniform color also respect to the previous case. Then this first ATL sample still has to be adjusted in the next future as a part of the project. He must important thing is the capacity of the contactless ultrasonic method developed based on antisymmetric Lamb wave mode.

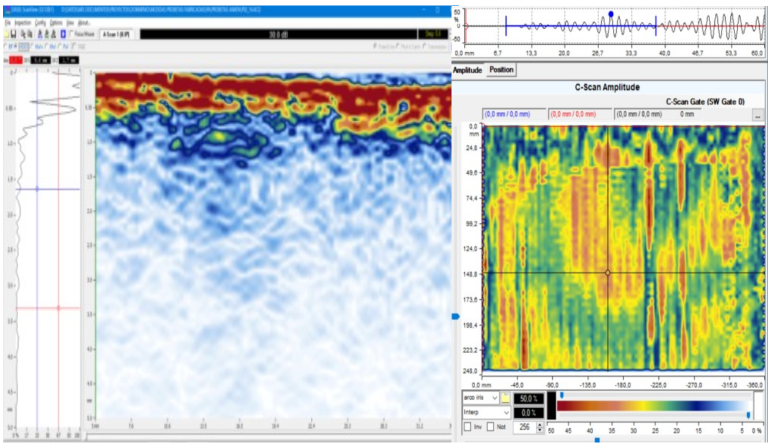

Figure 6. Images example for the ATL thermoplastic sample. Left B-mode phased array image. Right. C-Mode Contactless Lamb wave mode.

4. Conclusions

An ultrasonic contactless technology was developed in the Domminio project for testing the thermoplastic ATL samples. This could be considered as a first stage in this project. Of course, several work should be done in the ATL technology and in the own ultrasonic contactless technology, which must be applied online during the ATL process.

Acknowledgements

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References

[1] https://domminioproject.eu/about/project%20overview
[2] Martin, Isabel, et al. "Advanced Thermoplastic Composite Manufacturingby In-Situ Consolidation: A Review.." Journal of Composites Science 4.4 (2020): 149.
[3] Harik, Ramy, et al. Automated fiber placement defect identity cards: cause,anticipation,existence, significance, and progression. No. NF1676L-29045. 2018.
[4] Auld, Acoustic field and waves in solids, Krieger Pub Co, 1990.
[5] E. Moreno, N. Galarza, B. Rubio and J. A. Otero, "Phase velocity method for guided wave measurements in composite," *Physics Procedia 63 (2015) 54 – 60,* vol. 63, pp. 54-60, 2015.