

## Characterization of casting defects in composite carbon fiber material detected by ultrasonic inspection

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### Abstract

Technological innovations applied in the aeronautical sectors prefers the use of structures that are able to have great advantages in terms of performance with a significant weight reduction. This involves research and development of new materials, in which composite materials have an high importance in the study of new concept structural architecture. Objective of the presentation is the correlation of results obtained using non-destructive testing, ultrasonic method in particular, with the discontinuity which produce an indication in carbon fiber composites. The indication can be found by ultrasonic method in form of attenuation signal and/or reflection signal.

The characterization of typical defects enucleated in CFRP materials (Carbon Fiber Reinforced Polymer) or CRP (Carbon Reinforced Plastic) will therefore be supported by a significant activity of material testing laboratory. Laboratory activity will be directed to the identification, quantification and characterization of the discontinuities due to problems and/or failure during the production process.

**Keywords:** non-destructive testing, ultrasonic method, carbon fiber composite, carbon fiber reinforced polymer (CFRP), carbon reinforced plastic (CRP).

### 1. Equipment description

Given the numerous activities carried out in Bytest, the ultrasonic plants used, in order to perform inspection activities on materials of all kinds, three equipment are used for the inspections on composite materials (Fig. 1 - 3).

- Immersion ultrasonic system for control of parts in transmission or pulse-echo with three movement axes (Fig. 1).



Fig. 1. BYTEST immersion ultrasonic system

- Automatic ultrasonic system by water column for control of parts in transmission or pulse-echo, with four axes of movement, for structures with complex geometry (Fig. 2).

- Semi-automatic system with phased array technology (Fig. 3), which offers the possibility to create and manage an ultrasound beam in terms of angles, focal lengths and

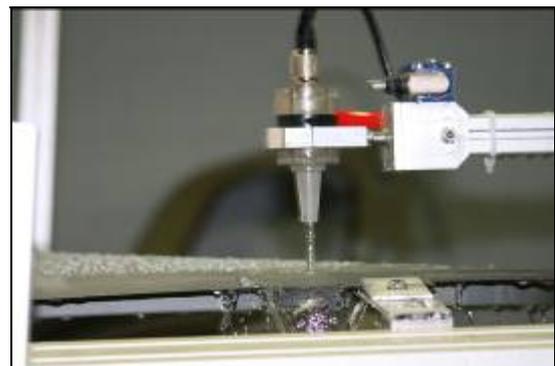


Fig. 2. BYTEST water column ultrasonic plant

sections of the beam. The equipment generates an ultrasound beam through the excitation of a series of piezoelectric elements (64 active elements), which can be managed independently by inserting a series of parameters concerning the number of elements used (size of the beam UT), the angles of inspection and the depth of focus, compared to the depth of the object to be inspected.



Fig. 3. Phased Array semi-automatic system

- Inspection system with X-ray Computed Tomography (CT), which allows 3D digital reconstruction of a particular, allowing it to be thoroughly inspected by virtual sections (Fig. 4).



Fig. 4. BYTEST computed tomography plant

- Leica digital microscope DM6000. This microscope is used with all common incident-light methods (bright field, dark field, polarization, interference contrast, fluorescence contrast), with engine scan table, also used in fully automated mode and in conjunction with an image analyzer (Fig. 5).

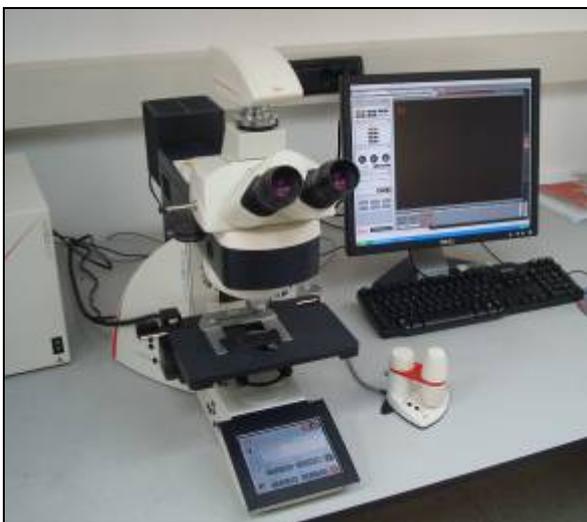


Fig. 5. Digital Microscope Leica DM6000

## 2. Inspection technique description

The ultrasonic inspection technique used in the control of parts in composite material depends on the configuration and on the applicable process specification.

Usually, for solid laminate structures using both the technique in transmission or in reflection, while for structures with honeycomb is used the technique in transmission.

In some cases the technique in transmission must be completed by reflection technique in order to characterize fully the founded indication. The tomographic method allows the 3D visualization of the indication, determining the spatial position, shape and size.

The laboratory activities are essentially related to macrographic and micrographic examination.

The first, that will not be the subject of this discussion, are made at very low magnification in order to identify relevant surface defects, such as delaminations or damage of the fibers in processing subsequent to the composite production.

Micrograph checks of composite materials identify examinations carried out by using conventional optical microscopes for highlighting the number of skins, their thickness and their orientation (unidirectional fibers or woven, characterized by warp and weft), or simply for characterization and sizing of defects such as porosity, inclusions, distortion between the blades and damage such as delaminations, microcracks or passing cracks.

Then there are specific applications of the micrograph for studies on the behavior of the composite to the fiber-matrix interface, which are carried out with the aid of scanning electron microscopes (SEM).

## 3. Examined parts

The solid laminate structures (monolithic) are structures that usually do not contain lines of adhesive, but take advantage from resin of pre-impregnated for polymerization. This means that a typical casting defects is the delamination between the skins that make up the structure. In an inspection with the ultrasonic method, the discontinuity detection is relatively simple because within the delamination there is a thin layer of gas (formed during the polymerization), which produces a considerable difference in acoustic impedance thus generating an high reflection.

A possible cause of delamination is due to the protective layer of skins that is not properly removed during manufacturing. Therefore, the indication founded by ultrasonic inspection is due to an inclusion of extraneous material. For the characterization of discontinuity, the detection is very similar between foreign body and delamination, because the protective skin of the composite material produces an inhibition of bonding, and thus remains a gap between the skins.

The presence of porosity inside the polymerized particular cause attenuation of the ultrasonic signal. In this case we speak of small reflectors that cause the diffusion of the ultrasonic signal. It is important for the equipment set up in order to determine the amount of ultrasonic signal that still has to go through the structure in order to ensure

its integrity. In fact, many specifications require that the polymering process guarantees a number of voids in the volume does not exceed 1% or 2% (Fig. 6, Fig.7). Normally, the porosity content is measured as a percentage of the volume of the laminate, making the determination on a sample obtained from a cross section of the same considering in the overall evaluation the size contribution of each individual detected porosity. When the distance between individual pores is less than 3 mm we can speak of substantial presence of porosity that, to the level of acceptance standards must be treated as an actual delamination.

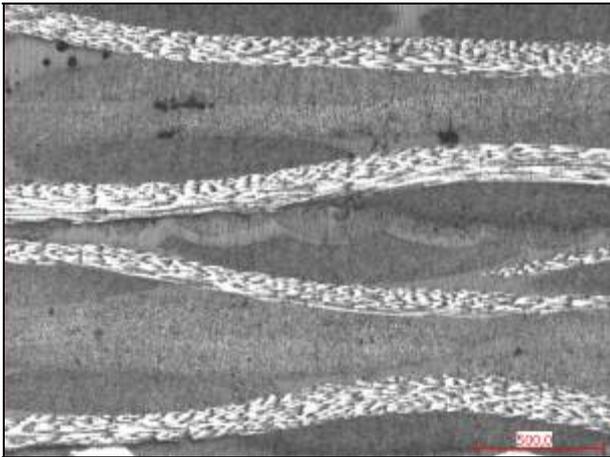


Fig. 6. Micrographic evidence to 50X cross-section of a sample with evidence of both elongated and isolated porosity areas

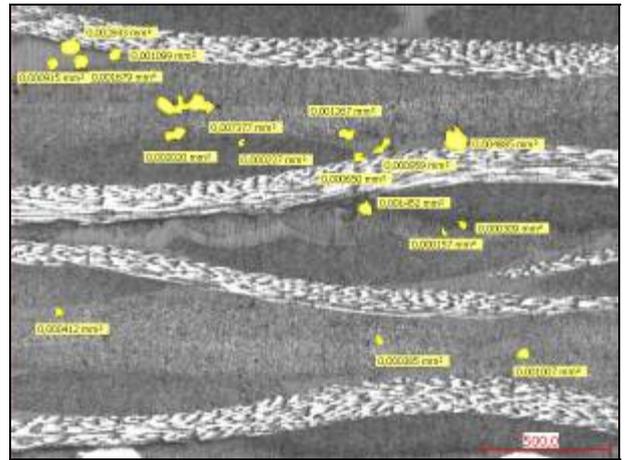


Fig. 7. Evidence of dimensional measurements of each porosity made on sample to the side by image analyzer

The Reference Standard on which it is conducted the instruments calibration, must now ensure the required percentage of voids in volume is in accordance to the specification requirement.

The reference sample is constructed with the same process of the tested particular with inside the volume a series of artificial discontinuities of different materials and sizes, placed in critical areas and different depths to simulate delaminations (Fig. 8).

The size of the discontinuity is defined by constructive characteristics given by the drawing or by requirements specified by the design (Engineering).

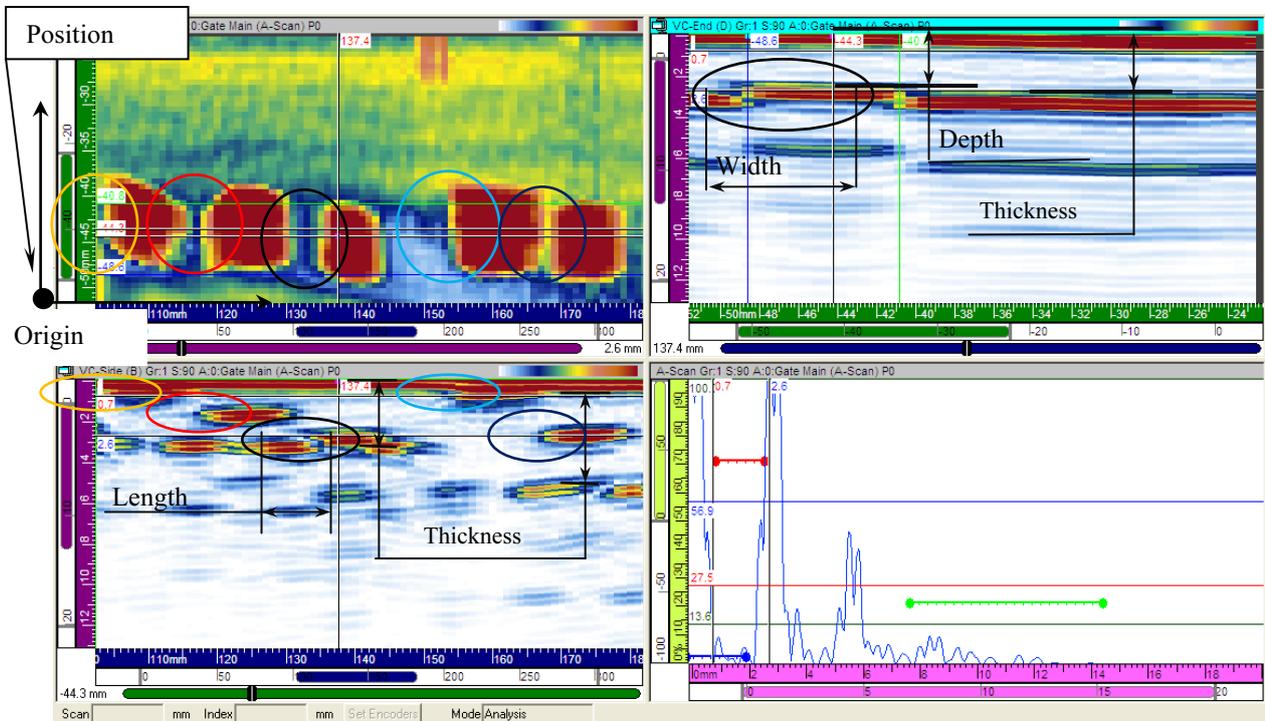


Fig. 8. Reference standard representation

Honeycomb structures are usually carried out by inserting between two skin of carbon of variable thickness, a honeycomb structure (also of variable thickness) joined

together through one or more adhesive lines. Typically, the adhesive consists of a thin film cut to size smoothly covers the entire bonding area.

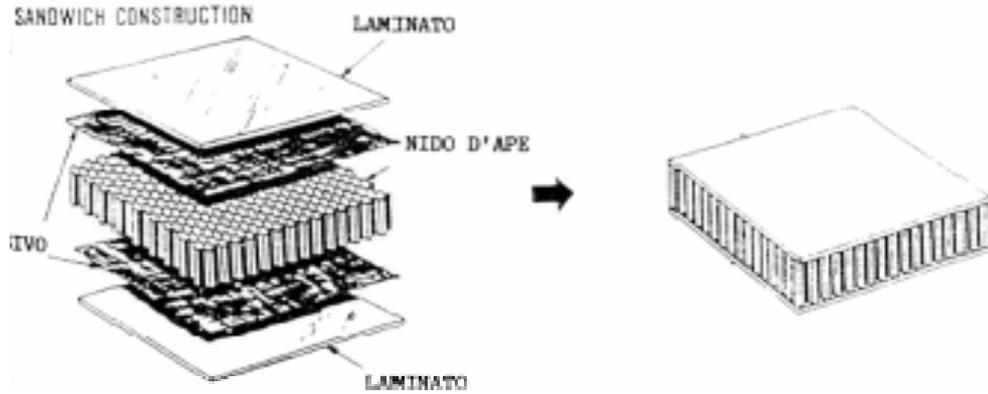


Fig. 9. Honeycomb structure

The typical casting defects differ between discontinuity in the area of solid laminate (delamination) and casting defects in the honeycomb area where there may be a series of discontinuity, such as: lack of bonding honeycomb/panel, honeycomb crushing, broken honeycomb, voids in the connecting ramps between honeycomb and panel, etc.

These last types of discontinuities can be detected in part by ultrasonic inspection and partly by other NDT methods.

The lack of bonding (disbonding) caused a lack of adhesion between the panel and the honeycomb; even it

determines a non-continuity of particular due to gas presence between the two elements (honeycomb and skin) which produces a significant reflection of the ultrasound beam.

Even the breaking and crushing of honeycomb can generate an interruption in the continuity of the structure and so must be detected in ultrasonic inspection. A typical casting defect in the line of adhesive is the porosity (Blue area in Fig. 10a, b). The presence of air bubbles generated during polymerization causes a significant change in the amplitude of the ultrasound signal.

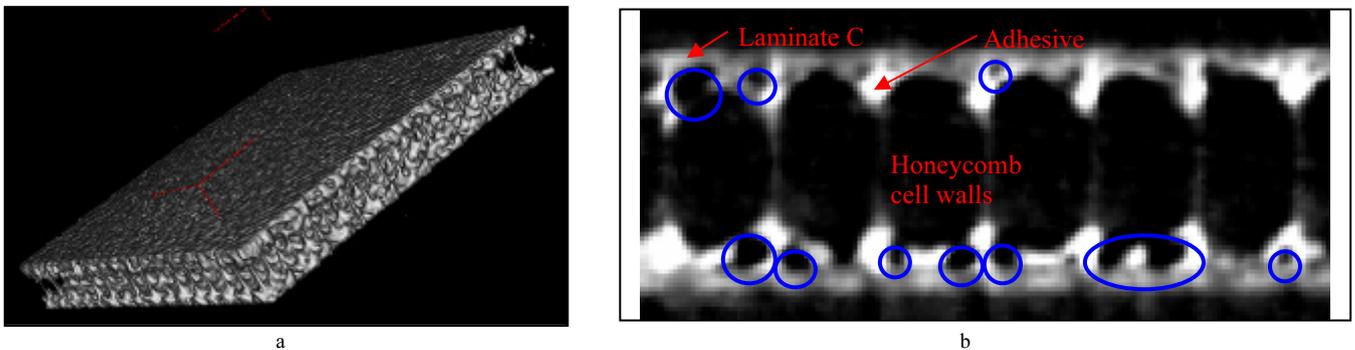


Fig. 10. a – CT specimen, b – frontal section CT specimen with porosity areas

The reference standard should follow the same instructions listed above for particulars in solid laminate. For areas with honeycomb must consider the presence of adhesive which allows bonding of dissimilar structures such as honeycomb and solid laminate. The areas being considered for the inclusion of artificial defects are between adhesive and laminate and between adhesive and honeycomb.

Wrinkle: in composite structures often occur surface irregularities due to wrinkle that are generated during lamination of the skins.

They may have different sizes and orientations resulting from the lamination direction, are easily detected

by ultrasonic inspection, generating an attenuation of the ultrasonic signal due to their geometrical shape. In fact, within these is to form an accumulation of resin, which compensates for the swelling caused by the wrinkle itself.

By sectioning and embedding of a micrograph specimen in these areas, you get the photographic evidence of the sinuous trend of skins which confirms the absence of other structural anomalies such as porosity or delamination compared with a high structural fill factor by resin so that compensates for the variation in thickness in that area. These type of discontinuity is evaluated by Visual and dimensional inspection.

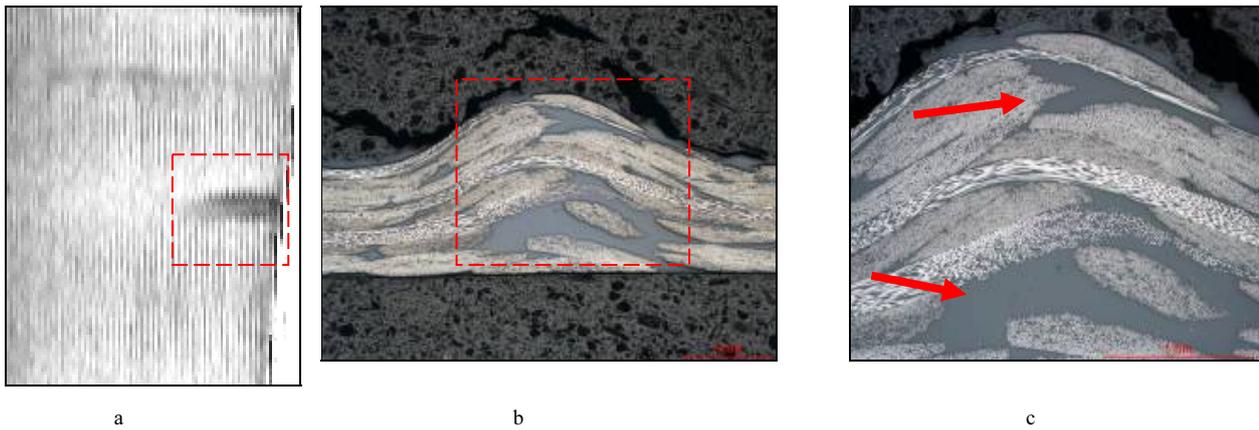


Fig. 11. a – c-scan representation in amplitude, b – micrographic evidence to the wrinkle 25X, c - detail of the same at 50X (See dashed area in the previous photo). The arrows indicate areas with the highest concentration of resin.

#### 4. Results

Ultrasonic techniques for the detection of these discontinuities may be pulse-echo or through transmission, as illustrated in Fig. 12a ,b.

The choice of the most appropriate technique depends on a number of factors such as thickness, configuration of the part and type of ultrasound representation that is required for the analysis and the inspection report.

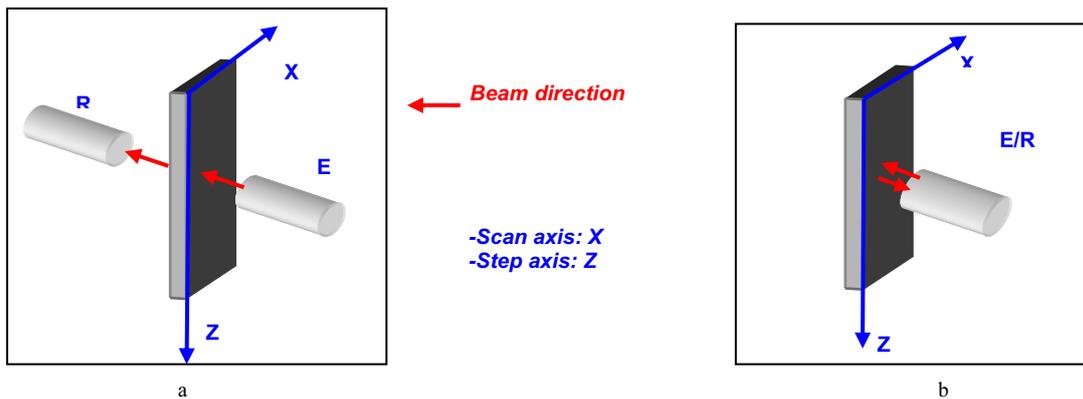


Fig. 12. a – pulse-echo technique, b - through transmission technique

Contact reflection: technique performed with portable instrumentation with frequencies that provide a good sensitivity on a material that determines a discrete structural attenuation.

The frequency of 5 MHz is usually required for inspections of monolithic solid laminates with thickness less than 20 mm.

The analysis is performed by the operator through the A-scan representation, directly visible on the ultrasound instrument. The depth and position are defined during the characterization of the defect.

The major difficulties encounter during an inspection of parts with very complex configurations such as J-Spar, I-rib etc. In this case it becomes essential to have an appropriate reference standard and a detailed knowledge of the section of the inspected area.

Reflection with water film: technique performed with automatic or semiautomatic equipment that allows a representation in plan and in section of the inspected particular. The ability to carry out the analysis by these representations greatly facilitates the operator having available directly on system screen the result of the

acquisition data by performing the analysis and the possible image processing (Fig. 13).

Applicable to solid laminate structures usually with frequencies of 5 MHz with thickness less than 20 mm.

The analysis performed with a phased array system allows with the help of the acquired image processing (full wave) to be in possession of all the information about the detected discontinuities, such as depth, length, width, orientation and position relative to the origin point of the scan.

Contact transmission: technique performed with portable instrumentation with frequencies usually related with inspected configurations. In fact, on solid laminated parts usually use frequencies of 5 MHz, and on structures with honeycomb usually use frequencies ranging from 1 to 2.25 MHz. The results provide the attenuation value obtained in the ultrasound signal transition, initially in the panel and then going through the only cell walls that make up the honeycomb. The operator performs the data analysis on the basis of the signal value represented on the screen (A-scan representation).

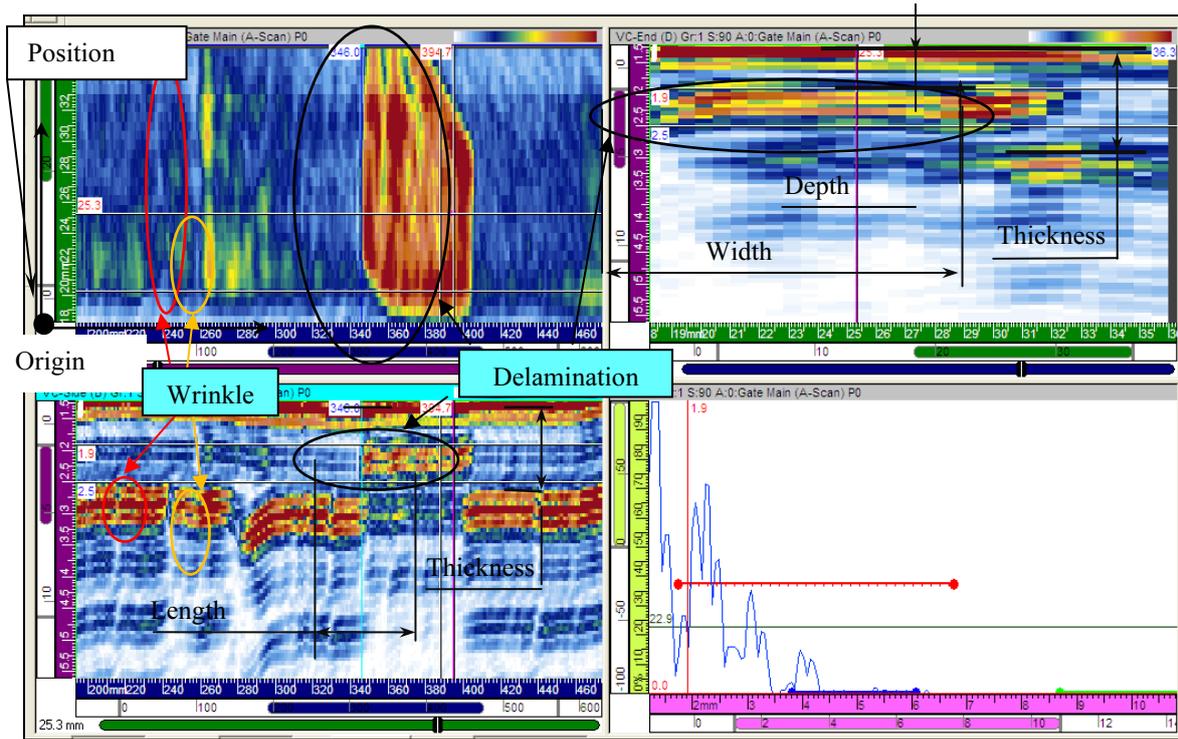


Fig. 13. UT phased array representation

Transmission by water column or immersion: technique performed by an automated system that allows reconstruction in plant (C-scan representation in grey scale) of the particular inspected with a frequency of 2.25 MHz (see Fig. 14).

In the following C-scan representation performed after acquisition data processing, are marked with different colors the different attenuation areas of transmission echo of the inspection above (see Fig. 15).

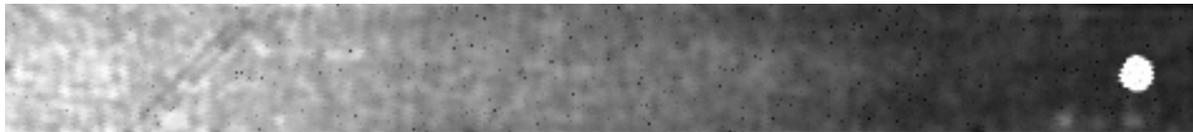


Fig.14. c-scan TTU laminate/honeycomb sandwich structure

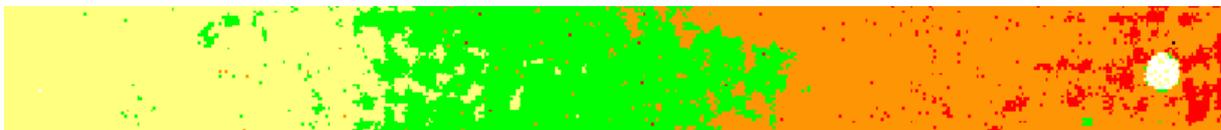


Fig.15. TTU attenuation areas in laminate/honeycomb sandwich structure

In order to determine the location of the porosity on the detail in the Fig. 15 was extracted a sample from the part at an attenuation of -12 dB to allow CT examination.

The performed acquisition analysis revealed the presence of porosity in the line of adhesive at the interface between solid laminate and honeycomb cells. Both lines of adhesive (Fig. 16) had the porosity but in the spindle side had a significant preponderance (Fig. 17).

The standard ultrasonic techniques used for inspection of honeycomb structures (transmission) do not provide the depth data of the detected discontinuity. In order to determine on which side is the attenuation of the ultrasonic

signal is necessary to adopt the technique of reflection which, using traditional instruments, presents considerable difficulties.

Through the application of pulse-echo phased array technique is possible to have a C-scan representation able to appreciate where is present an area with the higher presence of porosity.

The ultrasonic signal detected in correspondence to the interface laminate / honeycomb increases substantially if it is detect a lack of continuity generated due the presence of porosity inside the adhesive layer.

Usually the adhesive layer creates even a reflection of the ultrasonic signal with a amplitude that depends on the quality of the process of polymerization. If within this one there is porosity, the reflected signal increasing proportionally to the quantity of porosity generated during the manufacturing process.

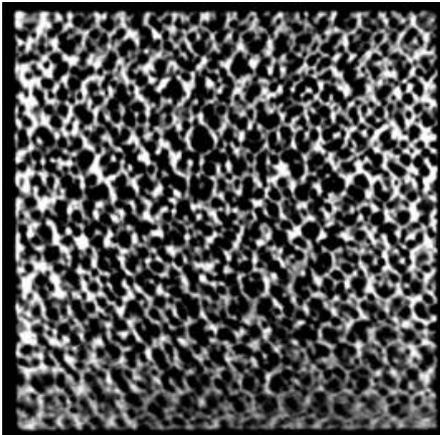


Fig.16. CT section sandwich structure

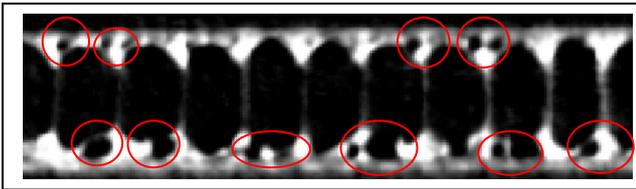


Fig. 17. CT section of the line of adhesive with porosity

○ - porosity in the line of adhesive

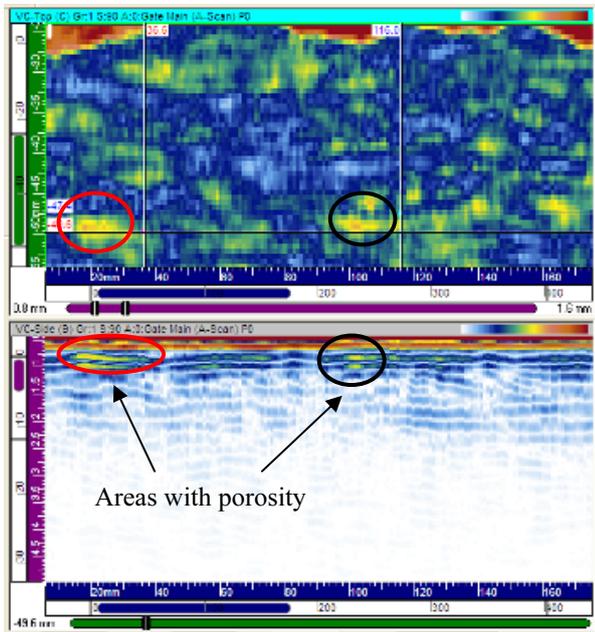


Fig. 18. ○ ○ - areas with porosity

## 5. Conclusions and comments

The broad subject has not allowed a closer look at all the actual configuration of parts in carbon fiber and the resulting types of discontinuities detectable by non-destructive testing, in particular with the ultrasound method.

We have tried to give more importance to the porosity in the composite structures. In fact, the porosity characterization is very difficult because of the technique normally used (ultrasound transmission), not forgetting the difficulties often encountered in the trial stage of the conformity of the particular.

Not always there are acceptance criteria specification that deal directly with the attenuation of ultrasonic signals based on the actual level of porosity in the structure. This creates uncertainty on the conformity of these areas, particularly when, based on the attenuation value, they should be considered as areas of disbonding and then treated as such.

## 6. References

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### Kompozicinėje anglies pluošto medžiagoje ultragarsiniu metodu rastų liejimo defektų apibūdinimas

Reziumė

Technologinės inovacijos aeronautikoje yra pagrįstos sumažinto svorio ir padidinto stiprumo struktūromis. Tuo tikslu kuriamos ir tiriamos naujos medžiagos, kuriose kompozitai turi ypatingą svarbą. Šio darbo tikslas buvo rasti ryšį tarp ultragarsinių neardomųjų bandymų rezultatų ir konstrukcijoje surastų nehomogeniškumų. Tam buvo naudojamas ultragarso bangos slopinimas ir signalo atspindys.

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