MODERN APPROACH FOR COMPOSITE INSPECTION IN THE ROTOCRAFT INDUSTRY AND ROTORCRAFT MAINTENACE

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1. ABSTRACT

Taking into consideration the increased usage of composites for aircraft structure there is a necessity for gathering information about structural integrity of such components. During the manufacturing of composites as well as during in service and maintenance procedures there is a possibility for damage occurrence. There is a large number of failure modes which can happen in such structures. These failure modes affect structural integrity and durability. In this work approach for detection of composites damage detection such as: delaminations, disbonds, foreign object inclusion and core damage has been presented.

In that article effort of manufacturers for the quality control as well as mobile inspections will be delivered. Modern detection is possible with the use of advanced P-C aided Non Destructive Testing methods. In this article diversity automated methods for detection of such damages were considered and will be presented. These techniques are such as: ultrasonic, mechanical impedance analysis, resonance, laser shearography, thermography, D-Sight.

NDI techniques delivered in the article are based on different physics phenomena. In this work detectablity for selected methods and accuracy will be determined. Moreover discussion about advantages of different techniques for specific failure modes and materials will delivered. Another point that will be presentation of approach for automated data analysis with the use of numerical data processing.

This work was done for the needs mostly of composite elements in the rotorcraft industry.

2. INTRODUCTION

This paper presents the modern approach for the detection of various types of defects in composite structures used in aerospace (rotorcraft industry). In such structures, including Glass Reinforced Plastics (GFRP) and Carbon Reinforced Plastics (CFRP), different failure modes could occur at a manufacturing stage and during service life. Defects are connected with inadequate technology, poor workmanship, cycling fatigue loads, impact damage and environmental conditions. The main types of defects are delaminations, disbonds, foreign object inclusions and porosity. To detect such defects, several NDE (Non Destructive Evaluation) techniques can be applied, merely to mention ultrasonic, low frequency acoustics, infrared thermography, D-sight and shearography. The use of multimode NDE techniques enables characterization of defects which cannot be detected by using single NDE methods. Composite structures are becoming increasingly popular in the aerospace industry because of their unique features, such as excellent strength/weight ratio, corrosion resistance and the possibility to manufacture samples of complicated shapes. Nowadays, the extensive use of composites in Aerospace components has become a real fact; for example, in the Boeing 787 *Dreamliner* aircraft, nearly 50% of structures have been made of composite materials [1].

Presently, such responsible components as Main Rotor Blades (MRB) of Helicopters are also manufactured of composite materials. This study has been done on the basis of aerospace composite elements, such as epoxy and carbon epoxy parts. These parts are characterized by a laminar and sandwich structure. There is a number of failure types which may appear in composites being related to both a manufacturing and operating stages. The typical failures, which affect structural integrity and residual strength of the composites, include disbonds, delaminations, foreign object inclusions and a kind of damage which is called *Barely Visible Impact Damage* [2,3,4]. Characterization of such failure modes is not easy when using single NDT techniques [5]. In order to perform a complete damage description, multimode Non Destructive Evaluation (NDE) of composites should be implemented. A list of candidate techniques may include ultrasonic, Mechanical Impedance Analysis (shearography), thermography, D_Sight, and many others.

3. Inspection Approach

Depending on the inspection technique, several physical phenomena can be considered to achieve the inspection goal, i.e. to evaluate a type of failure in a material under test.

These phenomena are connected to both a physical nature of excitation signals and a type of inspected materials. Attenuation of acoustic waves in composites, depends on the thermal conductivity of fibers (glass or carbon), type of structure (sandwich or laminar), as well as material quality. The analysis of the corresponding physical phenomena is of a primary interest [6] because they decide about a proper choice of a NDE technique [7], especially if to take into account that the number of failure scenarios is vast [8]. The most expected failure modes have been studied in this work along with the corresponding experimental results.

3.1. Disbonds detection

Adhesive joints are commonly used in the manufacturing of aerospace components (the so-called *bondlines*). In particular cases, this bonding technique is supposed to be more efficient than regular ones, such as bolts, rivets etc. Moreover, it allows the integration of different materials (composite-to-metal, skin-to-honeycomb, etc.), as well as the conduction of a possible future repair. However, such joints may collapse because of the presence of manufacturing faults, operating cyclic loads and impact damages. Depending on a particular bondline and a type of structure, the inspection of adhesive joints may be accompanied by some problems. At the exploitation stage, because of a specific stress distribution and operating loading cycles, critical areas may propagate from bondline edges, as shown in Fig. 1.

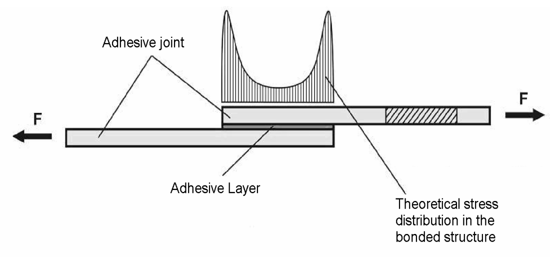


Fig.1 Stress distribution in the bondline

To apply NDE techniques for the inspection of disbonds, some standard specimens, used in *UltraLight* aircraft, as well as in gliders and rotor blades of helicopters, were manufactured.

The first inspection technique used to monitor bond quality was the ultrasonics [9]. This technique enables the generation of elastic waves in structures under test. The following formula describes the propagation of elastic waves [10]:

$$(\lambda + \mu)u_{j,ji} + \mu u_{j,jj} + \rho f_i = \rho \ddot{u} \qquad (1)$$

Here λ and μ are the Lame constants, ρ is the medium density, and u is the displacement. In the case of isotropic media, Eq. (1) allows to obtain solutions for different coordinate directions. Anisotropic composites represent a more difficult case because their acoustic properties vary with fiber directions. There are some special inspection devices which allow to evaluate both propagation direction and signal amplitudes. In composites, the attenuation of acoustic waves, which mainly appears due to scattering and reflection, is an important phenomenon which limits wave propagation. Scattering is reduced to minimum if the acoustic impedance of the fibers Z_z is close to the acoustic impedance of the matrix Z_o [11]:

$$Z_z \cong Z_o, \qquad (2)$$

with the length of the acoustic wave meeting the condition:

$$l >> d \qquad (3)$$

Here l is the acoustic wavelength, and d is the fiber diameter.

In practice, the reduction of scattering is effectively achieved when:

$$l_{\min} = a \cdot d, \qquad (4)$$

where a is the coefficient of which value is in the range from 3 to 4. The last equation allows the empirical determination of acoustic wave frequency:

$$f = \frac{c}{a \cdot d}, \qquad (5)$$

where c is the wave velocity. Choosing a correct frequency requires a certain compromise between the sensitivity (a lower frequency reduces sensitivity) and the attenuation which increases with higher frequencies. Another issue is related to material thickness. The example presented in Fig.1 shows a very thin skin attached to a reinforcement through an adhesive.

The ultrasonic assessment of bondlines is possible by using a 6dB criterion or another signal index, such as Signal-to-Noise Ratio (*SNR*) [12]:

$$SNR = \sqrt{\frac{16}{\rho V W_x W_y \Delta t}} \frac{A_f(f_0)}{SN(f_0)} \quad (6)$$

where ρ is the material density, V is the sound speed in the material, W_x and W_y are the lateral beam widths, A_f is the amplitude signal from the flaw (at a centre frequency).

The use of the criterion above enables the bondline evaluation.

Also, the so-called kissing bonds can be hardly evaluated by using the ultrasonics [13]. To detect such defects, other NDE techniques should be used, such as Mechanical Impedance Analysis and shearography [2].

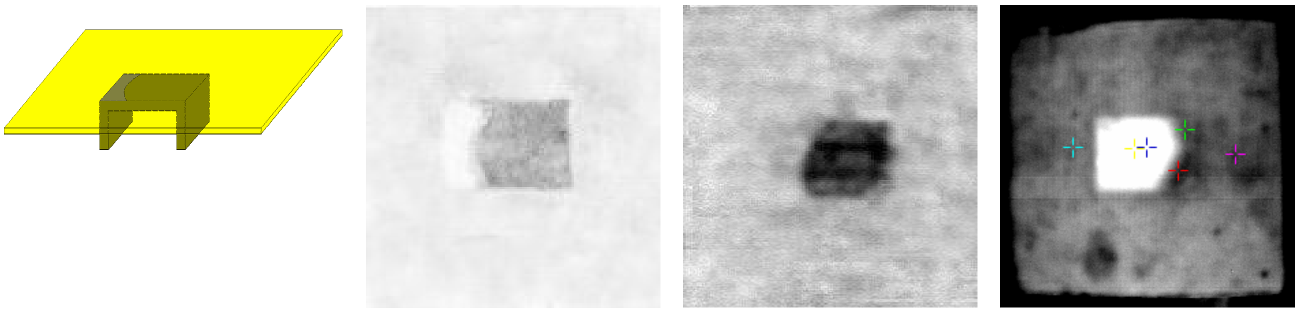
The use of ultrasonic NDE for the inspection of thicker composites may be difficult because of problems related to attenuation. To characterize this phenomenon, some techniques of attenuation measurement can be used. These techniques are based on the measurement of [15]:

- damping or ultrasonic attenuation (double through transmission) (dB) ;
- damping or ultrasonic attenuation per mm (dB/mm) with the use of pulse echo.

As always, a compromise between the frequency and the sensitivity should be achieved when inspecting thick or high-dispersive composites.

Figure 2 presents disbond detection possibility with the use of MIA, ultrasonic and flash thermography. Also the scheme for the disbond geometry has been presented. All damages were possible to detect with the use of the following techniques: ultrasonic, MIA, resonance, shearography, thermography.

There is also opportunity to the use of D-Sight. But these technique is much more efficient for larger elements where the time required for inspection is issue.



Specimen Ultrasonic Results MIA results Thermography results

Fig.2 Disbond detection results

The disbond in this sample can be well-detected with all above mentioned techniques. For thicker structures, the focused ultrasonic, or Phased Array technique, can be applied in order to increase the power spectrum of ultrasonic waves introduced into material.

In many aerospace structures, in particular, used in small-size airplanes (helicopters), sandwich panels stiffened with foam – core material are frequently used. In such panels, continuing loading and specific stress distribution (see Fig. 1) may cause disbonds between composite layers and cores. Detection of such structures may be very difficult with the use of classical NDE methods.

Examination of such structures is difficult, especially by using the ultrasonic technique because of a low mechanical impedance of a core that may be expressed as follows:

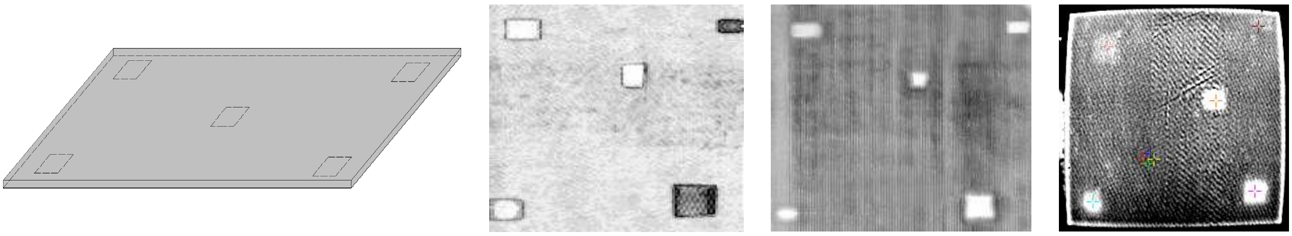
$$Z_i = \rho_i c^{(i)}{}_l \approx \sqrt{\rho_i E_i} \qquad (7)$$

A low mechanical impedance is caused by low density of a core material. The use of a single ultrasonic sensor in the framework of the pulse-echo technique has proven to be inefficient. To improve detection efficiency, ultrasonic phased arrays have been used. Successful experimental results in the inspection of the above-mentioned structure were obtained by focusing the beam and defining the aperture. Also the possibility for detection of such defect was successfully determined with the use of thermography and MIA.

3.2. Detecting delaminations and inclusions

During the manufacturing, some structural elements, such as peel plies, paper etc., may not be properly removed from a composite. The presence of such elements, called foreign inclusions, in a final product affect mechanical properties (durability) of composites. Inclusions may not be visually seen, particularly, in carbon and/or painted (opaque) parts, but they can be effectively detected, for instance, ultrasonically.

Figure 3 shows the result of the detection of foreign inclusions and delaminations in a laminar carbon fiber composite. All defects are clearly seen by applying the pulse–echo ultrasonic technique. Assessment of defect size and depth is also possible in the case of ultrasonic data.



Specimen | Ultrasonic Results | MIA results | Thermography results

Fig.3 Foreign object inclusion detection results

One more type of serious defects which might appear in composites is impact damage which affects the structural integrity of components [15]. According to R. Smith [16], "*Composite structures can suffer quite severe impact damage without a noticeable surface indentation – known as barely – visible impact damage (BVID)* – and *this makes large – area defect detection a necessity for critical structural components*". Impact damages may appear at both manufacturing and in-service stages if solid bodies, such as hail, stones, bullets etc., strike component surface. Low-energy damage is often accompanied by no visible surface indications but may significantly worsen the component structural integrity [16] by producing delaminations, disbonds, multiple cracks etc. In complex structures, such as rotor blades, structural defects can be classified by the following groups:

- skin defects (delaminations, cracks);
- skin to honeycomb defects (disbonds);
- honeycomb defects (core crush).

Figure 4 shows disbonds and delaminations which were produced by the impact of the so-called blunt impactor [2]. Since impact damage affects residual strength of composite parts, its duly detection represents an important diagnostic problem.

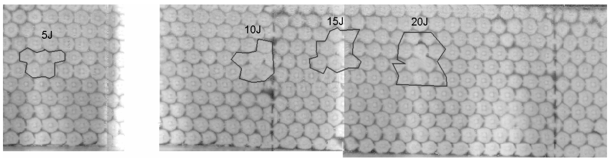


Fig. 4 Disbonds and delaminations

4. SUMMARY

This paper describes some diagnostic problems related to the assessment of structural integrity of composites. There is a variety of defects which may appear in composites. Some of them, such as disbonds and delaminations, are quite typical, while others (porosity, inclusions) appear randomly, in particular, in the manufacturing process. Very crucial for composites is impact damage which may produce the so-called Barely Visible Impact Damage. Often impact damage is accompanied by no visible surface marks but significantly affects residual strength of materials.

In the aerospace industry, there is a bunch of NDE solutions for characterization of composite integrity. A type of materials, component design and peculiarities of access to inspected components decide about the choice of proper NDE techniques. In this study, some approaches to the detection of disbonds, delaminations and foreign object inclusions have been analyzed. In particular, the following NDE techniques have been used: ultrasonics, MIA, resonance, IR thermography, D_Sight and shearography. More detailed inspection results will be delivered in the conference presentation.

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