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REVIEW ON NON-DESTRUCTIVE TESTING OF COMPOSITE MATERIALS IN AIRCRAFT APPLICATIONS

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ABSTRACT

The increasing usage of composite materials has immersed simpler techniques for inspecting the integrity of composite structures, as composite materials typically have probability of getting material imperfections. In non-destructive testing, shearography reveals defects in associate object by distinguishing defect-induced deformation anomalies. Non-destructive testing (NDT) methods skit and streamer role in physical characterization of new composite materials and in assessment of their quality and serviceability in structures. Non-destructive testing (NDT), Non-destructive inspection (NDI), and Non-destructive evaluation (NDE) are concerned with the techniques and measurements that provide data on the condition of the materials and structures at the time of manufacturing and in-service.

Keywords: Composite materials; Tension test; Compression test; Impact test; Fatigue test; strain measurement; Non- Destructive Testing (NDT); Non-Destructive Inspection (NDI); Non-Destructive Evaluation (NDE).

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1. INTRODUCTION

Composite materials are used more and more in aircraft production. Main composite types are Carbon Fiber Reinforced Plastics (CFRP), Glass Fiber Reinforced Plastics (GFRP) and metalaluminum laminates (e. g. Glass Fiber Reinforced Aluminum). Typical parts made of CFRP are flaps, vertical and horizontal tail planes, center wing boxes, rear pressure bulkheads, ribs and stringers. For the Airbus A380 GLARE is used even for some shells of the upper fuselage. The weight percentage of composites in modern civil aircrafts like the A380 is in the order of 25%. It may be expected that this percentage will further increase for the next generation of civil aircrafts and that main structure parts like fuselage and wings will be composed of composites, too [9]. These composite parts require adequate Non-Destructive Testing (NDT) methods. NDT is applied in production as well as during maintenance (inservice). Flaws to be detected are delaminations and debondings, porosity and foreign body inclusion. The most applied NDT method is ultrasonic testing (manual as well as automatic, in pulse echo and through transmission, with single element transducers and linear phased array probes). But also resonance methods, shearography and thermography and special methods are used. This papers reviews the present NDT methods for composite inspection in aircraft industry and reports about future demands.

2. NON-DESTRUCTIVE TESTING

Non-destructive methods of testing, inspecting, or evaluating a product utilize physical measurements that do not alter the condition or life of the product for its continued use. NDT and NDI are generally considered synonymous, with both being related to the use of measurement tools per specification and assessment against specified criteria. NDE and non-destructive characterization are terms intended to convey the use of non-destructive measurements for material condition, property, or state assessment, especially in a quantitative manner[3].

Polymer composite structures used in aerospace applications require NDT at various levels depending on their designation as a primary or secondary structure. A primary structure is a structure where the failure could result in loss of the air vehicle or life and therefore usually requires 100% instrumented NDT. A secondary structure is a structure where failure does not affect flight safety, and it may or may not require inspection beyond a visual one, depending on the manufacturing process control. Both primary and secondary polymer composite structures may require in-service NDT. While metal structures may have a required frequency of inspection due to fatigue life and potential cracking, polymer composites are generally only inspected in-service as a result of damage or unplanned events. Visual observation of damage may trigger an instrumented NDT inspection for the measurement of damage or degradation to determine repair or replacement.[1]

The two major categories of polymer composite used in aerospace are laminates and sandwich structures, which require some differences in NDT inspection methods. The inspection of choice at the time of manufacture may be different from the inspection of choice for in-service assessments. The form of the structure determines the types of features of concern and the NDT techniques that may be applied to detect and measure them. The Conclusion summarizes some general thoughts and considerations on NDT of polymer composite structures. American Society for Testing and Materials (ASTM) also provides guidance on NDT for polymer composites. [2]

A. Visual Testing (VT) - (VI - Visual Inspection)

This is the most basic type of NDT that many instances use because it can save both time and money by reducing the amount of other testing, or in some cases reducing the need for other types of testing all together. The most important advantage of the visual inspection is its quick process. The other advantage of visual inspection is the relative affordability of the process. The visual inspection needs no equipment but this method has its intrinsic disadvantage.

B. Ultrasonic Testing (UT)

This evaluation system consists of a transmitter and receiver circuit, transducer tool, and display devices. Based on the information carried by the signal, crack location, flaw size, its orientation and other characteristics could be achieved.[4] Advantages of ultrasonic testing

include speed of scan, good resolution and flaw detecting capabilities, and ability of use in the field. Disadvantages include difficulty of set up, needed skill to scan a part accurately, and the need of test sample to insure accurate testing. This type of testing is excellent for use in an assembly line where the same part design must test repeatedly.

There are two approaches of ultrasonic NDT generally used in different applications; pulse echo and through transmission approaches. Both of these approaches use high frequency sound waves on the order of 1-50 MHz to detect internal flaws in a material [5]. Ultrasonic testing conducted in three modes, transmission, reflection, and back scattering. Each of which uses a range of transducers, coupling agents, and frequencies [16]. Pulse echo ultrasonic method can readily locate defects in homogeneous materials. In this method, the operator more concerns about the transit time of the wave and the energy loss due to attenuation and wave scattering on flaws. It helps to locate inconsistency in a material whether it is homogeneous or heterogeneous [6].



Figure 1 Locating defect

For large defect detection, location, and imaging purposes, and quality control, ultrasonic pulse velocity measurements are quite suitable. The through transmission ultrasonic method is different from conventional ultrasonic methods. This method keeps the transducer and receiver off the surface and at a fixed distance away from the sample. This is particularly advantageous when complex geometries do not allow for the contact of a traditional transducer and receiver to the surface of the part. The most commonly used indicators of properties are wave propagation velocity and amplitude (or energy) loss. Some of the testing methods described herein only address one property, while others, more versatile, may measure two or three [7].



Figure 2 Ultrasonic Setup

Most applications consider only the pulse velocity and relate it to different parameters. Considering energy loss can discover a few additional characteristics of a material. A number of authors have studied the method of pulse attenuation analysis. Scattering, absorption and geometric are three parameters that affect the attenuation. Small discontinuities like grain boundaries are the source of scattering.

C. Thermography testing

This is also called thermal imaging. The thermal conductivity of a material may change by the presence of defects, thermography inspection used for thin parts because when defects moved deeper under the surface of a part, they tend to produce less heat fluctuation than defects seen closer to the surface of the part. As a generally rule, defects that have a diameter smaller than their depth in the part, cannot be picked up by this type of inspection. A flaw, such as a delamination or impact damage causes a change in the thermal radiation of the area [8].



Figure 3 Thermography

There are many advantages and disadvantages to this type of inspection. One advantage is it can inspect a large surface of a part. The second advantage is that unlike many other types of inspection it does not have to couple. This allow for the inspection of parts where only one side of the part is accessible to inspection. Disadvantages of this type of inspection include the need for sensitive and expensive instrumentation, the need for highly skilled inspectors to run the instruments, and the lack of clarity of defects if they fall too deeply under the surface of the part. Infrared Thermography Testing (IRT) is based on the recording of the thermal radiation emitted by a surface of a specimen by means of an infra-red camera.[20]

D. Radiographic Testing (RT)

It's the most commonly used testing method. The most common type of damage to composites is a delamination resulting in an air pocket; a delamination can only be seen in RT if its orientation is not perpendicular to the x-ray beam. There are many types of radiography and each has specific applications. Conventional radiography is the most useful when the parts are neither too thick nor too thin. For thin parts, 1 to 5 mm, low voltage radiography is used and γ -rays radiography is good for thick parts.

These types of radiography are useful in detecting large voids, inclusions, trans-laminar cracks, non-uniform fiber distribution, and fiber disorientation such as fiber wrinkles or weld lines [5]. Another type of radiography uses γ -rays to penetrate the composite. Gamma rays radiography is good for thick parts because the gamma rays have shorter wavelengths. Penetrant-enhanced is another type of radiography employed specifically to detect small matrix cracks, and delaminations in a sample [10].



There are varieties of radiographic testing methods for different applications. These methods are film radiography, computed radiography, computed tomography, and digital radiography. X-ray Computed Tomography (XCT) is a nondestructive technique for visualizing interior features within solid objects, and for obtaining digital information on their 3-D geometries and properties. The great advantage of XCT in comparison with the projection radiology is the 3-D visualized image of the structure while in projection radiology the image is only 2-D. Therefore, the XCT data is readable quickly and simply. XCT will modify the scale of observation from macroscopic to microscopic scale so the results of the XCT method are very reliable [11].

E. Electromagnetic Testing (ET)

This methods use magnetism and electricity to detect and evaluate fractures, faults, corrosion or other conditions of materials. ET induces electric currents, magnetic fields, or both inside a test object and observes the electromagnetic response. Electromagnetic (EM) methods include Eddy Current Testing (EC)[19], Remote Field Testing (RFT), Magnetic Flux Leakage (MFL) and Alternating Current Field Measurement (ACFM). In each of these techniques, the underlying physics is fundamentally different as the fields described by different classes of partial differential equations (PDEs).[21]



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Figure 4 (Eddy Current Technique)

F. Acoustic Emission (AE)

It *is* an effective method of imperfection analysis. This mechanical vibration generated by material defects such as matrix micro cracking, fiber-matrix debonding, localized delamination, or fiber pullout and breakage [12].



Figure 5 Acoustic Emission

The stress waves that result from these types of defects spread out concentrically from their origin and are detected by an array of highly sensitive peizoelectrics. Acoustic emission technique is different from most other NDE techniques in two aspects. The first difference is the origin of the signal. Instead of supplying energy to the object, this method listens to the "sound" generated by energy released in the object. The second difference is the method that AE deals with dynamic processes in a material. The ability to discern between developing and stagnant defects is significant. Other advantages of AE method include high sensitivity, fast and global inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen [13].

The second advantage of the AE is that it is very useful in detecting many different types caused by fatigue loading. Fatigue damage types which acoustic emission testing can detect include fatigue cracks, fiber fractures, matrix micro-cracks, fiber-matrix debonding, and delamination. The drawback to this type of testing is the great skill that is required to correlate acoustic emission data to specific types of damage mechanisms.

G. Acoustic-Ultrasonic

It is a combination method of acoustic and ultrasonic testing that used specifically to determine the severity of internal imperfections and inhomogeneity in a composite. In nondestructive testing, the acoustic/ultrasonic class of testing has great potential based on optimal economy, flexibility and sensitivity. However, no available method is sensitive or reliable enough to effectively detect. It is useful method because it allows non-critical flaws to see and assess. The second advantage is that it is a good indicator of accumulated damage in a structure due to fatigue loading or impact damage.[9] The disadvantage of this type of inspection is the setup and pre-calculations that is mandatory before any testing. The second disadvantage is that this type of testing is not useful to detect individual large flaws such as delamination or voids [14].

H. Shearography Testing

It is a laser optical method. The failure of composites usually happens by stress concentrations and the criticality of defects will easily deduct by the degree of strain concentrations around a particular defect, this is an advantage of shearography [15]. A second advantage of shearography is that it is less susceptible to noise than many other types of nondestructive testing. This is good because it allow less skilled users to be able to inspect and determine the usability of a part without extensive training. A major disadvantage of shearography is that

characterization of defect types other than delamination is extremely difficult. Therefore it is sometimes paired with other types of non-destructive evaluation techniques that can help to identify certain defects.

I. A new X-ray backscatter imaging technique for non-destructive testing of aerospace materials

In difference to conventional transmission X-ray radiography, the X-ray backscatter technique (XBT) utilizes the scattered radiation caused by the Compton effect. As the Compton effect depends on electron density in the scattered object, low-atomic-number (Z) materials (e.g. Al, PMMA, composites and water) exhibit predominant scattered radiations compared to the heavy metals such as Fe, Cu and Pb, respectively.[18] The efficiency of the XBT depends on how accurate and fast the scattered radiation beam from the object is realized on the detector using only a single-sided access.For the first time, the X-ray backscatter measurements were carried out using highenergy (> 500 kV) X-ray sources.[17]



Figure 6 Backscattering

The preliminary experimental results show the ability of the present technique to image internal features of complex structured stringer component, low density material inclusions in thick honeycomb structured plates using only a single-sided access. The measurement time was reduced to 3 minutes by utilizing the high-resolution (180µm) digital detector arrays. Future work will focus on employing photon counting detectors for backscatter imaging. This detector technology is able to record only the X-ray photons and hence there is no electronic noise in the image which results in enhanced image quality of the backscatter image. The efficiency of the backscatter camera will be further improved by using multiple twisted-slit collimator. We expect that using the multiple-slit collimator not only reduces the measurement time but also improves the backscatter signal strengths. Further field trials and validations with existing X-ray backscatter imaging systems are also planned for the future work.

3. CONCLUSION

This paper reviewed NDT methods for aircraft composite structures evaluation by categorizing their advantages and disadvantages as well as describing NDT methods of composite materials in order to have a comprehensive review of NDT of composites. Due to the fact that composite tools are mostly used in critical-safety applications for example in aircraft primary constructions, the non-destructive testing of composite materials has become



more crucial and demanding. Factors such as efficiency and safety should be used in analyzing the best method to be used. Furthermore, the method chosen should minimize the costs incurred in the operation. It is based on methods that depend on the use of physical values to determine the characteristics of materials. In addition, non-destructive tests use physical principles to identify and evaluate faults or destructive defects. This emphasizes the need to test polymer composite aircraft structures both at the time of manufacture and while in service.

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