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A Review on Application of Non Destructive Techniques on Composites

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Abstract –. *When manufacturing composite structure, material and structural components are created concurrently. Thus, for composite materials in critical structural applications, it is more important than ever to independently assure structural integrity. Complexity of the advanced composite materials manufacturing and composite in service maintenance represents challenges in developing optimized nondestructive tools and tests. Traditional metals based NDT methods are inappropriate and often misleading. In advanced technology applications such as aerospace and with industrial emphasis on economics and safety, it is critical to use and develop robust and practical composites NDT methods. Composite NDT encompasses a range of modified traditional and new tools including ultrasonic, xray, acoustic emission, thermography, and a variety of hybrid methods. This paper provides overview of the current use of the NDT tools in the composite applications.*

Keywords: Composite Inspection, NDT, Delamination, NDT on composites,

1.0 INTRODUCTION

This review gives an overview of flaws in composites, applicability of non-destructive techniques on composites in recent years. Composite materials consist of two or more elements, one of which, the fiber and other is matrix (binder). The two elements work together to produce material properties that are different to the properties of the element on their own. Composite offer the designer a combination of properties that is not available in traditional materials. It is possible to introduce the fibers in polymer matrix at highly stressed regions in a certain position, direction and volume in order to obtain the maximum efficiency. This materials' benefit enables structural designs that outperform the conventional application limitations commensurately improving system performance such as reducing weight, increasing fuel efficiency or increasing speed[1]. Other advantages of composites are light weight, resistance to corrosion, resilience etc.

Composites have a number of advantages when used as components for the aerospace, navel, automotive or construction industries. Due to their high strength to-weight and stiffness-to-weight ratios as well as their fatigue and corrosion resistance, it is possible to produce components that exhibit significant weight savings and improved service-time performance over that of more

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traditional materials (steel and aluminum alloys) [2]. It is known that the mechanical properties of fiber reinforced composites, among others, highly depends on fiber content variations. There are many research works directed towards understanding the influence of reinforcement content on the selected characteristics of composites [3-6].

The catastrophic aspect of the fractures by fatigue always requires an entire examination and a knowledge of material used and therefore much effort has been devoted to studying the fatigue behavior of materials by non-destructive methods (NDT)[7-10]. Inspection of composite materials possess a particular challenge, since the materials are often non-homogeneous and anisotropic In the past two decades, due to high cost of inspection of composite structures, when compared to metallic structures [11-13], the scientific community have been trying to develop reliable and effective non-destructive technique (NDT) to detect the occurrence of critical failure modes, such as delamination and debonding, and to estimate its position at the early stage so as to reduce the risk of further catastrophic failure.

Delamination's, cracks, braking of bonding, Impact damage, porosity, erosion, core splices, matrix cracking, fiber breakage. These type of damage is often referred to as barely visible impact damage (BVID), and it can cause significant degradation of structural properties. These flaws can be classified according to the composite constituent that is affected or the stage of the life cycle at which fault occurs, Composite flaws can be summarize in following four categories (a)In fibers or fiber distribution, (b) in matrix or fiber distribution, (c) During production, (d)In service

2.0 INSPECTION TECHNIQUES

There are different techniques to monitor flaws in composite materials each techniques has its own advantages some of these techniques are discuss in the paper:

- Radiography Testing
- Thermography Testing
- Acoustic Emission & Acoustic Ultrasonic Testing
- Ultrasonic testing

2.1.Radiography Testing

Advanced non-destructive inspection (NDI) techniques like X-ray radiography and X-ray micro-computed tomography (μCT) have been widely used in medical applications. Besides clear reason that a living body would best not be inspected destructively, such high-tech inspection methods have the supreme competence of providing detailed investigation of internal micro-structures and fine flaws embedded inside the inspected body.

In the field of polymer based composites, μCT is successfully employed to analyze the micro-structure of multi-axial multi-ply stitched carbon preforms by characterizing the size and shape of

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resin-rich regions of the composites and 3D micro cracks created by hygrothermal fatigue [14]. μCT appears aptly suited to analysis of textile [15], and woven composites attributed to their micro-structures [16,17], which are fundamentally three-dimensional. μCT is regarded as a reliable technique to acquire input for three-dimensional model generation of textile and woven composites. Both X-ray radiography and μCT have been effectively exploited to observe the meso-structure and fiber architecture of composite materials [18-20].

Besides analyzing internal structures and complex architectures, researchers use X-ray radiography and μCT to better understand the behavior and damage of composite materials undergoing fatigue, tensile or impact loading [21-27].

Low-energy radiographic inspection of polymer-based composites can reveal useful information about discontinuities such as voids, entrapped foreign materials, matrix cracks, resin-rich or resin-starved areas and other damage. X-ray techniques include film radiography, microradiography and real-time radioscopy, the latter with image intensifiers, sensitive cameras or solid state detectors[28].

2.2.Thermography Testing

Transient thermography is one of the latest NDT & E techniques in development for effective use in the assessment of aircraft materials. It is a non-contact technique where the investigated area material is heated or cooled by an external source (flash lamps, air gun, etc.) and the presence of flaws is determined by monitoring the flow of heat over the surface of structure presence of flaw disrupts the normal pattern of heat pattern. While in modern thermography infrared camera were used for flaw detection [29].

Thermo graphic methods fall broadly into two groups: active methods, and passive methods. Active methods are those in which the thermal gradient is produced and continuously maintained. Passive methods are those methods in which the thermal gradient result from a transient change. Passive methods are widely applied NDT technique in composites inspection. Two commonly used thermo graphic techniques are: thermal pulse thermography (passive) that involves the use of an externally applied transient heat source; and vibrothermography the active method.

The advantages of the technique are that it investigates rapidly large areas for surface or near surface defects and that it produces easily interpretable results. Its disadvantage is that its success is highly dependent on defect depth and size, which restricts its application to near surface defect imaging[30].

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2.3.Acoustic Emission & Acoustic Ultrasonic Testing

2.3.1 Acoustic Emission

The examination of acoustic emissions (AE) is a very successful tool for the sensitive detection and location of active damages in polymer blends, particle-filled and fiber-reinforced polymer composites[31,32] . The AE measurement is based on the detection of surface movements caused by stress waves of the fracture processes on a microscopic scale. The interpretation of the signals and, hence, the evaluation of the damage stages is a major problem of the AE method. AE monitoring offers a solution to experimental and theoretical problems by the characterization of the failure on microscopic scales, by classifying the mechanisms involved and by quantifying the extension of damage zones [33-36].

The development of these composite materials is linked to their advantages, notably ease of design and production of complex shape pieces, light weight, low cost, interesting mechanical properties, etc., and now some possibility of recycling. The damage mechanisms of composites have to be understood in order to improve and optimize these materials according to their application.

Acoustic Emission (AE) can be used to discriminate the different types of damage occurring in a constrained composite. Acoustic emission is well established as a method of testing GRP tanks, vessels and piping. It can be used to detect flaws i.e. crack, broken fibers, delamination and the breaking of the fiber–matrix bond[37].

2.3.2 Acoustic Ultrasonic

The acousto-ultrasonic technique was developed in the late 1970s as an NDE tool for characterizing the mechanical properties of reinforced composite materials[38-40]. Acousto-ultrasonics is a technique in which the received signal is process in a similar manner as in acoustic emission testing but the acousto signal is externally introduced to the specimen with a transmitter. Two ultrasonic transduces are used, one acting as transmitter, the other as receiver[41]. Any flaw which affects the specimen's mechanical properties will affect the way in which stress waves travel in it. Measures such as the stress wave factor (SWF), the decay of this resulting incoherent field is then examined as a function of frequency [42,43].

Acousto-ultrasonics cannot detect small individual localized flaw because these do not affect the mechanical properties. The wavelength is also much longer than other ultrasonic methods, thus only large defects can be detected.

Acousto –ultrasonic can be applied to the detection of porosity content, trans-laminar cracking, and delamination, to the checking of stacking sequence in composites. The acoustic- ultrasonic method does not always give satisfactory results for reasons that are not well understood but ongoing development aim to improve their reliability.

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2.4.Ultrasonic testing

Ultrasonic testing is most widely used non-destructive testing inspection method for the examination of composites. In Composite materials the testing range is significantly reduced because of the increased attenuation (energy absorbing). The operating frequency limit is usually 5MHz or less[44]. However the ability to resolve small flaws will also reduce. In most of the techniques the short pulses of ultrasound are passed thorough into the composite material and detected after having interrogated the structure. The techniques include pulse echo, thorough transmission, back scattering, acousto-ultrasonics and ultrasonic spectroscopy. In these methods it is important to avoid frequencies at which resonance occurs between ply interfaces it usually occur at 12MHz for woven fabrics it is approximately 8MHz of 0.25 mm plies. Above mention techniques are the sub types of ultrasonic testing with slight difference in their operating procedure. These slight difference enhance the probability of flaw detection. Figure (1a & 1b) shows the detail comparison of detecting the flaw by the each technique.

	Visual	Through-transmission	Shearography	Pulse-echo	Velocity	Low frequency	Radiography	Acoustic emission	Thermography
Flaw sought									
Fibre type					•				
Porosity	•	✓		✓	•				
Fibre-matrix bond	•							•	
Matrix properties				•	•				
Fibre misalignment		•				•	•		
Volume fraction		•		✓	•	•	•		
Stacking sequence									
Ply-end discontinuity				•					
Foreign inclusions		•	•	✓			✓		✓
Trans-laminar cracks		•	✓	•			•	✓	•
Fibre breakage								✓	
Delamination	✓	✓	✓	✓		✓	•	✓	✓
Moisture ingress					•				
Impact damage	✓		✓						✓

• Application limited
✓ Method has proved ability to detect given flaw

(A)

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	Ultrasonic back-scatter	Acoustography	Spectroscopy	Acousto-ultrasonics
Flaw sought				
Fibre type				
Porosity	(✓)		(✓)	(✓)
Fibre-matrix bond				
Matrix properties			(✓)	
Fibre misalignment	(✓)			
Volume fraction				
Stacking sequence	(✓)			(✓)
Ply-end discontinuity	(✓)			
Foreign inclusions		(✓)		
Trans-laminar cracks	(✓)	(✓)		(✓)
Fibre breakage				
Delamination		(✓)	(✓)	(✓)
Moisture ingress				
Impact damage		(✓)		
(✓) Method has proved ability to detect flaw				

(B)

Figure 1: (A)-Established NDT Methods for PMC Inspection, (B)- Established NDT Methods for PMC Inspection

3.0 CONCLUSION

There is a long list of NDT methods and sub techniques that are applicable for composite testing. No one method currently has ability to meet all the needs for the composite integrity assessment. Historically focused on defect, emerging technology work is in areas of health monitoring and materials mechanical properties characterization. As critical composite structures become part of commercial use such as new Boeing 787, additional developments will be needed to enable economical, full mechanical integrity characterization of these systems.

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