Ultrasonic Testing of Fiber Reinforced Polymer Composites- An Overview

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***Abstract*— Fiber reinforced composites are susceptible to fabrication defects, impact damage, moisture absorption, variability in material properties. It is often required to produce evidence through NDT methods to establish integrity of structures, repeatability of manufacturing process to ensure design stipulated strength, stiffness, thickness variation and material homogeneity. Usually a combination of complementary NDT is used for this. Conventional method of NDT, namely-Ultrasonic has been successfully applied to test, evaluate and certify composites.**

Keywords—Composites, NDT, Ultrasonic test

I. INTRODUCTION

Composite structures may suffer damage at any stage of life cycle: Production, Transportation, Assembly or Service and require repair. The first step for repair is to identify the nature and extinct of damage. Generally the damage is classified as:

- Negligible damage
- Repairable damage
- Sever damage
- Non Repairable damage

The Damaged composite part could be solid laminate or sandwich. As far as the repair is carried out with identical reinforcement and core material. Often fast curing resins are used to save time.

The objective of repair is to:

- Ensure Freedom from harmful defects and inhomogenities.
- Restore strength and stiffness
- Achieve thickness variation within allowable limits
- Restore surface counter

The repair is intended to restore load bearing capability of the structure making the area similar to the original design. But departure is often permitted in low stress zones. Repair is carried out by reverted or adhesive bonded reinforcements. If the damage extends through the entire thickness of the laminate, repair is carried out in following steps:

- Back side of the laminate is supported by back up plate
- Removal of damaged area
- Grinding of continuous or stopped overlaps
- Cleaning of ground surfaces
- Surface treatment with low viscosity resin
- Lay up of sufficient layers to match the original thickness
- Curing under vacuum at proper temperature and pressure
- Grinding, polishing and replacement of surface coatings

The role of NDE in pre repair stage is to determine nature of damage and determine the nature and demarcate extension of damage. In post repair stage NDE ensures the freedom of harmful stage and in – homogeneities.

Ultrasonic pulse –Echo methods with attenuation and transit time mapping facilities are used for restoration of thickness, strength and stiffness validation. Defects usually found after repair are- porosity, poor filleting and non-uniform bond line thickness of sandwich. Thickness and counter variation often occur. Repaired honeycomb structures are evaluated using through Transmission ultrasonic method.

II. ULTRASONIC TESTING

This is the most preferred method for evaluation of composites. The method is effective in defecting delaminations, voids, porosity and in some cases other flaws like broken fibers and inclusion. The defect is presented in A, B or C-scan form. Figure.1 illustrates the defect presentation forms.

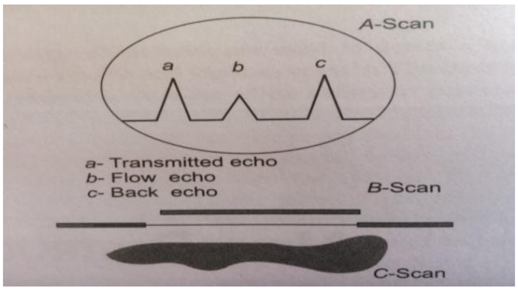


Figure 1. A, B and C- Scan Presentation of Defects

It may be noted that , A-scan records both amplitude and depth of defect on the CRT , B-scan gives sectional view of the defect and C-scan gives plane view of the defect , projected on a plane at right angle to the axis of ultrasonic beam.
Two common test methods used are:

2.1] Through transmission method :

In this method, ultrasonic waves are passed through the test sample to a receiver on the opposite side. An acoustic coupling between the transducer and the test object is applied. The most common couplant is water, used either by immersing the test object or with squirters at the transducer heads. Any air interfaces in the material-gaps, voids, porosity etc cause internal reflection , because the acoustic impedance of air is very different from that of the host material. Measuring attenuation of the sound energy transmitted through the structure indicates the presence of defects.

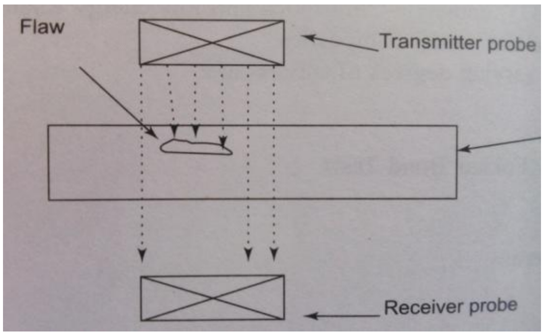


Figure 2. Through Transmission Technique

This method is employed to examine monolithic as well as honeycomb structure for detection of anomalies like gaps, voids, delamination , disband and internal assembly condition. It is possible to assess size of the defect. The technique of through transmission is preferred only detection of defect is required. Ultrasonic frequencies used are in the range of 1MHz-10MHz.

2.2] Pulse echo method:

Ultrasonic pulse-echo is a well-established and widely used non-destructive testing technique. A pulse of ultrasonic energy, typically a few microseconds, is transmitted into the specimen in a direction normal to the surface. The pulse is reflected from good matrix reinforcement boundaries and also from boundaries associated with flaws. Those signals which travel back towards the probe are detected and the position and size of a flaw is determined from the total pulse travel time and detected amplitude respectively.

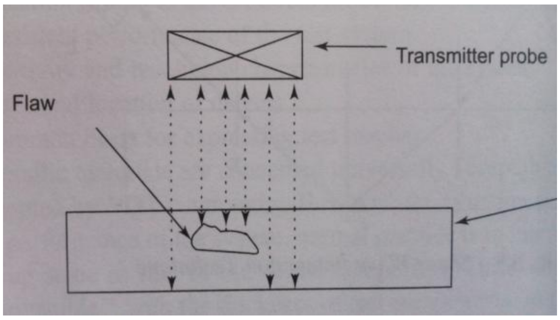


Figure 3. Pulse Echo Method

III. CALIBRATION STANDARD

All NDT results produce indirect indication of the physical state of materials and structures. These results could be in the form of data points, output of an electronic machine or pictures.

In order to understand the physical condition of the material/structure which produces this indication, it is necessary to fabricate standards. Calibration specimens is fabricated with same material and lay up as that of actual component. The standard serves the following function :

- Ensure consistent performance of the test system.
- Check sensitivity and resolution characteristics of the system.
- Evaluate size and location of defect.
- Provide common basis for expensing test results.

Details of such two specimens for carbon fiber polymer composite are given below. An example of calibration specimen is a laminate of 104 plies with 45^0, 90^0, 135^0 laid up and defects introduced at different levels. There are 7 defects implanted in the pane as shown figure 5.

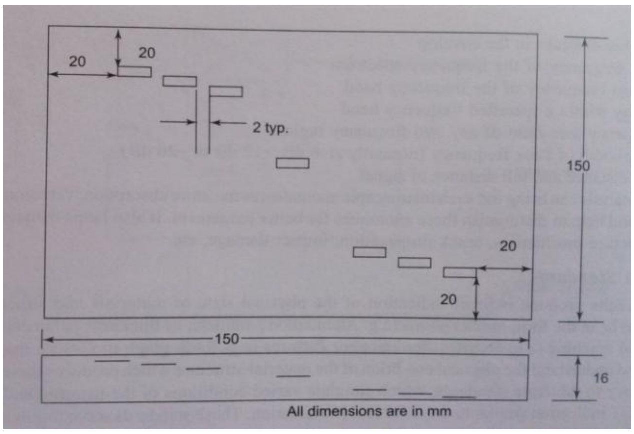


Figure 4. Flat Calibration Specimen With Implemented Defects of size 5*3mm

IV. DEFECTS IN COMPOSITES AND THIRE EFFECT

Range of defects observed during fabrication and service is shown in **Table 1**.

During Fabrication and services	**During Service**	
	Loading condition	**Corresponding defect**
Voids, porosity, delamination, broken fibers, inclusion,insufficient curing, missing plies, impact damage	Fatigue	Matrix cracking,crazing,fiber break,delamination
	Impact	Delamination , fiber damage
	Lightning stike	Debond between fiber and matrix, delamination
	Environmental	Matrix plasification, debond, irridation effect
	Deterioration	-
	Erosion	Reduction in thickness.

ULTRASONIC TEST CAN DETECT		
Defect	**Description**	**Effect of defect**
Porosity	Closed spaced small voids	Deterioration in mechanical properties
Delamination	Separation of plies in a laminate due to internal stresses.	Deterioration in mechanical properties
Inclusion	Foreign object	Local reduction in compressive strength and interlaminar shear strength
Blistering	Air pocket and heat during cure cycle leading to lack of bonding.	Effect is similar to that of delamination
Resin rich area	Resin bulid up during curing	Influence on shear stress
Fiber breakage	Broken fiber yarn at manufacture stage	Deterioration in mechanical properties
Bearing damage	includes fiber fracture	reduction of joint stiffness.
Impact damage	extensive internal damage	drastic reduction in compressive strength
Lack of integrity of bond line	due to internal stress, lack of curing, improper surface preparation	loss of stiffness, strength, local buckling
Lack of filleting between honeycomb core and face sheet	lack of adhesiveness	Fatigue resistance is reduced.
voids/moisture in core	small voids	effect similar to debond.

Table 2 gives summary of defects which can find out using ultrasonic testing.

V. INTERPRETATION

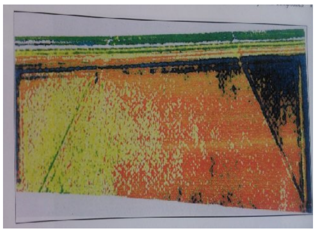
A number of experiments have been conducted in recent years on carbon fiber polymer composites simulating various-types of defects to get meaningful insight into the process and provide a reasonable basis for interpretation, which involves the following:

- Assessment of cure condition and material homogeneity.
- Establishing nature, size, location and volume dispersion of defects.
- Establish effect of defects on mechanical properties and facilitate evolution of acceptance criteria of defects and inhomogeneties.

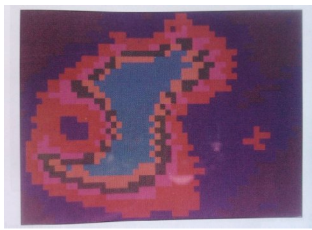
Experimental studies shows that as cure operation progress ultrasonic attenuation and velocity increase and optimize at a level, ensuring acceptable mechanical properties a ultrasonic parameters can be used as an index of material homogeneity strength and stiffness. Effect of thickness on ultrasonic specific attenuation is as shown in figure 8 These observations were made at 5 MHz and 10MHz.

Attenuation of ultrasonic energy and its time of travel through the test material is used to detect, locate, size of defect, while exact nature of the defect is established by correlating photo micrographic appearance of the defect with attenuation and transit time C-scan map. It is necessary to appreciate that attenuation of ultrasonic energy during its passage through the material could be due to as shown in following figure 5 :

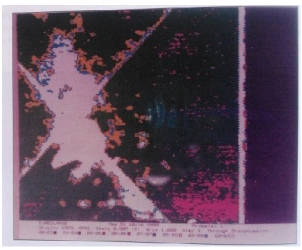
- Surface texture
- Presence of porosity
- Delamination
- State of cure of resin
- Fiber volume fraction
- Condition of fiber-matrix interfaced.
- Foreign inclusion.



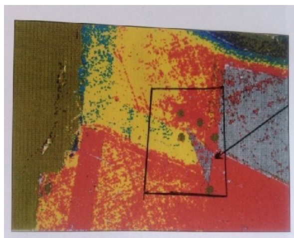
Porosity due to vacuum failure



Low energy Impact due to sharp tool



Delamination at the junction



Inclusion in composite component

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ACKNOWELEDGEMENT

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