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DAMAGE DETECTION OF COST EFFECTIVE CFRP COMPOSITE STRUCTURE USING FIBER OPTIC SENSOR UNDER DYNAMIC LOAD

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ABSTRACT

Recent advances and cost reductions has simulated interest in fiber optical sensing. This technique helps to detect the damage in aircraft structure. Nowadays, most of the critical components of aircraft structure made up of composite structure. CFRP can significantly reduce the weight while increasing strength and durability. The weight reduction of the structure will increase the fuel efficiency. The composite structure subjected to static and dynamic loading during the running condition. This paper overviews the cost effective material selection (CFRP) and damage detection setup using fiber optic sensor under dynamic loading condition. The spectrum received from the damage detection setup is analysed to ensure the size, shape and damage condition. The intensity of spectrum depends on the damage size of the given component. The entire paper shows the damage detection under dynamic loading with various indenter for impact.

Keywords: *Fibre optic sensor, Composite Laminate, CFRP, Impact.*

INTRODUCTION

Carbon-fiber-reinforced polymers are composite materials. They have unique properties of relatively high strength at high temperatures coupled with low thermal expansion and low density [1] . The physical properties of composite materials are generally not isotropic in nature, but rather are typically anisotropic (different depending on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depends upon the orientation of the applied forces and/or moments.

Static and Dynamic loads are known to induce damage to the composite in the form of matrix cracking delamination, debonding and fibre breakage (Serge Abrate, 2011). Research has shown that composites are capable of absorbing energy and dissipating it by various fracture and elastic processes when subjected to a loads. The ability of composite material is to absorb energy elastically depends on the mechanical properties of the matrix and fibres, the interfacial strength, the velocity of impact (Hualin Fan eLal, 2009) and the size of the component. Materials and structures, in addition to enabling technologies for future aeronautical and space systems, continue to be the key elements in determining the reliability, performance, testability, and cost effectiveness of these systems. The focus of the present paper is on developments damage identification using fiber optic sensor.

MATERIALS AND METHODS

1. MATERIALS

a. Carbon Fibre

Carbon fibers are commercially available with a variety of tensile modulus values ranging from 207 MPa on the low side to 1035 MPa on the high side. In general, the low-modulus fibers have lower density, lower cost, higher tensile and compressive strengths, and higher tensile strains-to-failure than the high-modulus fibers.

Carbon fibers are their exceptionally high tensile strength–weight ratios as well as tensile modulus–weight ratios, very low coefficient of linear thermal expansion high fatigue strengths, and high thermal conductivity. Their high cost has so far excluded them from widespread commercial applications. They are used mostly in the aerospace industry, where weight saving is considered more critical than cost.

b Epoxy Resin & Hardener

Epoxy resins are the most used just after polyesters, their price being the only limit to their usage. They have better mechanical characteristics in tension, compression, impact and others when compared with polyester resins, and so they are preferred in the manufacturing of high performance parts like those used in aeronautics and others. Besides they present good heat resistance up to 15^0 to 190^0 C, have good chemical resistance, [2] low retraction, good reinforcement wetting and an excellent adhesion to metallic materials. The hardener is used to cure the matrix materials in fibre as faster than usual curing time. From that we can get excellent adhesive bonding together and normally the proportion of hardener, epoxy resin is equal amount and equal to weight of fibre.

c. Fiber Optic Sensor

Fiber optic sensor technology has been a major user of technology associated with the optoelectronic and fiber optic communications industries. The ability of fiber optic sensors to displace traditional sensors (Shizhuo Yin, Paul B. Ruffin, Francis T. S. Yu 2008) for rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, chemical measurements, and a host of other sensor applications has been enhanced. The inherent advantages of fiber optic sensors, which include their ability to be lightweight, of very small size, passive, low power, and resistant to electromagnetic interference, high sensitivity [9].Fiber optic sensors are often loosely grouped into two basic classes referred to as extrinsic, or hybrid, fiber optic sensors and intrinsic, or all fiber, sensors.

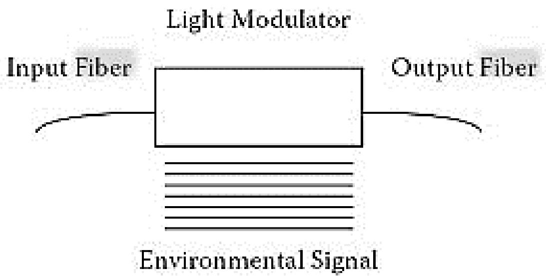

Fig. 1 Overview of Fiber Optic Sensors.

d. Material Properties

The following material properties from Test Data results [3,4] have been taken into account for analysis 1 Psi = 0.0069 MPa. Composites are the orthotropic material the property varies along the three directions. The stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel.

Table 1 Material Property of CFRP

Properties		Carbon/epoxy
E_a	(GPa)	125.485
E_b	(GPa)	8.067
E_c	(GPa)	8.067
G_{ab}	(GPa)	41.29
G_{bc}	(GPa)	2.42
G_{ca}	(GPa)	4.129
γ_{ba}		0.0176
γ_{cb}		0.0176
γ_{ca}		0.4657
Density	kg/m^3	4.152

EXPERIMENTATION

3.1 Low velocity impact test Data

Damage in unidirectional carbon/fibre composite resulting from low velocity/energy impacts was evaluated embedded fiber optic sensor. [6] The value for conducting experiments based on the experimental results taken from the output of the experimental value the Impactor and energy consideration taken into account for the further improvement of the velocity impact energy. Initially low velocity impact was conducted by using two types of impactor shape [7]. The laminates used in the low velocity impact tests were manufactured from uni-directional carbon fibre/epoxy prepreg. The panels 200 mm ×90 mm × 3 mm.

1. Impactor for testing
    - Conical -167gm
    - Hemi Spherical -180 gm
2. Impact Energy for conducting test
    - 0.33 J with Corresponding velocity 1.3 m/s
    - 0.56 J with corresponding velocity 2.5 m/s
3. Formula for calculating the impact energy
    - E=W × h

$V=\sqrt{2gh}$ Where W- Weight of the Impactor (N),h- Vertical height,

Courtesy: "*Evaluating impact damage in CFRP using fibre optic sensors" A.R. Chambers a,*, M.C. Mowlem b, L. Dokos a*

V- velocity (m/s), E – Energy (J)

3.2 Experimental Setup

Figure 2 – 4 shows the configuration of the test specimen of impact detection with flat plat. The specimen is a quasi-isotropic laminate plate. A single mode fiber sensor was bonded to the specimen surface for impact damage detection. The following components are used for the experiments (a) Electrical Input Signal – 1MHz, (b) Optical Transmitter, (c) Single mode fiber cable, (d) Optical receiver, (e) Digital Oscilloscope with data acquisition system. The low velocity impact experimental setup was created for damage detection.

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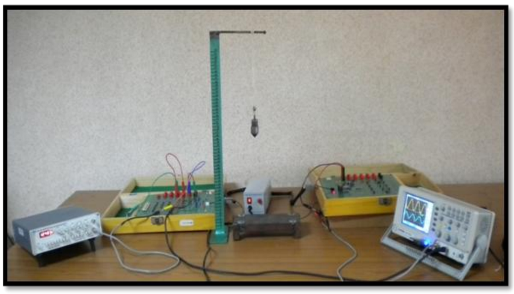


Fig. 2 Dynamic Load Test Setup Arrangement

Fig. 3 Test Setup arrangement

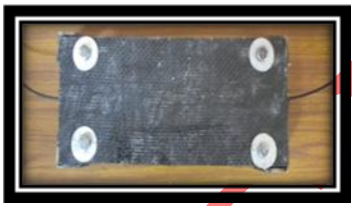
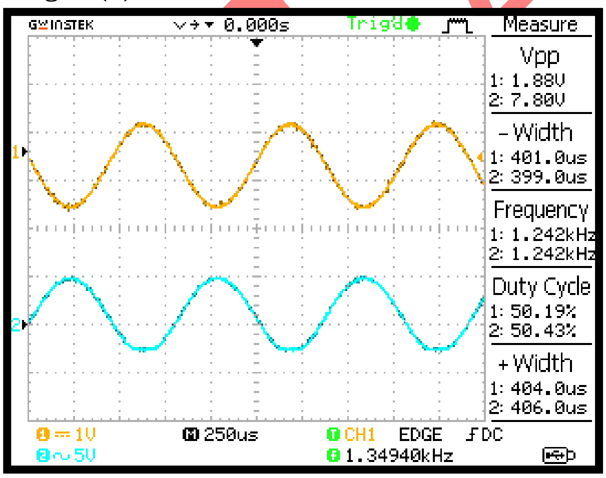


Fig. 4 Test Specimen with fiber optic sensor

RESULTS AND DISCUSSIONS

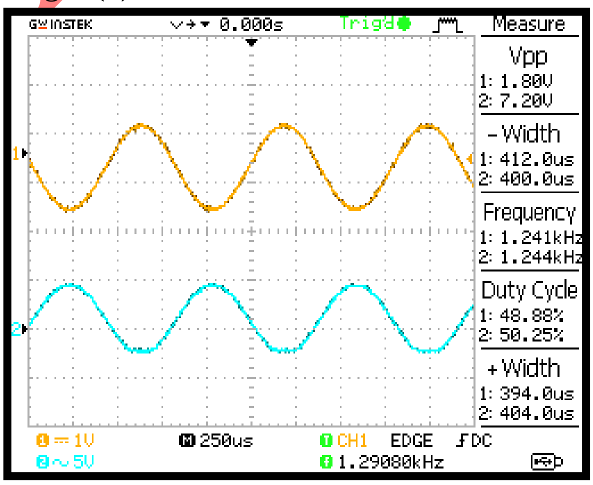
The following experimental result graph shows that the various impact energy with respect to the various height level [8].

Fig (1) h= 201.4mm at 0.33J Conical



Impactor

Fig (2) h= 341.4mm at 0.56J Conical



Impactor

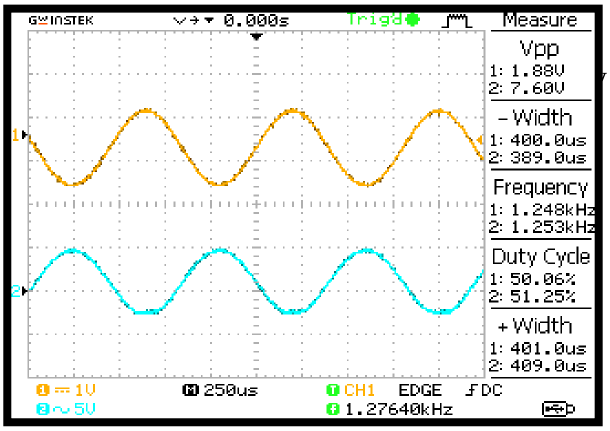


Fig (3) h= 186.88mm at 0.33J Hemi Spherical Impactor

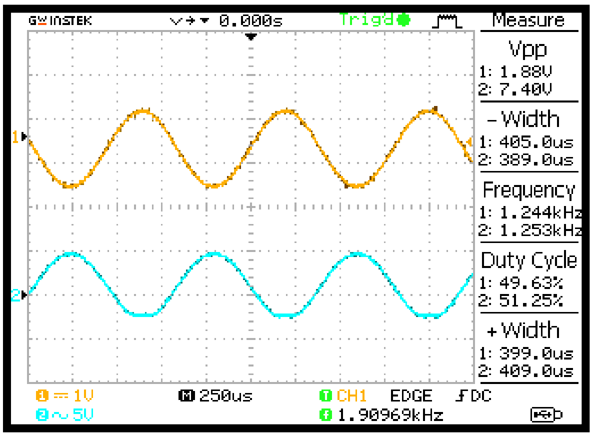


Fig (4) h= 317.1 mm at 0.56J Hemi Spherical Impactor

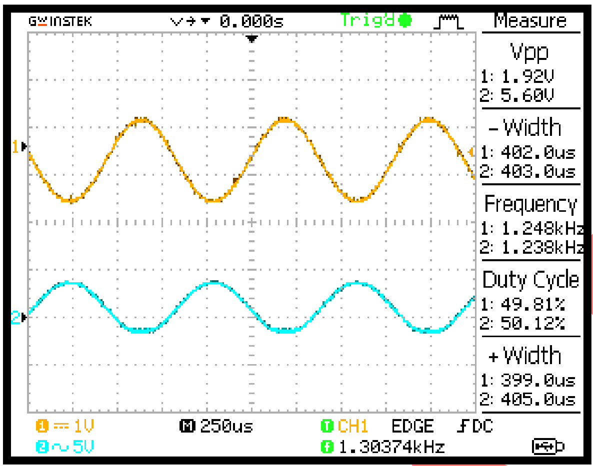


Fig (5) h= 320.4mm at 0.33J Conical Impactor (Ø 12mm)

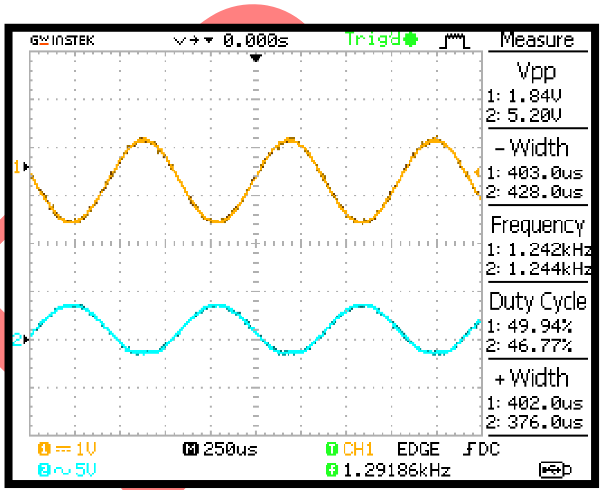


Fig (6) h= 543.66mm at 0.56J flat Impactor (Ø 12mm)

Fig. 5 Output Results for Dynamic Analysis

The damage detection principle of this system is based on the energy change of the received waveform. If a damaged section exists in the path of the elastic wave, the energy of the elastic wave will change. By detecting this change, the system can detect the damage in a composite structure. We could successfully detect the damage propagation by this system. Figure 5 [1-6] shows an output wave form of the impact load condition. We have conducted the impact detection test using a drop-weight type impact machine.

The weight of was 167 gm and its tip was a conical shape. The energy of the impact is 0.33 J at velocity 1.3 m/s. The figures 5 [1,3,5] shows the received waveform and the enlarged waveform of the elastic wave of fiber optic sensors under 0.33 J energy with height range of 201.6 mm, 186.88 mm and 320.4 mm. The figures 5 [2,4,6] shows the received waveform and the enlarged waveform of the elastic wave of fiber optic sensors under 0.56 J energy with height range of 341.4 mm, 317.1 mm and 543.6 mm. Based on this output wave the experimental setup detect the resulting damage. As the result of this study, it was revealed that two kind of detections, damage monitoring and impact detection, with the same system construction by the damage monitoring using single mode fiber sensor.

CONCLUDING REMARKS

The following conclusions were drawn from the present experimental investigations:

1. Carbon fibre is suitable material for absorbing more energy during the impact loading condition. Based on the material property.
2. For the constant input voltage of 1.88v the output voltage varies with respect to the impact [Fig. 5 (1 – 6)] load energy of 0.56 J, the output voltage is 5.20v.
3. The shape of the impactor in this experimental work: conical, Hemi spherical and flat shape.
4. In this paper, the low velocity impact load is applied in between the range of 1.3 to 2.5 m/s.
5. The figure 5 [1 – 5] shows the output of the impact load on the composite plate and it shows the energyabsorption capability of carbon fiber material.

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