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Detection and Evaluation of Impact damage in CFRP Laminates Using Ultrasound C-Scan and IR Thermography

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ABSTRACT

Advanced composite structural components made up of Carbon Fibre Reinforced Polymers (CFRP) used in aerospace structures such as in Fuselage, Leading & Trailing edges of wing and tail, Flaps, Elevator, Rudder and entire wing structures encounter most critical type of damage induced by low velocity impact (<10 m/s) loads. Tool dropped during maintenance & service, and hailstone impacts on runways are common and unavoidable low-velocity impacts. These low-velocity impacts induce defects such as delaminations, matrix cracking and debonding in the layered material, which are sub-surface in nature and are barely visible on the surface known as Barely Visible Impact Damage (BVID). These damages may grow under service load, leading to catastrophic failure of the structure. Hence detection, evaluation and characterization of these types of damage is of major concern in aerospace industries as the life of the component depends on the size and shape of the damage.

In this paper, details of experimental investigations carried out and results obtained from a low-velocity impact of 30 Joules corresponding to the hailstone impact on the wing surface, simulated on the 6 mm CFRP laminates using instrumented drop-weight impact testing machine are presented. The Ultrasound C-scan and Infrared thermography imaging techniques were utilized extensively to detect, evaluate and characterize impact damage across the thickness of the laminates.

Keywords: Ultrasonic, Thermography, CFRP laminates, Composites, Impact damage.

1. Introduction

Carbon Fiber Reinforced Polymer (CFRP) composite materials are increasingly used in aerospace applications due to their very high in-plane strength and stiffness properties. However, the use of these materials is limited by their poor through thickness properties such as tensile, Compressive and shear strength and their modulus in thickness direction. Also, studies have shown that, these CFRP materials have good in-plane fatigue response and respond poorly to transverse impact loads.

In aircraft, Low-Velocity(<10 m/s) impact loads, that are common and unavoidable during manufacturing, maintenance and in-service life of the structure, such as tool dropped during maintenance, bird strike and hail impacts induces subsurface defects and damages which are not clearly visible on the surface[1-3]. When these defective structures were put into service, subsurface damages may grow and eventually structure fails catastrophically[4]. Hence, it is necessary to characterize these defects nondestructively to avoid early failure of the structure, to help in damage tolerance design and fail safe design.

2. Experimental Details

High strength T300/914C, Carbon/Epoxy material, widely used in construction of wing structures of an aircraft is chosen for experimental investigation of damage induced due to low-velocity impact and its growth and hence the life due to flight loading spectrum. These flight loading spectrum were measured during flight and are programmed into the fatigue testing machine and are dynamic in nature.

Non-destructive testing methods Ultrasonic (UT) and Infrared Thermography (IR) were used for damage characterization throughout the experimental program. All the specimens were C-scanned before impact tests to ensure it is free of any gross defects that could have been imparted during the manufacturing of the specimens.

Experiments were carried out in two stages. In the first stage, T300 / 914C CFRP specimens were subjected to low-velocity impact with an incident impact energy maintained at 30 J using drop-weight testing machine to induce delaminations or sub-surface damage in the specimens. C-scan and IR images were recorded and used to evaluate the induced damage on the specimens.

In the second stage, impact damaged specimens were subjected to Flight loading spectrum loading as experienced by a typical wing of a supersonic aircraft. Spectrum loading equivalent to three life cycles was applied on each specimen. Ultrasonic C-scan and IR images were recorded after each life cycle of spectrum loadings.

2.1 Experimental Programme:

Experiments on the T300/914C C/E composite specimens were carried out in two phases. First phase of the experiment involves in generation of impact damage in the specimen followed by damage characterization using Ultrasound C-Scan and IR Thermography. In the second phase, impacted specimens were subjected to spectrum loading equivalent to three life cycles. Ultrasound C-Scan and IR Thermography images were recorded after each cycle.

2.2 Equipment and Instrumentation

The test equipments and instrumentation used for the above mention tests are as given below.

1. Drop-weight impact testing machine DYNATUP 8250 with an instrumented tub.
2. MTS 810 servo hydraulic dynamic test system for spectral loading.

3. Ultran-NDC 7000 with three axis bridge and water tank for immersion, pulse-echo ultrasonic test to obtain C-scan images of the specimens
4. FLIR system's AGEMA 570 IR camera for obtaining IR images of the specimens.

The tests carried out on the specimens were sequenced as follows:

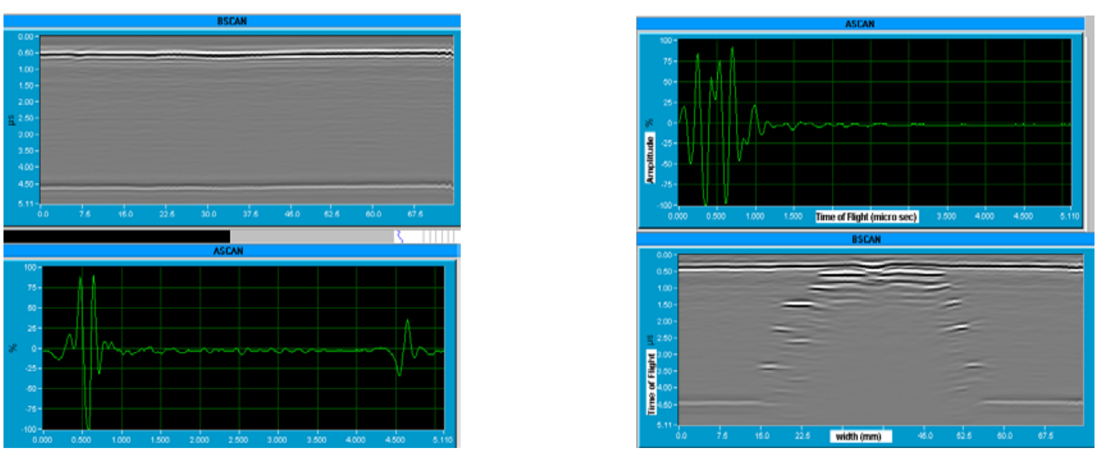
2.3 First Phase:

1. **Ultrasound C-scan:** Ultrasound C-scanning was performed on unimpacted specimens to ensure specimens are free of defects and flaws, which might have been caused during fabrication of the specimens.
2. **Low velocity impact loading on the specimens to induce Impact damage:** All the specimens were subjected to 30 J (30 N-m) of incident impact energy corresponding to the hail stone impact on the upper and lower wing skin structures of the aircraft during flight [2].
3. **Ultrasound C-scan and IR Thermography:** Ultrasound C-scan and IR Thermography tests were carried out on the impacted specimens to evaluate the induced impact damage on the specimens

2.4 Second Phase:

4. **1st Life cycle spectrum loading:** All the three specimens were subjected to a spectrum loading with a peak load of -110 kN in compression to 40 kN in tension at a frequency of 0.5 Hz. One life equivalent of spectrum loading is equivalent to 15 blocks, with each block of loading corresponds to 10380 cycles. 50 hours of flight corresponds to 2076 cycles. Hence 1 block corresponds to 250 flight hours and 1 life is equivalent to 3750 flight hours. This is the typical loading experienced by a fighter aircraft.
5. **Ultrasound C-scan and IR Thermography:** Ultrasound C-scan and IR Thermography tests were carried out on the spectrum loaded specimens to characterize the damage growth on the specimens.
6. **The steps 4, 5 and 6 were repeated for 2nd and 3rd life spectrum loading on the specimen.**

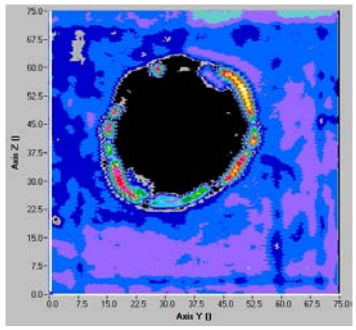
3. Results and Discussion



(a) (b)

Figure 1. A, B – Scans of (a) healthy and (b) impact damaged CFRP sample

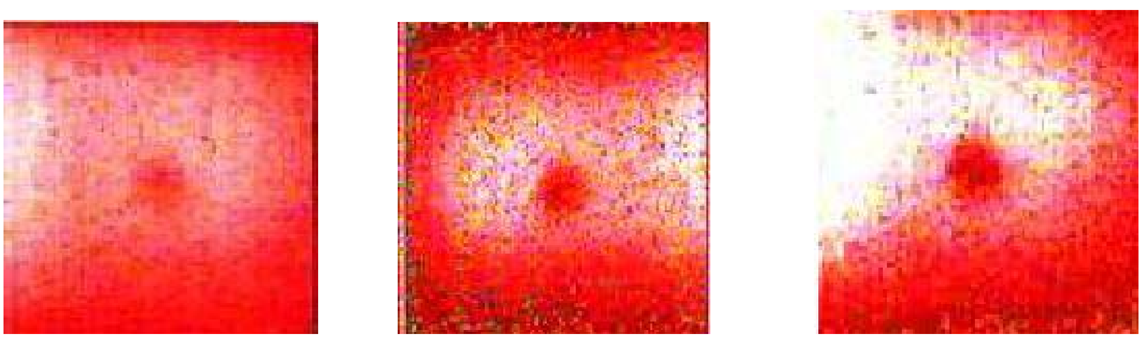
Ultrasound A-Scan (Amplitude v/s Time) and B-Scan (Time v/s scan length) for healthy specimens are shown in figure 1a. Figure 1b shows the images of the impact damaged specimens. While A-scan provides the information on the amplitude variation against the depth of the specimen, B-scan maps the depth wise damage distribution across the thickness of the specimen. Also, it can be observed that the damage pattern in the impacted specimen follows pine tree formation with increase in damage area along the thickness.



Before spectrum loading **After 2 life** **After 3 life**

Damage Area = 1263 mm^2 **Damage area = 1294 mm^2** **Damage Area = 1365 mm^2**

Figure 2. C-Scan images of damage at different stages of the spectrum loading



Before spectrum loading **After 2 life** **After 3 life**

Figure 3. I R images of damage at different stages of the spectrum loading

Ultrasound C-scan image obtained after impact loading showed that the induced damage has elliptical shape with typically major axis measuring approximately 50 mm along 45 degree direction to the loading axis with minor axis of approximately 45 mm. This measured length of 50 mm coincides with the fibre splitting noticed at the back surface oriented at 45 degree to loading axis. Other specimens also have showed similar damage shape.

The area of the induced damage increased from one life to the next life, though the incremental damage area was found to be small(< 5%) till the completion of second life equivalent number of load cycles. However, the damage growth was significant at the end of three life equivalent loading cycles (8 – 10 %). Further, it was observed that the maximum extension of the damage was again at 45^o with respect to the loading axis.

IR images obtained at these stages though indicate the increase in the damage area from impacted condition to after1st, to after2nd and then on to after 3rd life equivalent loading cycles, precise mapping of the boundary of the damaged area could not be achieved. Hence, it is very difficult to quantify the damage growth as compared to the C-Scan results. However, the I R imaging can be utilized to obtain a qualitative information about the damage extension with the advantages that it can be fast and on-line.

4. Conclusions

Extension of low velocity impact induced damage in the T300/914C Carbon/Epoxy quasi-isotropic laminate under flight spectrum loading conditions was investigated experimentally. Intermittent ultrasound scanning and Infrared imaging was performed to detect and measure the damage growth.

Impact damage induced and its growth could be mapped and quantified using ultrasound C-scanning. IR imaging though could detect the impact induced damage and indicate its growth under spectrum loading, accurate sizing and quantification could not be achieved.

Thus, while ultrasound scanning has its advantage in providing us with precise measurement and quantification of damage and its growth I R imaging is able to give us a qualitative information on the same in a shorter time without the specimen being taken out from the loading machine.

Effects of size of the damage and its growth on the CFRP laminate in terms residual strength and residual life are being investigated.

5. Acknowledgements

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