Assessment of impact damage in CFRP by combined thermal and speckle methods

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ABSTRACT

In this contribution we show experimental results for combined thermal and DSPI measurements on several fiber reinforced polymer test samples that have been impacted in a drop tower. Active thermography can give complementary information with regard to the type and size of the damage, but DSPI is used for assessing the effect of the damage, i.e. the difference in the displacement or strain field of a damaged and undamaged specimen.

Keywords: DSPI, strain, damage assessment, CFRP, thermography, thermal testing

1. INTRODUCTION

Damage assessment in fiber reinforced polymer (FRP) structures is well advanced. In-situ condition evaluations of polymer composite materials, i.e. Non-Destructive Evaluation (NDE), are usually aimed at revealing flaws after fabrication and in-service, such as delaminations and debondings or cracks. Different types of damage can be identified using e.g. ultrasonic testing (UT) or active thermal techniques (TT), i.e. pulse or lock-in thermography [1,2]. Current NDE techniques involve some form of active excitation, e.g. for active thermography (thermal testing, TT) a heat input is required and for ultrasonic testing a high frequency mechanical pulse. The output, usually in the form of an image, can be related to the extent of the damage but the severity is inferred. Ultrasonic testing is the most popular as it can penetrate into the material while thermography is restricted in general to a few millimeters below the surface.

Strain measurement techniques, such as strain gauges, can provide prognostic measures that are directly related to the integrity of the material and hence its remnant life. If the defect is close enough to the surface, its identification with laser based methods, e.g. Digital Speckle Pattern Interferometry (DSPI) is also possible [3]. The techniques are complementary in their detection limit as well as their advantages and drawbacks [4]. Both UT and TT can help in assessing the type of the defect as well as its geometrical parameters. While ultrasonic testing is very much appropriate for delineating debonding areas, it is a scanning technique and therefore limited in lateral resolution and speed of application, lock-in thermography has better imaging properties, but its acquisition time increases with depth. Finally, Digital Speckle Pattern Interferometry (DSPI) gives information complementary to the size and location of the defect in that it helps in assessing the surface strain field around the defect [5]. Since strain is an ideal parameter to quantify damage in a manner that supports the assessment of structural integrity and in particular residual life, the combination of thermal and laser based methods allows for an assessment of both the defect size and structure as well as its effect on the component behavior under service load.

2. IMPACT TESTING

For the present work different CFRP specimens have been selected. Centro Ricerche Fiat (CRF) has provided injection molded flat panels made from Polypropylene (PP) reinforced with Long Glass Fibers and Polyamide (PA) reinforced with Short Glass Fibers. The panels have been manufactured with a size of 260x180 mm² and thicknesses of 3 mm and 4 mm. In addition, honeycomb core sandwich panels have been provided by High Performance Space Structure Systems

(HPS). The dimensions of the honeycomb panels are $150 \times 150 \times 40 \text{ mm}^3$. The core material is Al T5056, the cell shape is regular hexagon with 0.0254 mm thickness and 4,7625 mm cell size. The skins covering the cellular core are produced of carbon/epoxy $[0/90]_4$ fabric composite material of 2 mm thickness (Figure 1).

a) Honeycomb core sandwich panel (HPS)

b) PA short glass fiber panel (CRF)

Figure 1. Two specimens for impact testing

To assess the panel energy absorbing capability, the panels have been tested in hard-body low velocity, low energy, mass-drop impact loading, using the drop-tower of the university of Patras [6]. The PA and PP panels have been impacted with energies ranging from 2.5 J to 30 J while for the sandwich panels an energy range between 148 J and 493 J has been applied. Figure 2 and Figure 3 show the damages induced on the specimens from the impact.

a) Panel during impact test.

b) PP after impact of 30 J.

c) PP after impact of 2.5 J.

Figure 2. Damages induced from the impact on PP panels of 3 mm thickness.

a) Panel during impact test

b) Upper skin after impact

c) Lower skin after impact

Figure 3. Damages on honeycomb core sandwich panels induced by the impact.

3. DAMAGE ASSESSMENT

The specimens have been investigated by use of two different measurement techniques: Active Thermography and Digital Speckle Pattern Interferometry (DSPI). The comparison of the results coming from both techniques enables to assess the damage induced from the dynamic event.

3.1 Measurements on Polypropylene (PP) and Polyamide (PA) panels

The PP and PA panels have been investigated using pulse thermography. Thermal images were recorded in the impulse transmission mode using a 4 kJ Xenon flash lamp and an InSb focal plane array camera (Cedip Jade III MW) sensitive to infrared radiation from 3.5 – 5 μm . The frame size was 240 x 320 pixels. Figure 4 shows results obtained on PP panels in both thicknesses of 3 mm and 4 mm. The presence of cracks is well distinguishable in both samples. In Figure 4 (a) the arrow highlights the presence of a rectangle in the image. This is a piece of adhesive tape that has been stuck on the back side of the sample. The adhesive tape glued on the PP plate of 4 mm is invisible in Figure 4 (b) suggesting that PP becomes intrinsically transparent to infrared radiation for thicknesses above 4 mm.

a) PP 3 mm thickness after impact of 2.5 J

b) PP 4 mm thickness after impact of 4.5 J

Figure 4. Cracks in PP panels detected by pulse thermography in transmission..

In Figure 5 the results of a 4mm thick PA panel are shown. The presence of three cracks can be noticed radiating from the central part of the impacted area. Figure 5 (a) shows the front side of the sample, the one that has been in contact with the drop mass, while Figure 5 (b) shows the back side.

a) PA front side

b) PA back side

Figure 5. Cracks in a PA panel of 4 mm thickness detected by pulse thermography in transmission.

Measurements of the same PA sample with 4mm thickness have been carried out by using DSPI with thermal excitation. The presence of the cracks is revealed as a discontinuity in the interference fringes as shown in Figure 6. However comparing the results obtained from thermography (Figure 5 (a)) with the one obtained from DSPI (Figure 6) it is clear that in the DSPI image the crack in the right part (arrow in Figure 5 (a)) is missed.

a) PA in plane (x-)direction

b) PA out of plane (z-)direction

Figure 6. Interference fringes from DSPI in PA panels of 4 mm thickness after thermal excitation.

3.2 Measurements on honeycomb core sandwich panels with thermal excitation

The measurements carried out on the honeycomb sandwich panels demonstrate how different types of defects can be detected. While in the PP and PA panels cracks have been detected, the honeycomb panels reveal the presence of detachments of the skin from the core in the area surrounding the hole produced by the impact. The measurement result in Figure 7 was obtained with Lock-in Thermography at 1Hz frequency. The delineation of the damage area is visible in this lock-in phase image.

Figure 7. Detachment of skin from honeycomb core sandwich panel detected by Lock-in Thermography in reflection.

For comparison, DSPI measurements with thermal excitation have been carried out. The presence of the delaminations disturbs the interference fringes (Figure 8 (a) and 8 (b)) and the shape of the defect can be identify especially from the fringe gradients (Figure 8 (c) and 8 (d)). When compared to the results obtained in Figure 7, DSPI suggests that the damage extends beyond the delineation as obtained by thermography.

Figure 8. Detachment on honeycomb core sandwich panel detected by DSPI. Deformation fringe patterns for in-plane x- and out of plane z-directions, as well as fringe gradient.

3.3 Measurements on honeycomb core sandwich panels with mechanical loading

A measurement set-up has been developed where the sample is loaded in bending with known forces and the induced displacements have been measured by DSPI (Figure 9). The knowledge of the forces is important to reproduce the same loading conditions for different specimens, e.g. damaged and undamaged ones.

Figure 9. Measurement set-up.

To this aim the sample has been equipped with a system of four supports (threaded connectors) glued at the four corners of the sample. The threaded connectors have been screwed to four 1 kN force transducers (K1, K2, K3, K4) previously fixed in a breadboard standing in front of the interferometer. Two more force transducers (K5, K6) are mounted on the breadboard. They are linked to two small threaded connectors with a ball on the top to guarantee a single point of contact with the sample. The two threaded connectors give the possibility to load the sample with increasing or decreasing force according to the need. The forces are recorded for K5 and K6, and due to the bending of the sample a force of approximately half value and opposite direction is recorded for the transducers at the corners of the sample (Figure 10). The use of a pair of loading pins is motivated by the intention to avoid a direct interaction with the damaged central part of the sample. A choice of six transducers allows also for realizing different load cases such as diagonal bending modes.

Figure 10. System of force transducers to take control of the bending force.

The measurements have been performed in both the Polypropylene/Polyamide Glass Fiber panels and the sandwich honeycomb panels. Unfortunately the measurements on the Polypropylene/Polyamide Glass Fiber panels have not shown good results. The panels are too soft and the material starts to creep under mechanical loading. Therefore only

measurements on undamaged and damaged sandwich honeycomb panels are reported. In order to avoid rigid body movements, in the first acquisition the samples have been pre-stressed with a force of 200N (K5 and K6) which corresponds to a force of -100 N in K1, K2, K3 and K4. The second acquisition has been carried out increasing the force to 230N. Figure 11 shows the displacement patterns in z direction of the undamaged sample in two orientations with a rotation by 90 degrees. Comparing the two results it can be noticed that the honeycomb has a predominant direction of deformation. This shows that the stiffness can not be considered isotropic.

Figure 11. Fringe patterns for out-of-plane displacement of the undamaged sandwich honeycomb panel.

Figure 12. Fringe patterns for out-of-plane displacement of the damaged sandwich honeycomb panel

Figure 12 represents the corresponding results from the same load step for the damaged sample. The predominant fringe patterns are recognized again, but the local fringe pattern around the defect has drastically changed. However, in contrast to the thermal loading (Figure 8) the shape of the defect can not be identified from the deformation fringe pattern using this type of mechanical loading. Analyzing the results after a subtraction between the damaged and undamaged out-of-plane displacement patterns (Figure 13) shows the asymmetry induced by the damage as well as the affected zone. Finally, in Figure 14 we show one corresponding change of in-plane deformation pattern. From the difference image the strain change can be obtained.

Figure 13. Result of the subtraction of the out-of-plane displacement patterns for the two orientations

a) In-plane deformation in x-direction for undamaged (left) and damaged (right) honeycomb panel

b) Difference of in-plane deformation in x-direction

Figure 14. Result of the subtraction of the in-plane x-displacement patterns for one orientation

4. CONCLUSIONS

While Non-Destructive Evaluation can find and characterize defects in a structure, it is of limited use for assessing the effect of the defect on the structural behaviour. A loading similar to the expected in-service load must be used for a meaningful assessment. In our case, this is a mechanical loading of the structure (test plate in bending). Such an approach can circumvent the necessity of using contacting ultrasonic testing, because it measures the (surface) strain field which in most cases is related to the failure criterion. This method can be recommended in cases where the structure is gradually weakened by the damage, but the damage is not inducing immediate failure. A quantitative limit as of how big a change in the deformation or strain field can be tolerated must be set on a case-by-case basis.

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