Combining Optical Techniques to Assess the Damage Tolerance of Composite Materials

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Abstract. The performance of composite materials is investigated using the full-field optical techniques of digital image correlation (DIC) and IR-thermography (IRT). A novel loading methodology has been developed and applied in an open loop servo-hydraulic test machine to initiate damage but prevent complete specimen failure. A new methodology has also been developed to study the damage propagation in components subjected to fatigue loads using the simultaneous application of DIC and thermoelastic stress analysis (TSA).

Introduction

Fibre reinforced polymer (FRP) structures may encounter impact or high strain rate loading in their service life. Examples include hail storms, bird strikes, slamming loads in rough seas or simply as the result of an accident during routine maintenance [1-3]. The mechanical behaviour of FRP materials under static loading is relatively well understood [4] but the behaviour during and after an impact event has been less well documented. Compared to metallic structures, the energy absorption behaviour and interacting damage mechanisms are far more complex hence motivating the use of full-field techniques to provide a better understanding of the accumulation of damage. The focus of the current work is to establish an experimental methodology for the study of FRP material during a simulated impact event and to study its effect on subsequent material performance.

Damage Initiation Methodology

An Instron VHS servohydraulic test machine was used to provide tensile loading to composite specimens at intermediate strain rates. Once fired, the machine actuator operates in an open loop configuration, necessitating the use of a mechanical fuse to provide loading but prevent complete specimen failure. The mechanical fuse takes the form of a 12.5 mm diameter aluminium 6082 rod, with a reduced diameter at two locations, which acts as a shear pin. Fig. 1 shows a schematic of the loading apparatus used.

Crossply glass fibre-epoxy and carbon fibre-epoxy samples were loaded to 70% of the material ultimate tensile strength (UTS) at a strain rate of approximately 32 s⁻¹ using the loading methodology shown in Fig. 1. Specimens were imaged using a CEDIP Silver 480M IR camera and two Photron SA1 high speed white-light cameras. IR images of 64 x 24 pixels (3 pixels/mm), were captured at a frame rate of 9.37 kHz, whilst white light data of 624 x 448 pixels (30 pixels/mm) were captured at 18 kHz. DIC was performed on the white light images to obtain surface strain plots of 0.33 strain points/mm. Strain maps are used together with surface temperature plots to inform on the onset and location of damage. Nominally identical specimens were also loaded quasi-statically to the same load range. Fig. 2 shows a typical example of surface damage found in a carbon-epoxy specimen from IRT and DIC data during quasi-static tests. The presence of damage was confirmed through microscopic analysis of the specimen cross section.
Figure 2: Comparison of DIC Longitudinal strain ($\varepsilon_{yy}$) plots and cumulative $\Delta T$ images of a crossply carbon-epoxy specimen quasi-statically loaded to 68% of its failure stress

**Damage Propagation Assessment**

The damaged specimens were loaded under fatigue to promote damage propagation. A Labview code was developed to collect test machine data and to capture white-light and IR images at various stages in the fatigue life. White light images were collected using a calibrated stereo system of 5 MPixel cameras with a spatial resolution of 42 pixels/mm and an exposure time of 1 ms. The cameras were synchronised to collect a set of images at the maximum point in a loading cycle. Images were processed using DIC to obtain surface strain maps of spatial resolution 5.25 strain points/mm, highlighting regions of high strain and identifying the location of damage. A set of IR images were analysed using TSA to obtain $\Delta T$ data relating to the sum of the principal stresses in the surface layer. An example of such data is presented in Fig 3, for a previously undamaged glass-epoxy specimen loaded at 100 ±85 MPa. As cracks form, the stress in the surface layer is reduced, reducing the thermoelastic output and highlighting damage. In the latter stages of the test fibre breaks occurred, eventually resulting in complete specimen failure. DIC strain plots were obtained of the same specimen area. Through comparison of optical data captured during fatigue loading of damaged and undamaged samples, the effect of intermediate strain rate loading on the damage tolerance of crossply glass-epoxy and carbon-epoxy was examined. The damage observed was confirmed as actual cracking by microscopic examinations.

Figure 3: $\Delta T$ TSA data collected during the fatigue loading of a crossply glass-epoxy specimen

**References**


