Assessment of damage in multi-directional laminates using full field imaging

R. Ruiz Iglesias, I. Jimenez Fortunato, G. Olafsson, O.T. Thomsen, J.M. Dulieu-Barton

Faculty of Engineering, University of Bristol, UK

rafael.ruiziglesias@bristol.ac.uk

Introduction

The identification of the inception and progressions of damage in composite components is crucial for efficient design to avoid unnecessary and early failure of components. Thermoelastic Stress Analysis (TSA) is a full field, non-contact infra-red imaging technique which relies on the thermoelastic response (ΔT) to cyclic loading to extrapolate the stress state on the surface of a component [1]. Similarly, Digital Image Correlation (DIC) is a full field surface measurement technique, where white light illumination is used to track changes in contrast to obtain displacements and hence calculate surface strain fields [2]. The main focus of the study is the use of a novel full-field imaging methodology which combines TSA and DIC to identify damage evolution and the source of thermoelastic response in composite laminates under cyclic loading [3]. Cyclic loading frequencies are typically chosen with the aim of achieving adiabatic conditions, which are essential for preventing internal heat diffusion and its subsequent influence on temperature change in the outer lamina [6]. As loading frequencies are reduced, heat diffusion will occur allowing subsurface thermal signatures to conduct towards or away from the surface of a component. Hence, judicious selection of loading frequency could provide sub-surface information. In contrast, the white light used in DIC cannot be used to deduce any information beyond the surface of a specimen. As a result, the combination of both techniques could result in an effective means of full field damage identification and characterization [4]. To further explore this idea, damaged multidirectional GFRP and CFRP laminates are investigated.

Methodology and Results

The tests consist of cyclically loading multi-directional composite laminate strip test specimens in uniaxial tension. Cross-plies CFRP (IM7/8552) and GFRP (RP-528) laminates $[90,0]_{3S}$, $[0,90]_{3S}$ and $[\pm45]_{3S}$ are considered. In the first place the cyclic loads used are below the first ply failure load at different frequencies (3.1 Hz – 30.1 Hz) while carrying out simultaneously TSA and DIC. After which the specimens are subject to incremental damaging loads and then returned to the original mean load value to conduct the TSA and DIC.

Sinusoidal loading conditions allow a least-squares fit algorithm to be applied to the images sequence captured from an infrared camera and the strain data derived from DIC. For the DIC three different models can be used to convert the measured strains into the thermoelastic response : $\Delta T_{\text{Resin Rich Layer}}$, $\Delta T_{\text{Surface Ply}}$, $\Delta T_{\text{Global laminate}}$ [5, 6]. Figure 1 shows an example of the results from previous work [6], where the source of thermoelastic response was identified by comparing $\Delta T/T_0$ (where T_0 is the surface temperature) with predicted values based on the strain measurements at different loading frequencies; Figure 1 (a) is for CFRP and Figure 1 (b) is for GFRP [6].

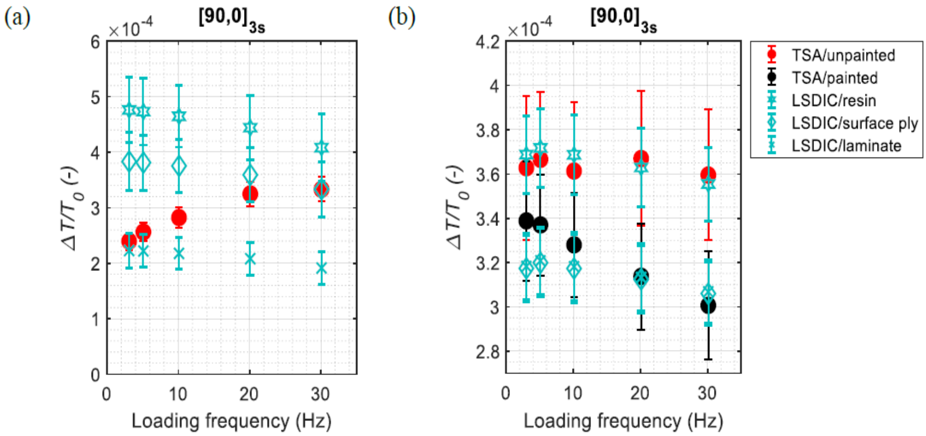

Figure 1. $[90,0]_{3S}$ Normalised $\Delta T/T_0$ vs Loading frequency of (a) CFRP and (b) GFRP [6].

Figure 1 (b) reveals that GFRP thermal response remains almost invariant with loading frequency, displaying a close fit with the resin rich layer model. The induced ply-by-ply temperature change remains constant because of the combination of coefficients of thermal expansion and material stiffness, exposing that even if the resin rich layer was removed, no heat transfer could occur and ΔT would occur adiabatically. Differently, as seen in Figure 1 (a), the CFRP thermoelastic response is homogenised at laminate level for low loading frequencies, whereas at higher frequencies the thermoelastic behaviour corresponds to the isolated orthotropic surface ply. Hence, CFRP thermoelastic response is increased with frequency revealing a heat transfer from subsurface plies to the surface one. Therefore the work in the current paper will show that CFRP coupons loaded at low frequencies can be internally analysed to detect possible damage and defects while GFRP constant thermoelastic response impedes any possibility of internal damage evaluation.

References

[1] G. Pitarresi, E.A. Patterson, The Journal of Strain Analysis for Engineering Design 38 (2005) 405-417.
[2] M. Mehdikhani, M. Aravand, B. Sabuncuoglu, M.G. Callens, S.V. Lomov, L. Gorbatikh, Composite Structures 140 (2016) 192-201.
[3] J.M. Dulieu-Barton, P. Stanley, The Journal of Strain Analysis for Engineering Design 33 (1998) 93-104.
[4] G.P. Battams, J.M. Dulieu-Barton, Composites Part A: Applied Science and Manufacturing 91 (2016) 420-435.
[5] F. de Sá Rodrigues, R. Marques, I.E. Tabrizi, A. Kefal, H.Q. Ali, M. Yildiz, A. Suleman, Optics and Lasers in Engineering 146 (2021) 106689.
[6] I. Jiménez-Fortunato, D.J. Bull, O.T. Thomsen, J.M. Dulieu-Barton, Composites Part A: Applied Science and Manufacturing 149 (2021).