Verification of mirror assisted full-field imaging for large scale structure testing

H.L. Leung[1a], J.M. Dulieu-Barton[1] and O.T. Thomsen[1]

[1]Bristol Composites Institute, School of Civil, Aerospace, and Mechanical Engineering, University of Bristol, UK

[a]emily.leung@bristol.ac.uk

Abstract

Full field imaging techniques, such as Digital Imaging Correlation (DIC) and Thermoelastic Stress Analysis (TSA), require optical access to the region of interest on a structure or component. Therefore, the size and geometry of the structures under investigation pose restrictions on the test-set up. The available space for cameras in the vicinity of the test is also a key consideration. In particular, the test rigs used for large scale structure testing can mask regions of interest and restrict fields of view. For this reason, the use of mirrors to view inaccessible regions and to extend the field of view of camaras is studied. To ensure a mirror can be used for infra-red (IR) thermography, an aluminium front coated mirror was assessed using a black body to determine potential attenuation effects. Likewise, the use of mirrors to capture images for DIC was investigated by verifying predefined displacement and strain fields viewed using mirrors. The techniques were then used to study the face sheet of a sandwich structure beam loaded in three-point bending (3PB).

Introduction

Sandwich structures have been commonly used in a wide range of applications including aerospace, transportation and green energy (wind turbine blades) because of their high bending stiffness and strength to weight ratio. Damage such as face sheet wrinkling, core crushing, local indentation and face/core debonding can reduce the stiffness and strength of the structure, and can lead to catastrophic failure without prewarning. Recent studies[1–3] have shown that the combined use of FE analysis and full-field imaging techniques, including DIC and TSA, can be used to identify the crack tip response at the face sheet/core interface and the subsequent damage progression. However, most studies have focused on beams which have enabled the internal features to be observed by viewing the transverse (through-the-thickness) plane of the sandwich structure. This means that the methodologies developed are not applicable to investigate in service structures, where the transverse (through-the-thickness) plane cannot be observed without disassembling or cutting the structure. Hence, to gain an understanding of actual sandwich structure performance, techniques are required that can monitor the damage initiation and progression from the exterior of the face sheet. Ultimately this will mean application to a plate-like structure to observe behavior at a structural scale. Large or complex geometry structures can limit the use of full-field imaging techniques because of limited space for any imaging equipment. Hence, it is the aim to develop a mirror-assisted imaging methodology that enables observation of the face sheets and characterization of the fracture behavior through the face sheets (instead of the through-the-thickness plane) for sandwich structures.

Methodology

The initial steps in the project entail assessing the accuracy and precision of the temperature field, out-of-plane displacement and strain field results using an aluminum (Al) front coated mirror (ME8S-G01 from THORLABS). A temperature controlled black body (IR-2106 from Infrared Systems Development Corporation) was used to generate a temperature target. A Telops FAST M3k infra-red camera was set-up so that in the first set of the tests the camera viewed the black body through the mirror and in the 2nd set of tests the camera viewed the black body directly as shown in Fig. 1. The temperature of the black body was adjusted and once stable the measurements were taken again.

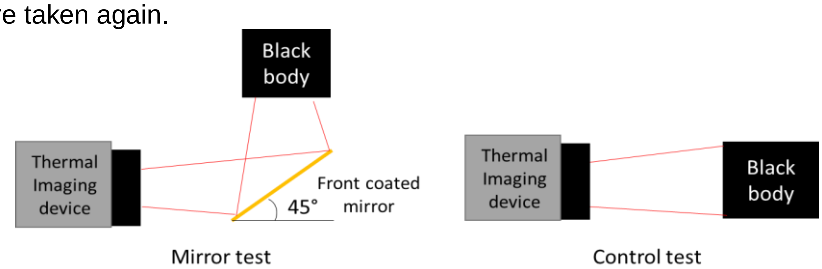

Fig. 1: Schematic of mirror testing using thermal imaging device

Table 1 shows the temperature difference between data collected using a mirror and without a mirror (control) is larger than the standard deviation and that the mirror affects the standard deviation. The standard deviation was calculated using data from each individual pixel in the field of view. The increase in standard deviation could be caused by the variation in reflectivity across a range of wavelengths[4], the surface roughness of the mirror [4] and the alignment of the mirror during testing. While the Al mirror is not 100% reflective, the difference between the mirror and control measurements was found to be in the region of only 0.1%-0.2% error. So it may be concluded that a temperature correction is not required for the small attenuation, however this maybe important in TSA as the temperature changes caused by the thermoelastic effect are small.

Test Group	Control Test [K]	Mirror Test [K]
1	302.50 ± 0.09	302.31 ± 0.12
	302.51 ± 0.09	302.30 ± 0.12
2	331.22 ± 0.20	330.48 ± 0.38
	331.19 ± 0.20	330.49 ± 0.38

Table 1: Thermal data collected using a mirror and without a mirror (Control)

For the use of DIC, both displacement and strain fields imaged using the mirror are studied. To verify the displacement field measurement, a specimen was displaced using the cross head of a universal testing machine, while stereo DIC images were captured using two cameras (100mm lenses and resolution of 12MP) and the front coated mirror, which was placed at 45° underneath the specimen. The displacement recorded using the mirror is plotted against the cross head displacement in Fig. 2. The DIC displacement was calculated by averaging the field of view. The slope of the plot is 0.98, this 2% error can be caused by experimental error such as inaccuracy of the testing machine during testing.

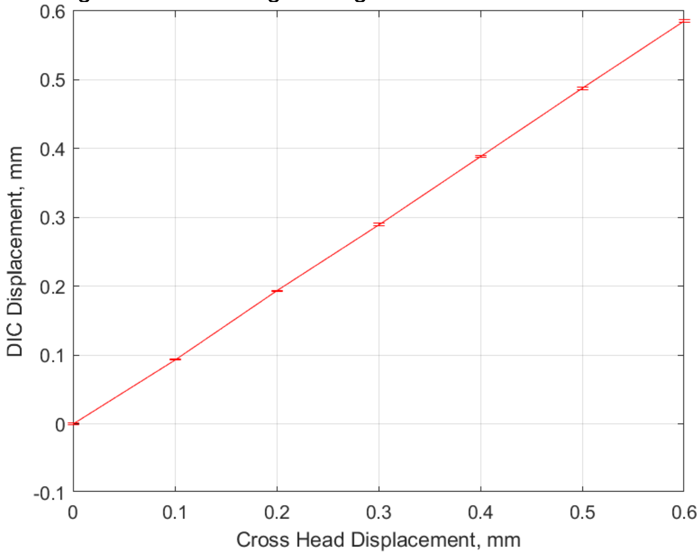

Fig. 2: Displacement data collected based on DIC and cross head measurement

Conclusions and Future work

- There is attenuation in the temperature recorded using the front coated Al mirror. A correction factor may be required to account for this effect in TSA.
- 2% error was found in the displacement results recorded using the mirror, which could be the result of experimental error from the testing machine and warrants further investigation.
- To verify the strain fields, a sandwich structure beam was tested in 3PB, with the front coated mirror placed at 45°underneath the specimen, to image the bottom face sheet. The DIC strain field will be compared with the Finite Element (FE) results.
- Investigate the damage initiation and progression of sandwich structure from the exterior of the face sheet using mirror-assisted imaging methodology with FE studies is the next focus of this work.

References

1. Wang, W., Martakos, G., Dulieu-Barton, J. M., Andreasen, J. H. & Thomsen, O. T. Fracture behaviour at tri-material junctions of crack stoppers in sandwich structures. Composite Structures 133, 818–833 (2015).
2. Martakos, G., Andreasen, J. H., Berggreen, C. & Thomsen, O. T. Interfacial crack arrest in sandwich beams subjected to fatigue loading using a novel crack arresting device – Numerical modelling. Journal of Sandwich Structures and Materials 21, 422–438 (2019).
3. Martakos, G., Andreasen, J. H., Berggreen, C. & Thomsen, O. T. Experimental investigation of interfacial crack arrest in sandwich beams subjected to fatigue loading using a novel crack arresting device. Journal of Sandwich Structures and Materials 21, 401–421 (2019).
4. THORLABS Protected Aluminum Mirrors datasheets. https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=264.