Motion compensation for complex deformations in thermoelastic stress analysis

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Abstract. A motion compensation approach for thermoelastic stress analysis (TSA) using digital image correlation (DIC) is presented. The novelty is using high spatial resolution displacement fields obtained from white light DIC to correct for complex motion that affects the TSA. The use of black and white paints with similar emissivity in the infrared (IR) spectrum enable the TSA to be conducted without the requirement to remove the speckles, thereby enabling fatigue tests to be conducted in which the displacement field changes as damage progresses. Results are shown for a face sheet / core debond in a sandwich specimen.

Introduction

Thermoelastic stress analysis (TSA) is based on infra-red (IR) imaging, where image data between subsequent images are processed on a pixel by pixel basis, so the motion of the object under observation results in spurious readings. The thermoelastic response is provoked by a deformation, and hence the specimen moves relative to the stationary infrared (IR) detector, hence Digital image correlation (DIC) provides a suitable means to track the displacement and correct for it in the infra-red image.

The motivation for this work is to use TSA to assess the stress field associated with the growth of a face sheet / core debond in a composite foam cored sandwich structure. TSA was employed because it can provide stress information with very high spatial resolution. A double cantilever beam (DCB) test [1] was used and it was found that existing motion compensation approaches [2,3] were not effective as they had insufficient spatial resolution to capture the discontinuous motion field. The solution presented herein employs DIC to obtain the displacements and subsequently apply this to correct the IR images. TSA and DIC are applied using the same surface preparation; the white speckle is visible only in the white light images, having the same emissivity as the matt black paint in the IR spectrum. Hence the maximum resolutions of both DIC and TSA are exploited.

Experimental arrangements

DCB specimens (200 mm length, 32 mm width) were cut from a resin infused sandwich panel with a 25 mm thick PVC foam core (DIAB H100) and 1.6 mm thick woven E-glass/epoxy composite face sheets, as shown in Fig. 1. A 50 mm long initial debond was introduced using a 25 µm Teflon film; from here an interfacial crack was grown. The load was applied via adhesively bonded hinges using an Instron E1000 test machine operated in position control mode. IR and white light images were then collected for a static crack – cyclic displacement with an amplitude of 1 mm (approximately 30 N) and a frequency of 3 Hz was used for the TSA, two static loads (min and max of the TSA cycle) where used for the DIC data.

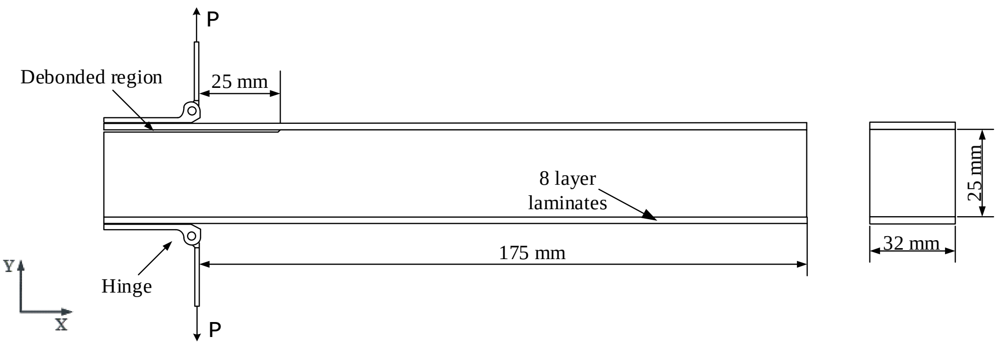

Fig. 1: DCB test specimen geometry and load introduction.

The specimen was coated in RS matt black paint to provide a uniform emissivity background. The speckle was generated using Ambersil matt white, which has an emissivity in the 3 – 5 µm spectrum that was indistinguishable from the matt black background in the IR images. Hence the surface preparation did not need to be altered between collecting the white light and IR images. The IR imaging system used in this work is a Cedip Silver 480M with a 320 × 256 pixel InSb detector, recording both IR images and a reference signal from the test machine load cell at 383 Hz. For the white light imaging a LA Vision VC-Imager E-lite digital camera with a 5 mega-pixel sensor array was used. The displacements were calculated using a 32 x 32 pixel subset size. The first step was overlay the displacement field onto the first IR image obtained at zero displacement, using a bilinear interpolation of the displacement field. The coordinate setup for this is shown in Fig. 2 a). However, the displacement vector associated with each IR image pixel is the displacement at the maximum load. Since IR images are sampled throughout the loading cycle, the reference signal recorded with each IR image was used to scale the displacement vector according to the location in the load cycle where the IR image was collected, as shown schematically in Fig. 2 b).

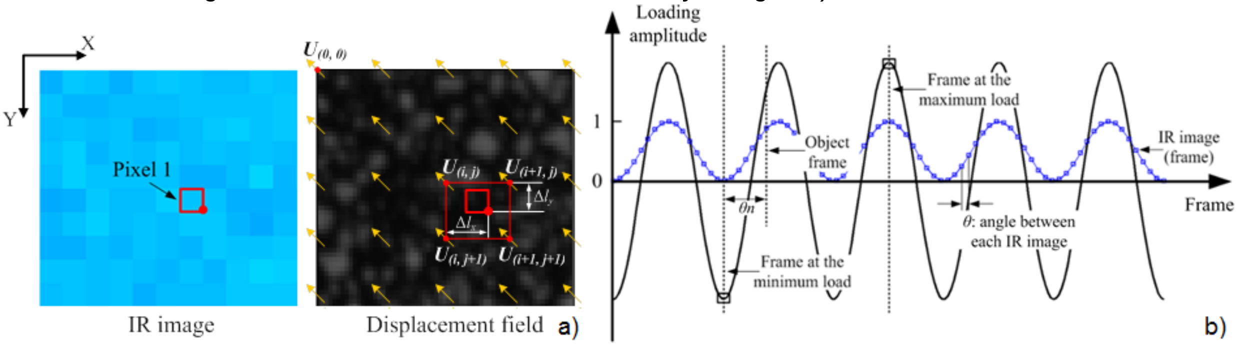

Fig. 2: a) IR and white light images showing the coordinate system for interpolating the displacements onto the IR images, b) a schematic of the reference signal sampling to calculate the motion for each IR image.

Results

The motion field at the interfacial crack contains a strong gradient across the field of view and a discontinuity between the face sheet and the core where the two have separated, as shown in Fig. 3 a). Using the linear interpolation described above, the motion correction for IR image pixels lying close to the interface will incorrect due to averaging across the discontinuity. To deal with this, the image was divided into two rectangular regions: one for the face sheet and one for the core. IR image pixels positioned at the edge of the face sheet region were assigned a motion based on the nearest displacement values obtained entirely within the face sheet region, and similarly for the core region. A comparison between the TSA obtained without and with motion correction is shown in Fig. 3 b) and c). In Fig. 3 b) several indicators of motion induced spurious results can be seen, the double crack line, the double appearance of the position markers. By comparison, the motion corrected data in Fig. 3 c) show clearly the stress gradient in the face sheet, the stress concentration at the crack tip and the effect of the cell structure on the thermoelastic response in the foam core.

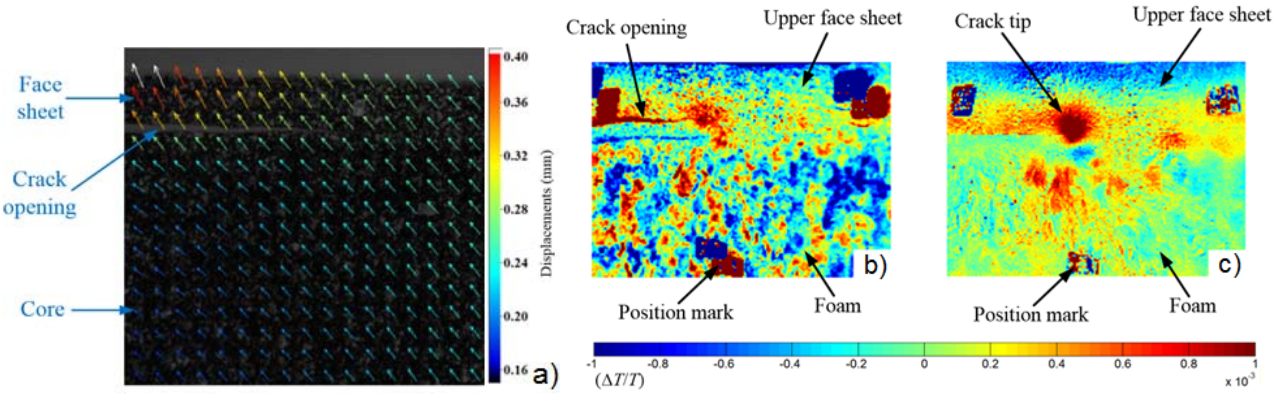

Fig. 3: a) displacement field at maximum load, b) TSA data without and, c) with motion compensation.

Conclusion

The motion compensation approach using paints with strong contrast in the white light spectrum, but minimal contrast in the IR spectrum offers the opportunity to conduct high spatial resolution motion compensation of IR video data. Since the speckled paint does not need to be removed for obtaining IR data, the approach lends itself well to tests in which the displacement field changes with time, as defects are propagated incrementally. The example of the interfacial crack in a DCB specimen highlights the importance of motion compensation to enable TSA to be conducted at high magnifications. It also demonstrates how effective the approach corrects the effects of discontinuous and varying motion fields.

References

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