March 19-22, 2018
PhotoMechanics 2018, Toulouse, Fr **PM2018**

Locating cracks in bolted double-lap joints using thermoelastic stress analysis

C. A. Middleton[1*], A. Gaio[1†], R. J. Greene[2], and E. A Patterson[1]

[1]School of Engineering, University of Liverpool, The Quadrangle, Brownlow Hill, Liverpool, L69 3GH, U.K., *ceri.middleton@liverpool.ac.uk

[2]Strain Solutions Ltd, Dunston Innovation Centre, Dunston Road, Chesterfield, Derbyshire S41 8NG, U.K.

†Now at: Additive Manufacturing Technologies Ltd, Alison Business Centre, 39/40 Alison Crescent, Sheffield, S2 1AS, U.K.

Abstract — Crack growth has been monitored in simple coupons and bolted joints using thermoelastic stress analysis (TSA). Cracks are evident in TSA data before becoming apparent in visible light observations. The observation of initiation and propagation of cracks has been automated to map the crack tip position at given times.

Key Words — thermoelastic stress analysis, crack-tip tracking, fatigue, bolted joints

Introduction

Thermoelastic stress analysis (TSA) is a non-destructive method of monitoring stress fields in materials. A surface stress map for a material under a transient load is constructed from changes in the surface temperature measured using an infrared detector [1]. Where cracks are present, their position can be determined based on these mapped stress fields [2]. Knowledge of the initiation and propagation of cracks is important in a range of industrial settings, where current methods of detection include visual inspection, magnetic particle testing and ultrasound [3,4], which often require surface preparation and are labour intensive [3]. As TSA has been shown to be very sensitive to the early initiation of microcracks [5] and only requires minimal surface preparation, it is an effective alternative to these methods.

Method

Specimens of two different geometries have been loaded to generate fatigue cracks. Simple coupon specimens with one central circular hole were cyclically loaded at 5.28 ± 4.32 kN, at a frequency of 19 Hz. Thermoelastic stress analysis (TSA) data were collected with a Deltatherm 1780 system (*Stress Photonics, Madison, WI*). The output data from the Deltatherm system were processed using an automated algorithm which compares the normalised TSA signal magnitude data at given time intervals. Differences between the TSA maps highlighted by this algorithm are indicative of the position of the crack tip. To explore the application of this methodology to complex geometries that are more representative of likely industrial environments, bolted double-lap joints were loaded at 16.577 ± 13.563 kN at 13 Hz, to generate fatigue cracks, whilst TSA data were collected in the same manner as for the simple specimens.

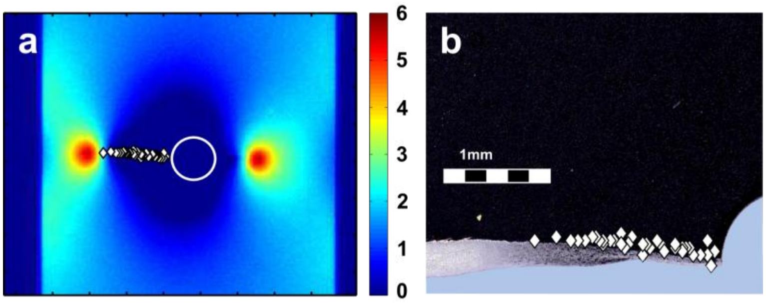

Figure 1: a) Crack tip position over time overlain on final normalised TSA signal magnitude data; b) Comparison of mapped crack tip positions with final crack geometry.

Results and discussion

Results of automated crack-tip tracking in a simple specimen are shown in Fig 1. In Fig 1a, it can be seen that there are two areas of high signal magnitude which indicate the position of crack tips; here we track the crack on the left. The mapped crack tip positions are compared to the morphology of the fracture surface in Fig 1b, showing that crack initiation was indicated at a sub-mm length, and the positions found with the automated algorithm are within ± 1 mm of the final crack geometry.

The result of a comparison of the TSA and visible light observations of a bolted specimen during fatigue cracking are shown in Fig 2. At 10,000 and 60,000 cycles, an area of high TSA signal magnitude is observed underneath the lowest bolt, but there is no evidence that a crack has yet developed. At 70,120 cycles, the shape of the concentration of signal magnitude has changed, indicating the initiation of a crack underneath the bolt-head. This crack only becomes apparent in the visible light images at 70,770 cycles.

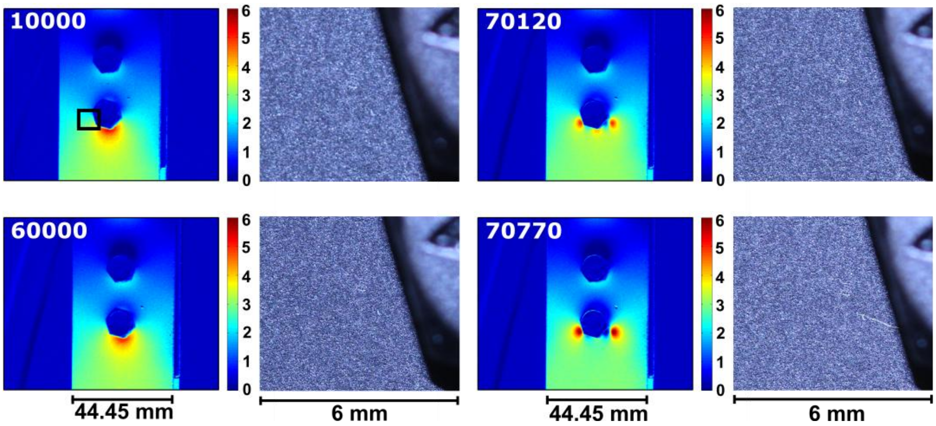

Figure 2: Normalised TSA signal magnitude data (left); and visible light image (right) at given cycle numbers during loading of a complex specimen. Box in the 10,000 cycle image indicates position of visible light image.

Conclusion

The optical algorithm has been shown to locate crack initiation at sub-mm lengths, and to track cracks as they propagate. TSA has also been shown to locate the initiation of cracks in specimens of complex geometry before those cracks are apparent in a visual inspection. These results show that TSA is a useful method for crack location in industrial environments, which also demonstrates the potential for real time analysis of crack initiation and tracking.

Acknowledgements

The INSTRUCTIVE project is funded by the EU Framework Programme for Research and Innovation Horizon 2020, Clean Sky 2, project number 686777. Helpful assistance was provided by the project topic managers, Niels Strohmaier (Airbus Operations GmbH) and Eszter Szigeti (Airbus Operations Ltd).

References

[1] R.J. Greene, E.A. Patterson, and R.E. Rowlands. Thermoelastic stress analysis *in: W. N. Sharpe, (Ed.) Springer Handbook of Experimental Solid Mechanics* p743-767, 2008.
[2] F.A. Diaz, E.A., Patterson, R.A. Tomlinson and J.R. Yates. Measuring stress intensity factors during fatigue crack growth using thermoelasticity. *Fatigue Fract. Engng Mater. Struct.* 27:571-583, 2004.
[3] T. Sakagami, Remote non-destructive evaluation technique using infrared thermography for fatigue cracks in steel bridges Fatigue *Fract. Engng Mater. Struct.* 38:755-779, 2015
[4] R.C. Tighe, G.P. Howell, J.P. Tyler, S. Lormor and J.M. Dulieu-Barton. Stress based non-destructive evaluation using thermographic approaches: From laboratory trials to on-site assessment *NDT&E International* 84:76-88, 2016.
[5] D. Backman, C. Cowal, and E.A. Patterson, Analysis of the effects of cold expansion of holes using thermoelasticity and image correlation. *Fatigue Fract. Engng Mater. Struct.* 33:859-870, 2010.