Automated crack tip tracking in stainless steel specimens using thermoelastic stress analysis

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Abstract. Thermoelastic stress analysis (TSA) has been used to monitor the stress field in stainless steel compact tension specimens during cyclic loading. Data output from experiments was post-processed to locate and track the position of crack tips using an automated algorithm.

Introduction

A knowledge of the position and movement of fatigue cracks in infrastructure is important as these cracks can be monitored and remedial measures undertaken. Monitoring of cracks in industrial contexts must be carried out through non-destructive methods, and often in environments which are difficult to access [1].

Methods which have been used previously include visual inspection, magnetic particle testing and ultrasound [1,2]. These methods are often time consuming, labour intensive and frequently require complicated surface preparation (e.g. paint removal for visual inspection, speckle for digital image correlation (DIC), or a fringe pattern for moiré [3,4].

Thermoelastic stress analysis (TSA) is a powerful alternative to these methods, which only requires minimal surface preparation. Surface stresses of a cyclically loaded material are mapped by measuring temperature changes using an infrared (IR) detector [5]. TSA is also sensitive to the initiation of cracks which are not visible using other inspection methods. For example, microcracks have been located using TSA which were only observed visually by inspection of thin section *ex situ* [6].

TSA has been used in the laboratory to determine the stresses around crack tips [7], and the extent of the plastic zone in front of an advancing crack tip [8]. In addition, field tests of TSA and other thermographic methods have shown its application to locating stress concentrations and cracks in industrial settings [1,2].

Method

Compact tension (CT) specimens of stainless steel were manufactured based on ASTM E647, with a width of 20 mm and thickness 0.7 mm. One side of a specimen was spray-painted with a fine layer of matt black paint, providing a surface of uniformly high emissivity, which improves the observed thermal response and allows quantitative stress analysis [5].

Specimens were loaded in an Electropuls E3000 testing rig (Instron, Buckinghamshire, UK). An initial pre-loading of 300 N ± 100 N at 20 Hz was carried out for 82,000 cycles, then the load was increased to 600 N ± 200 N at 20 Hz. During cyclic loading, thermal data were collected with a Deltatherm 1780 system (Stress Photonics, Madison, WI) at intervals of 1,000 cycles.

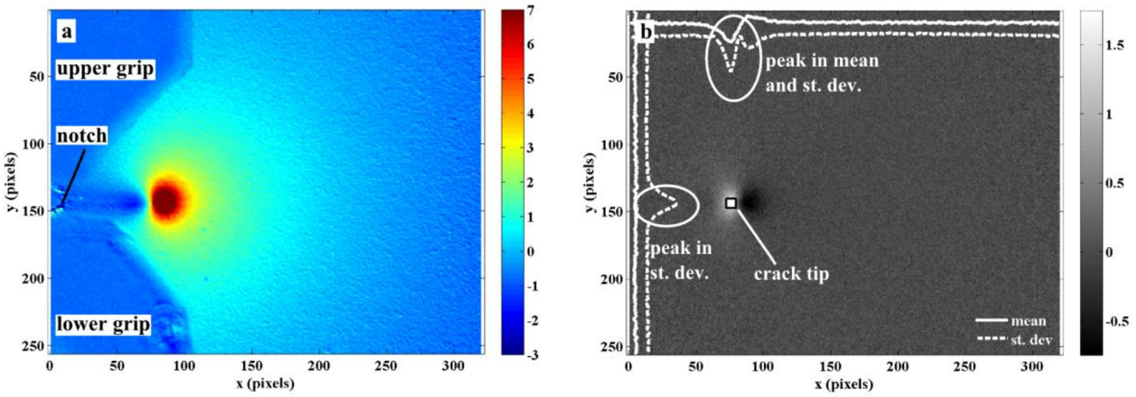

Fig. 1. a) Results of post-processing on one TSA image: a) Normalised magnitude b) Difference image comparing normalised image with that of previous time step, showing crack tip position found by the algorithm and the mean and standard deviation of each row and column of pixels.

An algorithm was used to process the data by normalising the initial signal magnitude for each pixel in the image, with reference to the mean and standard deviation of the whole image. An optical flow method was then used to determine the position of the crack tip. Two subsequent images, separated by a known gap in time (equivalently the number of loading cycles), were compared to determine significant differences, which revealed the crack tip position.

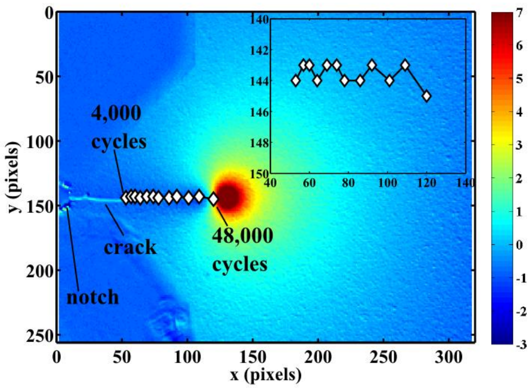

Fig. 2. Position of crack tip at 4,000 to 48,000 cycles, intervals of 4,000 cycles. Normalised magnitude data shown at 48,000 cycles to indicate specimen geometry. Inset shows detail of tip position, where horizontal movement is more evident.

Results and discussion

During loading, a crack developed from the notch in the specimen. Fig. 1 shows the normalised magnitude data at an instant in time and the difference image after post-processing with the algorithm.

The normalised magnitude data (Fig. 1a) show a quasi-elliptical area of high magnitude, indicating the plastic zone in front of the advancing crack. The crack tip position becomes apparent in the difference image (Fig. 1b) where areas of high difference are found. The values of standard deviation from the mean in both the x and the y direction show peaks, indicating the pixel position where the image differs the most from the previous timestep; i.e., the crack tip.

The position of the crack tip can be plotted for individual images, as in Fig. 2, where the progression of the crack tip is shown from 4,000 to 48,000 loading cycles (cycle number reported is that at the higher load: 600 N ± 200 N). The crack tip progresses from left to right in the image, the speed of progression increasing with a higher number of cycles.

Conclusions

This proof of concept test has shown that post-processing of TSA data can be automated to locate the position of a crack tip from data collected during cyclic loading in the laboratory. The position can be tracked over time, allowing the rate of progression of the crack to be calculated.

Currently, this processing is a useful technique which has been applied in laboratory environments in simple specimens. However, it also has the potential to be applied in a variety of industrial environments, where it would aid in early detection and tracking of developing fatigue cracks.

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