Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 188 (2017) 463 – 470

Procedia Engineering

www.elsevier.com/locate/procedia

6th Asia Pacific Workshop on Structural Health Monitoring, 6th APWSHM

Automated Crack Detection and Crack Growth Rate Measurement Using Thermoelasticity

Nik Rajic[a]* and Chris Brooks[a]

[a]*Defence Science and Technology Group, 506 Lorimer Street, Fishermans Bend, Victoria 3207, Australia*

Abstract

A new capability for automated crack detection and crack growth rate monitoring is described and experimentally validated. The capability is based on a low-cost industrial grade microbolometer mounted to an x-y linear slider assembly driven by a guidance algorithm that uses the thermoelastic quadrature signal to locate the crack tip. The approach furnishes a high density record of the crack path, as well as thermoelastic response imagery in the vicinity of the crack tip which can be used to determine stress intensity factors. The performance of the system is compared to that of travelling microscopy and shown to be similar at crack growth rates above 10^{-7} m/cycle, but inferior at lower rates due to increased scatter in the location estimates. This scatter is attributed in part to the limited spatial resolution of the system in its present configuration.

Peer-review under responsibility of the organizing committee of the 6th APWSHM

Keywords: thermoelastic stress analysis; fatigue; crack detection; crack growth monitoring; crack growth rate measurement; infrared

* Corresponding author. Tel.: +61 3 9626 7193; fax: +61 3 9626 7089.
E-mail address: nik.rajic@dsto.defence.gov.au

Peer-review under responsibility of the organizing committee of the 6th APWSHM
doi:10.1016/j.proeng.2017.04.509

1. Introduction

Current fatigue certification practice for safety critical load-bearing components relies on detailed knowledge of material crack growth behaviour. Such knowledge is normally obtained empirically from exhaustive laboratory testing carried out on standardised coupons under controlled conditions. Relatively large sample sizes are typically required because of the variability in growth rate between samples, which can be up to a factor of 5 in certain situations [1]. This sample-size requirement contributes to the generally high cost of material fatigue testing.

Automation of crack length measurement can reduce the cost burden of fatigue testing. Methods based on elastic compliance [2] and electrical potential drop (EPD) [3] are the mainstays for such automation however they have several disadvantages compared to visual inspection which is generally considered to be the benchmark method for crack growth monitoring. Firstly, they infer rather than directly measure crack length; from a displacement in the compliance method and a potential drop in the EPD method. For both methods, crack length estimates are obtained from a functional relationship derived empirically or from theory. Even when such relationships are carefully derived, errors can still arise from inconsistencies between the actual test and calibration conditions and in-lot variation between specimens and probe/sensor placement. Another disadvantage is the inability of these methods to identify irregular crack growth, such as angled cracking which if severe enough can invalidate a test result. The relevant standard [4] stipulates that where irregular growth is possible a visual inspection must be used.

In the present paper an automated visual crack growth tracking capability based on thermoelasticity is described and experimentally validated. Crack length measurements are derived from the thermoelastic response of the crack tip stress singularity imaged using a low-cost thermal detector robotically controlled using a high precision x-y translational stage under feedback control. The advantages of such an approach over established automation methods derive chiefly from its direct determination of the crack tip coordinates. As is the case for visual inspection, this enables testing of a wider range of specimen geometries and can cater for non-symmetric crack growth.

The proposed approach also offers advantages over visual inspection. Polishing of a specimen is normally required to achieve optimal results with visual inspection, adding to specimen preparation time and overall cost. Thermoelastic inspections observe emissions of infrared radiation from the surface rather than reflected light so polishing is unnecessary and indeed counterproductive. Instead of high reflectivity the surface needs high infrared emissivity which can be easily and quickly achieved with a thin coating of an appropriate matt paint. This difference in surface preparation could confer advantages beyond just speed and convenience. For instance, where surface modification has been applied to enhance fatigue resistance (e.g. bead peening), any further alteration of the surface may influence fatigue behaviour. Crack growth monitoring of corroded samples is another example. The greatest advantage of the proposed approach over visual inspection however is the ease with which it can be automated.

2. Crack Detection Using Thermoelasticity

The use of thermoelastic stress analysis in fatigue and fracture mechanics is well established. A relationship between stress intensity factor (SIF) and bulk stress, the mechanical driving force for the thermoelastic effect, was first reported in the 1980's [5]

$$\sigma_b = \sigma_1 + \sigma_2 = \frac{2K_I}{\sqrt{2\pi r}}\cos\left(\frac{\theta}{2}\right) - \frac{2K_{II}}{\sqrt{2\pi r}}\sin\left(\frac{\theta}{2}\right) \tag{1}$$

Here, K_I and K_{II} are the mode I and II stress intensity factors (SIF) respectively, and r and θ are polar coordinates centred at the crack tip. For a solid deformed under adiabatic conditions a variation in bulk stress $\delta\sigma_b$ leads to an approximately linear variation in temperature given by,

$$\delta T = -\frac{\alpha}{\rho C_p} T \delta\sigma_b \tag{2}$$