Measurements of fatigue crack growth rate using mini-samples and Digital Image Correlation inverse method

Tomasz Brynk*, Zbigniew Pakiela and Krzysztof J. Kurzydlowski

Faculty of Materials Science and Engineering, Warsaw University of Technology
Wołoska 141, 00-507 Warsaw, Poland
**e-mail: tbrynk@inmat.pw.edu.pl*

Abstract

Crack growth rate tests provide important information on the properties of materials which are designed for cyclic loading applications. When using standardized samples such tests are performed using dynamical testing stands, electromechanical extensometers and appropriate compliance functions to determine the crack length and stress intensity factor from so called Paris plots. In the case of small sample, often the only available for new materials, e.g. materials after Severe Plastic Deformation (SPD), standard electromechanical extensometers are hardly applicable. In this situation accurate measurements of crack length can be performed by optical noncontact Digital Image Correlation method. This method is used to determine displacement fields near the tip of a propagating crack. Combined with the inverse analysis the difference between the model and true measurements can be maintained lower than the specified error. The proposed technique was applied for testing as delivered samples of Al 5483 and Al 7475 after hydro-extrusion (HE), which results in a grain refinement to sub-micron values. Three values of cycle asymmetry coefficient (R) were applied: 0.1, 0.3 and 0.5. The proposed algorithm for optical measurements provided a reliable estimate of stress intensity factor and crack length.

Keywords: fatigue crack growth rate, digital image correlation, inverse method

1. Introduction

The aim of the paper is to present application of Digital Image Correlation (DIC) [1-3] and inverse method for accurate measurements of stress intensity factor and crack tip position during crack growth rate tests with use of small-size samples. The experiments were carried out for aluminium 5483 and 7475 alloys subjected to sinusoidal loading conditions with cycle asymmetry coefficients R (the ratio between minimal and maximal load in the cycle) equal to 0.1, 0.3 and 0.5 and 20 Hz frequency.

The tests were performed using horizontal dynamic stand and appropriate gripping. A CCD camera, placed above the sample, allowed for in-situ observation of its surface. To assure high quality digital images for DIC measurements, the tests were interrupted at the moment of image acquisition.

2. Digital Image Correlation

Digital Image Correlation [1-3] is an optical non contact method for measurements of the displacements and strains on a surface of flat samples using artificial or natural speckle patterns. Computer algorithms are used to compare images of the surface taken before and after deformations. The interpolation functions offered by commercially available software Vic2d [4] allowed accuracy up to 0.01 pixel.

3. Algorithm

The iterative algorithm based on Newton-Raphson method was applied for finding the best fit coefficients for the following functions describing the displacements fields:

$$u_y = \sum_{n=1}^{\infty} \frac{K_{In}}{2G\sqrt{2\pi}} r^{n/2}\left(\kappa \sin\frac{n}{2}\theta - \frac{n}{2}\sin(\frac{n}{2}-2)\theta - (\frac{n}{2}+(-1)^n)\sin\frac{n}{2}\theta\right) - \sum_{n=1}^{\infty} \frac{K_{IIn}}{2G\sqrt{2\pi}} r^{n/2}\left(-\kappa \cos\frac{n}{2}\theta - \frac{n}{2}\cos(\frac{n}{2}-2)\theta + (\frac{n}{2}-(-1)^n)\cos\frac{n}{2}\theta\right) \quad (1)$$

$$u_x = \sum_{n=1}^{\infty} \frac{K_{In}}{2G\sqrt{2\pi}} r^{n/2}\left(\kappa \cos\frac{n}{2}\theta - \frac{n}{2}\cos(\frac{n}{2}-2)\theta + (\frac{n}{2}+(-1)^n)\cos\frac{n}{2}\theta\right) - \sum_{n=1}^{\infty} \frac{K_{IIn}}{2G\sqrt{2\pi}} r^{n/2}\left(\kappa \sin\frac{n}{2}\theta - \frac{n}{2}\sin(\frac{n}{2}-2)\theta + (\frac{n}{2}-(-1)^n)\sin\frac{n}{2}\theta\right) \quad (2)$$

where: $\kappa = \frac{3-\nu}{1+\nu}$ for plane stress, or $\kappa = 3-4\nu$ for plane strain, ν is Poisson's ratio, K_I and K_{II} are stress intensity factors, n is an order of calculations and G is a bulk modulus.

The position of the crack tip (x_0, y_0) was treated as the unknown parameter. Because of the rigid body movement (T_x and T_y) and rotation (T_r), additional 3 parameters were used for displacement field equations. Thus the algorithm was used to determine 7 independent parameters (K_I, K_{II}, x_0, y_0, T_x, T_y, and T_r) via fitting process.

Algorithm also required parameters defining the position of the fitting area in the area of DIC measurements. Application of this parameters allowed to maintain the same size of the fitting area during crack growth. Also the crack tip was always placed in the same position to the boundaries of the fitting area (see Figures 1-2).

4. Results and conclusions

The output data from the fitting algorithm gave values of stress intensity factors and crack position for analyzed digital images. These data allowed for preparing so called Paris plots showing the dependence of crack growth rate on the applied stress intensity factor.

The example of DIC measurements and the fitting process for Al 5483 sample loaded with R=0.1 is presented in Figures 1-2. White areas show total area of DIC measurements and colour maps show displacement fields, in the boundaries related to the position of the crack tip, obtained from the measurements and by modelling.

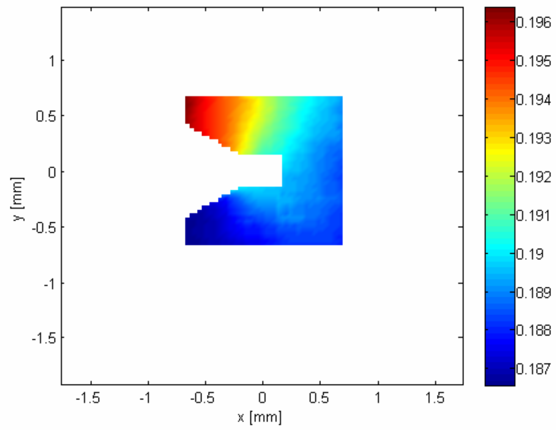

Figure 1: Exemplary results of DIC displacement measurements in vertical direction.

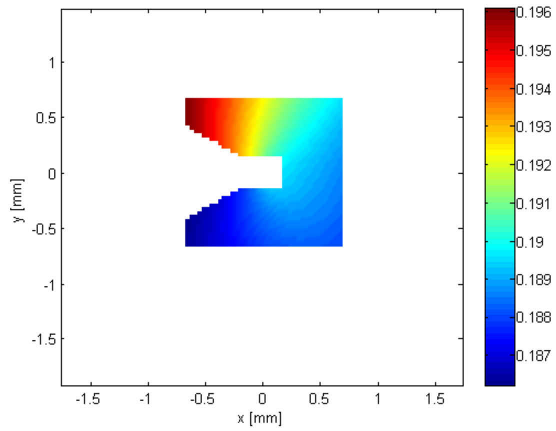

Figure 2: Exemplary results of fitting process for displacements in vertical direction.

The exemplary Paris plots for Al 5483 samples in as delivered state tested with different R are presented in Figure 3.

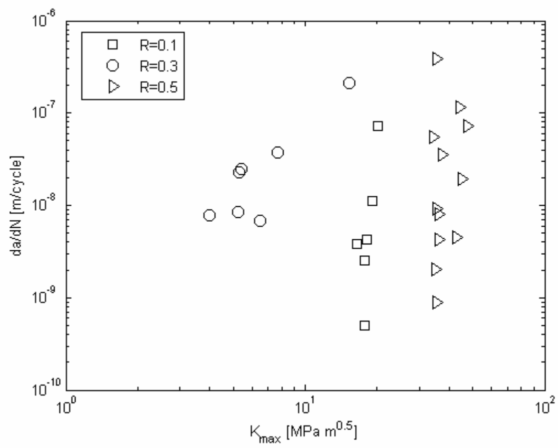

Figure 3: Paris plots for Al 5583 samples tested with different R

The main advantage of presented method, besides non contact measurements, is the automatization of crack length and stress intensity factor determination. Automatization of measurements make test faster and independent on an operator skills in comparison with manual crack tip tracking.

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