LOCAL ANALYSIS OF FRETTING DAMAGE BY MEANS OF FULL FIELD MEASUREMENT

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Abstract

The improvements in camera technology and image processing have caused full field measurement techniques to become more and more frequently used in the field of experimental mechanics. Nevertheless, few applications can be found in the field of contact mechanics. Therefore, the aim of this work is to present, a novel experimental set-up based on coupled kinematic-thermal measurements to assess fretting damage. A well known 35Ni Cr Mo 16 low-alloyed steel was studied under various plain fretting partial slip conditions. Analysis of the thermal signal have shown the possibility of decoupling thermal effects related to intrinsic dissipation, thermoelastic sources and dissipation due to friction.

Key words: Coupled kinematic-thermal measurement, Quantitative InfraRed Thermography (QIRT), Digital Image Correlation (DIC), fretting, thermoelastic sources, energy dissipation.

1 Introduction

Fretting, a localized oscillatory movement that occurs when two contacting surfaces are subjected to vibrations or cyclic stresses. Fretting damage has been recognized as a problem in several industrial applications (e.g., aircraft, trains, ships...[1]). The mechanisms of this damage highly depend on the sliding conditions. Figure 1 shows an overall approach of those sliding conditions [2]. The Qa-δa diagram can be divided into two regimes, each activate a different material response. Under partial slip conditions, the main damage is crack nucleation. While in case of gross slip conditions, the main damage is wear.

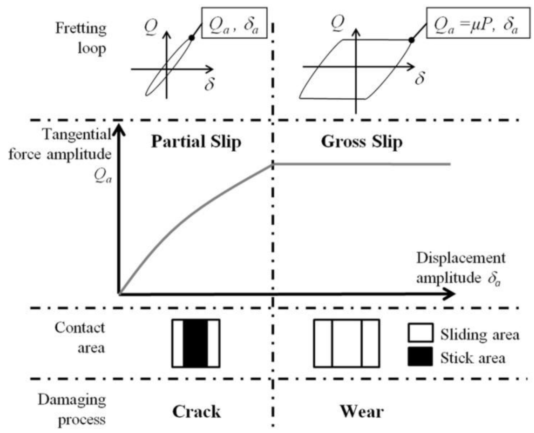

Figure 1- Basic sketch of plain fretting sliding conditions.

Considerable progress has been made in the understanding of the fretting damage under partial slip conditions and several methods have been developed to predict crack initiations [3]–[7]. Nevertheless, few studies treat problems related to the thermomechanical characterization of the damage induced by the contact. The first-order phenomena such as stress gradients and high hydrostatic pressures are also poorly reflected in the current models. Therefore, the aim of this study is to develop a new experimental approach based on coupled kinematic-thermal measurements in order to provide a better understanding of the damage caused by fretting loadings.

2 Material and experiments

A fretting test consists in applying a static normal force P, followed by a cyclic displacement δ, generating a cyclic tangential load Q on the contact zone [6] (fig. 2). P, Q and δ are recorded during the tests and the δ – Q fretting loop is plotted and monitored to maintain a partial slip contact configuration.

The present work was performed on a 35 Ni Cr Mo 16 low-alloyed steel, in a cylinder on flat contact configuration assuring a 2D contact configuration. Cylindrical pads are made from a heat treated steel alloy 100 C6 with a controlled roughness (Ra = 0.4 µm), ensuring that fatigue damage arise only in plane specimens and not the cylindrical ones.

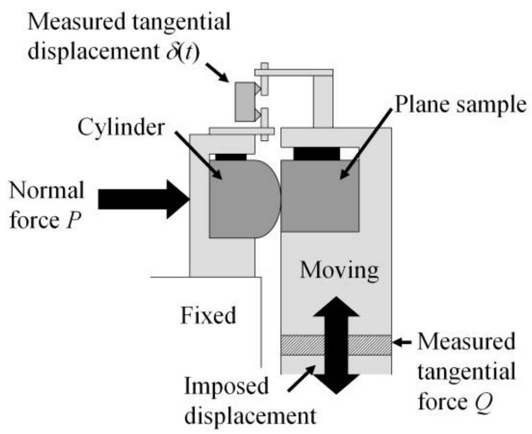

Figure 2- Basic sketch of a plain fretting test.

3 Coupled kinematic-thermal measurement

Figure 3 shows the experimental set-up of the two-face measurement used in this work. The main advantage of this set-up is the flexibility to choose the surface coating of each technique separately. And since the two metrologies are performed on two separate surfaces, this will also provide good measurement precision. Temporal matching of the two cameras was performed using a micro-controller (Arduino MEGA ADK), taking into account the physical delay of each camera. While spatial matching was done using a reference target and a transformation function τ defined as follows:

$$(\tau)\begin{cases} x_{IR} = a_x x_{CCD} + b_x y_{CCD} + c_x \\ y_{IR} = a_y x_{CCD} + b_y y_{CCD} + c_y \end{cases} \quad (1)$$

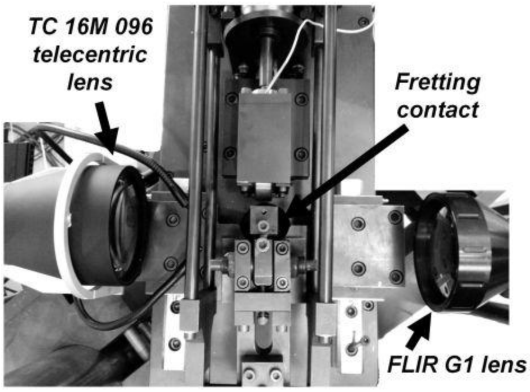

Figure 3- The two-face experimental set-up.

3.1 Data processing

All images were stored digitally with two seperate computers. A matlab script is then used to process the images as follows : A ZOI defined at the contact, is automatically selected on the IR image (figure 4(a)), using the spatial matching function defined as in (1), the same zone is found on the CCD image (figure 4(b)).

In-plane displacements for each pixels are then calculated using the DIC technique, and were implented back in the script. This will allow to track the ZOI on the IR images (figure 4(c)), and therefore build temperature maps.

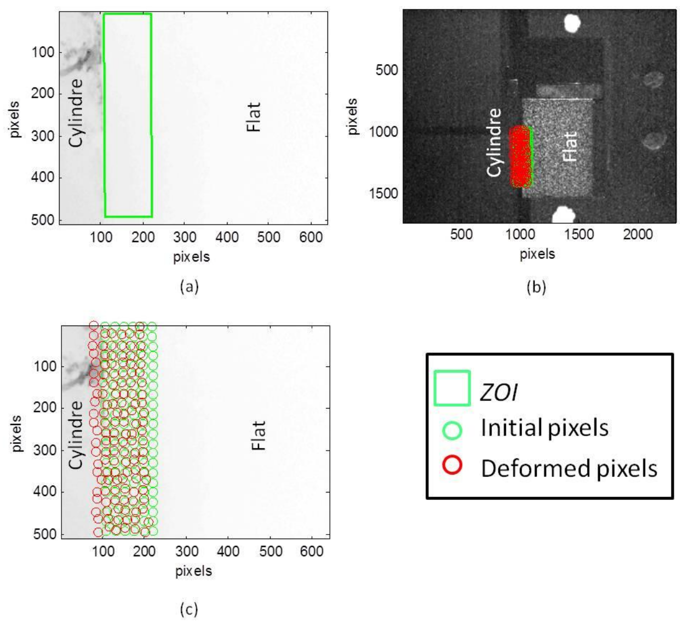

Figure 4- Images processing: (a) ZOI selection on IR image, (b) In-plane displacements determination using DIC technique, (c) new deformed ZOI.

(for representation purposes only few pixels were represented with a magnification factor)

4 First estimation of the heat sources

Under fretting loading the deformation of metallic materials when tested is associated with different heat sources (thermoelastic, plasticity and friction) and combined with irreversible microstructural transformations , increasing specimen's temperature (figure 5).

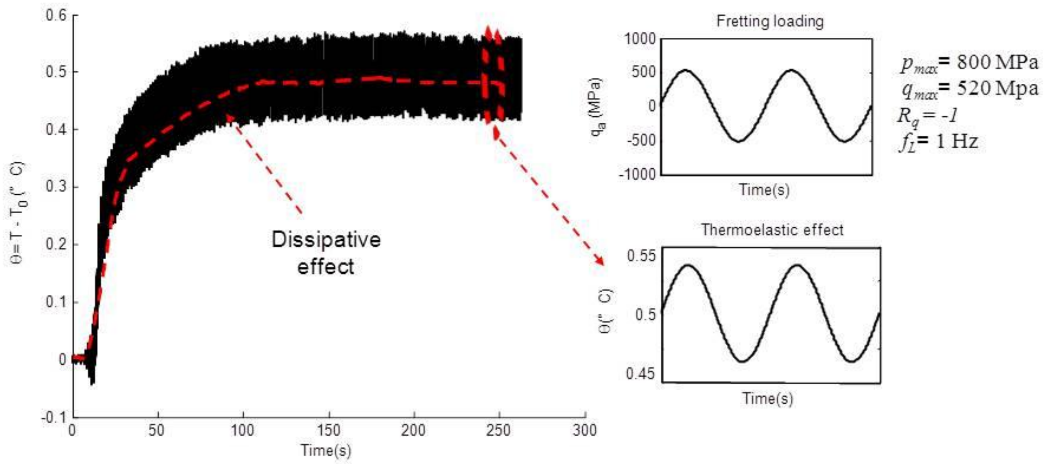

Figure 5- Temperature variation during a fretting test (thermoelastic and dissipative effects).

Among several possible methods, a local least-square fitting of the thermal signal was considered as in [9]. The temperature approximation functions account for the signal spectral properties. The local fitting function is defined as in (2) and the time-window used for the temperature fit was $N_{tfit} = (4f_a+1)/f_a$.

$$\theta^{fit}(t) = p_1 + p_2 t + p_3 \cos(2\pi f_L t) + p_4 \sin(2\pi f_L t) + p_5 \cos(4\pi f_L t) + p_6 \sin(4\pi f_L t) \quad (2)$$

Once the coefficients of the different polynomial are determined, the heat sources can be estimated using the 2D heat diffusion equation and the definition of each type of sources (figure 6). Thermoelastic sources are then compared with ones obtained from analytical solutions as shown in figure 6.

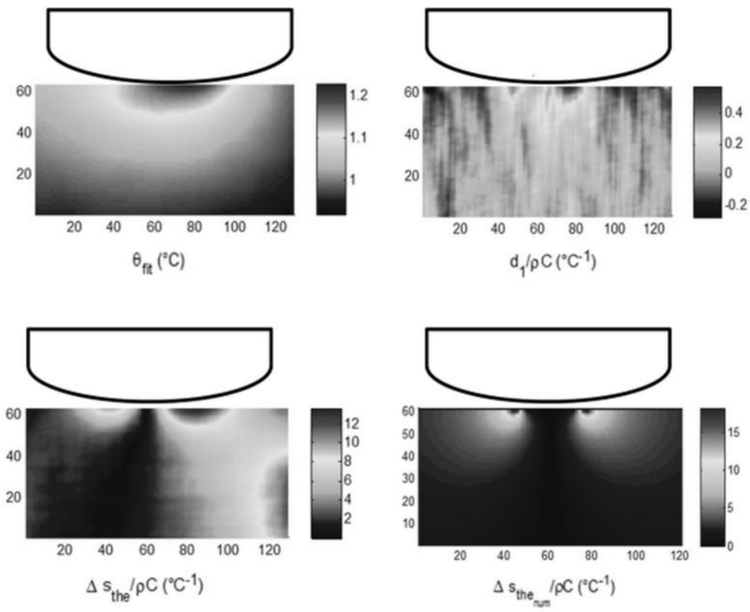

Figure 6- First estimation of the heat sources.

4 Concluding comments

In this study, a novel experimental set-up based on coupled kinematic and thermal measurements using quantitative infrared thermography (QIRT) and digital image correlation (DIC) in a two-face configuration was presented. DIC technique gave in-plane displacement vectors of a Zone Of Interest (ZOI) defined on the specimen surface, allowing a better tracking of this ZOI and therefore a better estimation of the temperature evolution. The thermal signal was fitted with a least-square function taking into account all the thermal harmonics. A first estimation of the heat sources for a fretting experiment is presented. The thermoelastic sources were then compared with ones obtained from analytical solutions and a good correlation was found between both results.

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