Wear 305 (2013) 23–35

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Analysis of the effect of a textured surface on fretting fatigue

J. Vázquez*, C. Navarro, J. Domínguez

Departamento de Ingeniería Mecánica, Universidad de Sevilla, Camino de los Descubrimientos s/n, C.P 41092 Sevilla, Spain

ARTICLE INFO

Article history:
Received 22 August 2012
Received in revised form
12 May 2013
Accepted 20 May 2013
Available online 3 June 2013

Keywords:
Fretting fatigue
Textured surface
Crack initiation phase
Crack propagation phase
Elastic—plastic finite element model

ABSTRACT

This paper analyses the effect of a wavy regular surface texturing on fretting fatigue life, and more specifically, studies the influence of this regular pattern on the initiation and crack propagation phases in fretting fatigue. In this work, an elastic—plastic finite element model (FEM) is used to simulate the contact between a half-plane and a cylindrical punch. In the simulations, three types of geometrical configurations are studied: one in which all of the contacting surfaces are smooth, a second with contact between a smooth half-plane and a cylindrical pad with a wavy surface, and the third that simulates contact between a half-plane with a wavy surface and a smooth cylindrical pad.

1. Introduction

Fretting is a superficial damage phenomenon that arises in mechanical contacts that are subjected to fluctuating loads. These loads cause relative oscillatory motions of small amplitude, usually on the order of tenths of microns, between mutually pressed surfaces. These motions produce oscillatory stresses in the contact zone that can lead to surface cracking [1]. In the presence of a bulk or global stress, these cracks can grow until the component fails [2]; in this situation, the phenomenon is known as fretting fatigue.

Because contact is the main method used to apply loads between solids, fretting fatigue may be present in a wide variety of mechanical components. For these reasons, fretting is a current focus for many researchers [3—5].

A variety of palliatives have been applied to reduce or suppress the potentially adverse effects of fretting in certain structural components. These include shot and laser peening treatments, surface coatings that reduce the friction coefficient, thermomechanical treatments that improve the tribological surface properties, the use of lubrication and other design improvements [6].

Other less intuitive methods for reduction of fretting damage include the texturisation (either random or regular) of the contacting surfaces. A type of random texturisation, or roughness is produced by shot peening treatments. It is known that shot peening produces significant effects at or close to the surface, such as residual compressive stress fields, work hardening and surface roughening [7]. The influence of the first two effects has been widely analysed. However, the effect on fretting of the surface roughness induced by the shot peening process has received less attention. A subset of related works are mainly experimental in nature and do not offer a detailed analysis of the reasons for the fretting improvement caused by the surface roughness [7—11]. Other works focus on the effects on the surface, and therefore on the crack nucleation phase [12]. Nowell et al. [13] offer selected qualitative explanations for the fretting fatigue behaviour of rough surfaces based on experimental results and with consideration of the relative scale between the contact size and the material microstructure.

When the surfaces display a regular roughness pattern, it may be more convenient to use the term "*textured surfaces*" to describe them. Usually, these types of regular roughness can be achieved via certain machining or electro-polishing methods [14]. Studies have been conducted in reference to the fretting behaviour of these types of surfaces, and, a subset of these studies perform an analytical elastic analysis of the surface stress field generated by the contact between a smooth surface and a regular wavy surface [15,16]. However, in a real rough surface, plastic deformation is produced at multiple real contact zones, and thus an elastic analysis leads to a notably high stress state on the surface that is unrealistic. Although other studies [17,18] present conclusive results with respect to the improvement in fretting fatigue life due to surface texturisation, they are essentially experimental in nature [17] or are focused on fretting wear phenomena [18]. Finally, although the work of Hattori et al. [19] offers experimental and analytical results, the latter are based on a rather simple elastic FEM that does not allow the modelling of the stress—strain field perturbations induced at the local scale by a surface texturisation.

* Corresponding author. Tel.: +34 954487387; fax: +34 954 460475.
E-mail address: jesusvaleo@us.es (J. Vázquez).

0043-1648/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2013.05.003

In view of the previous works, the main aim of this study is to provide a more complete understanding of the influence on fretting fatigue life of a particular regular wavy surface profile that resembles a realistic case. For this purpose, a series of elastic—plastic finite element models have been developed to simulate the contact pair between a smooth and a textured surface with a wavy shape. With the stress and strain fields obtained with these numerical models, and with the use of a fretting fatigue life analysis procedure, the potential beneficial or detrimental effects of such a regular wavy surface on the nucleation and crack propagation phases have been analysed. Additionally, a short study has been carried out in which the influence of the parameters that describe the wavy surface on fretting fatigue life is analysed.

2. Description of the finite element model

2.1. Pattern of the textured surface

The pattern that describes the regular wavy surface profile is assumed to be sinusoidal. It can be expressed as

$$y(x) = \Delta \cos\left(\frac{2\pi x}{\lambda}\right), \quad (1)$$

where Δ and λ are the amplitude and the wavelength of the surface profile. The parameters Δ and λ were chosen based on the bidimensional appearance of a shot peened surface. The main characteristics of the base material (a 7075-T651 aluminium alloy) and the shot peening parameters that characterise this real surface can be found in [7]. Fig. 1 depicts a section of this shot peened surface in which the ideal wavy surface used in the finite element model is also represented ($\lambda = 250\ \mu m$ and $2\Delta = 16\ \mu m$). The difference is that the peaks in the shot peened surface are more acute, which most likely produces greater and more localised stresses close to the surface in this case. Nevertheless, the conclusions obtained from the assumed surface are still valid, assuming that locally the peaks are subjected to high plastic deformations due to the local contact loads, which produce a rounding of these acute peaks.

The reason for the choice of this regular pattern is not unique. The main reason is because this type of regular wavy surface is easily obtainable via many processing methods and may be suitable for many practical situations. Secondly, and although any 2-D texture is an over simplification of the 3-D random pattern of a shot peened surface and presents some limitations, the study of this surface 2-D can yield some insight into the effects of the roughness induced by shot peening in fretting fatigue life.

2.2. Contact pairs configuration

The model simulates tests performed on a fretting bridge with cylindrical fretting pads. In these tests, the cylindrical pads with radius, R=0.1 m, are initially pressed against the test specimen with a normal load, N. Next, the specimen is subjected to a cyclic axial bulk stress, σ, with a stress ratio $R_\sigma = -1$. Due to the fretting bridge compliance, the axial bulk stress induces an in phase cyclic tangential force, Q, through the friction between the contact pairs [20,21]. These loads are shown schematically in Fig. 2.

Three contact pair configurations have been simulated to fully assess the possible benefits of such a regular surface. In the first one, all of the contacting surfaces are smooth, and this configuration is called smooth configuration (SC) as a basis for comparison. A sinusoidal surface is present on the specimen in the second configuration, called textured specimen configuration (TSC). In the third configuration, the sinusoidal surface is present on the cylindrical pad, known as the textured pad configuration (TPC). The TSC and TPC are shown in Fig. 3. The analysis of the latter two configurations determines whether a textured specimen or a textured pad configuration is a better palliative against fretting fatigue.

2.3. Software, mesh and material properties

A series of elastic—plastic finite element models have been developed to simulate the contact pair between the cylindrical pad and the test specimen. All of the models were built with the commercial software ANSYS™ 14.5. To ensure that the model is numerically tractable, all of the contact pairs have been modelled as plane contacts with the assumption of plane strain conditions. The test specimen and contact pad have been modelled with the necessary dimensions such that the stress and strain fields can be estimated considering booth bodies as half-planes [22]. All of the finite element models have approximately 90,000 d.o.f. The element type used to model the half-plane and the pad is PLANE182, and TARGE169 and CONTA171 are used to model the contact pair. The material properties applied correspond to those of the 7075-T651 aluminium alloy, and the mechanical and fatigue properties were set according to previous studies or were determined by testing in the laboratory [25,26]. Table 1 summarises the mechanical properties: the tensile properties, the parameters of the ε—N curve, the Ramberg—Osgood constants for the cyclic stress—strain curve and those for Paris' fatigue crack growth law. The equations involved with these parameters are:

$$\frac{\Delta\varepsilon}{2} = \sigma'_f(2N)^b + \varepsilon'_f(2N)^c \quad (\varepsilon\text{—}N) \quad (2)$$

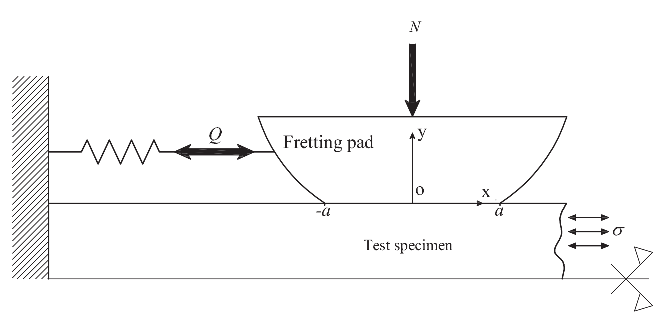

Fig. 2. Schematic view of the loads applied to the contact pair.

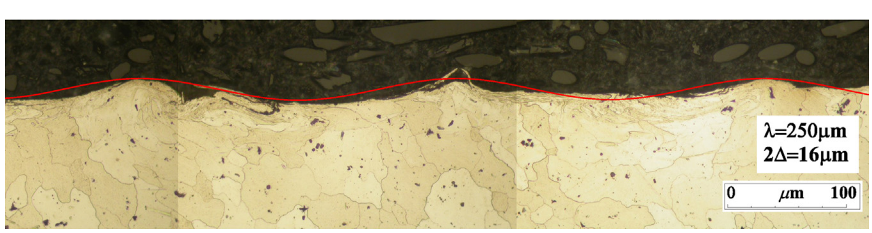

Fig. 1. A real shot peened surface and a regular wavy surface used in the model.