OPTICAL AND THERMAL METHODS

Thermoelectric Detection of Fretting Damage in Aerospace Materials

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Abstract—Fretting is a wear phenomenon that occurs when cyclic loading causes two surfaces in intimate contact to undergo small oscillatory motions with respect to each other. During fretting, high points or asperities of the mating surfaces adhere to each other and small particles are pulled out, leaving minute, shallow pits and powdery debris. Sometimes these surface conditions are neglected, but they are important in some application such as the aerospace industry. In this research work, non-contacting and contacting thermoelectric power techniques are performed in fretted 7075–T6 and Ti–6Al–4V samples. It has been found that the contacting and non-contacting thermoelectric power measurements are associated directly with the subtle material variations such as work hardening and residual stresses due to plastic deformation produced in the fretting zone but surface topography. Therefore, both techniques could be used for a global characterization of the most relevant fretting induced effects. Potential of these techniques to monitor subsurface changes in other severe surface plastic deformation processes are clearly envisaged.

Keywords: fretting damage, thermoelectric measurements, aerospace materials

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1. INTRODUCTION

Ti–6Al–4V and 7075–T6 alloys have an extensive application in aircraft structures since their combine high strength to weight ratio and corrosion resistance compare to other materials. However, fretting damage is a serious problem in the aerospace industries where structural assemblies are often subjected to intense vibration [1, 2]. Fretting is caused by the oscillating movement with small amplitude that may occur between contacting surfaces subjected to vibration. It mainly results in two kinds of damage: wear, by which the debris is generated as a result of a loss of fit between contacting surfaces, and rapid crack nucleation and propagation as a result of failure of engineering parts. Some of the failures initiated by fretting have had serious consequence [3–6]. So nondestructive evaluation of the fretted zone where the cold work induces residual stresses at the surface of the component could be necessarily in order to improve the fretting wear–resistant performance of materials. In addition to the primary residual stress effect, fretting damage also causes subtle variations in material properties such as hardness alternations, localized plastic deformation, heat-affected zone, recrystallization and so on [7–9].

Nondestructive technology currently exists that can detect and accurately quantified surface and subsurface residual stresses in aerospace materials [10–14]. The main residual stress detection methods commonly used are: (1) X-ray diffraction techniques, based on the measurement of the lattice spacing as a strain gauge. This non-destructive technique allow to differentiate between macro and micro stress but are only effective; for measuring stresses and require surface preparation; (2) ultrasonic techniques, based on variations in the velocity of ultrasonic waves in the material. Ultrasonic testing has a greater penetration depth than diffraction techniques but usually requires surface preparation and the use of a coupling medium. Rough, irregularly shaped, inhomogeneous materials are difficult to inspect; (3) eddy current techniques, based on the measurement of changes in the impedance of an electromagnetic coil as it is scanned on a conductive material surface. Eddy current techniques suffer from limited penetration depth especially in ferromagnetic materials; (4) active magnetic techniques, a magnetic field is applied to the material and variations in field parameters such as permeability, hysteresis and magnetic Barkhausen
emission are used to draw inferences about the material stresses. Active magnetic techniques commonly used high strength, low frequency fields to drive the material into saturation so offer fairly good penetration and finally; 5) the passive magnetic techniques, in which the magnetic field strength at the material surface is measured without prior application of a magnetic field. Passive magnetic techniques such as metal magnetic memory (MMM) make use of variations in the self magnetic leakage field of a ferromagnetic material due to geometrical discontinuities such as cracks and high density dislocations. These variations reflect the stress history of the material.

Ti–6Al–4V and 7075-T6 alloys produce a change in the thermoelectric voltage from positive to negative when two pieces of the same material are rubbed against each other as shown in Fig. 1. Although this so-called triboelectric method well illustrates the sensitivity of the thermoelectric method to detect fretting damage, this technique cannot be directly adapted to nondestructive inspection of critical engine components because of its poor reproducibility and the inevitable surface damage the inspection itself causes on the part to be inspected.

On the other hand, thermoelectric power (TEP) measurements have demonstrated their ability to non-destructively quantified grit blasting and laser shot-peening surface treatments and detected subsurface changes induced by both surface plastic deformation processes in metallic biomaterials such as Ti–6Al–4V and 316LVM alloys [15, 16]. TEP measurements of surface treatment effects could be provided the option to quantitatively measured initial treatment effectiveness along with the effect of operationally induced changes over the life of the treated component. The goal of this research work is to use two non-destructive thermoelectric techniques (NDTT), the non-contacting and contacting thermoelectric power measurements to detect and quantified the subsurface changes induced by fretting damage in aerospace materials such as Ti–6Al–4V and 7075-T6 alloys.

2. THERMOELECTRIC POWER

Thermoelectricity is defined as the direct conversion of heat into electrical energy or vice versa, in conductor materials by means of different phenomena as the Seebeck effect, the Peltier effect and the Thomson effect. In order to understand this phenomenon, in particular the Seebeck effect, in a better way, it was considered a conductor material that is heat at one side and cooled at the other side. When a small temperature gradient $\nabla T$ is established across a conductor, the electrons in the hot side has higher energy than those of the cold side. Therefore the heat is carried from the hot region to the cold region by a net diffusion of electrons. In general, the diffusion rate is a function of electron energy and thus, a net electron current will result. The flow of electrons leaves behind exposed positive metal ions (charges) in the hot region while pile