Available online at www.sciencedirect.com
ScienceDirect
Wear 263 (2007) 518–531
WEAR
www.elsevier.com/locate/wear

A global–local wear approach to quantify the contact endurance under reciprocating-fretting sliding conditions

S. Fouvry *, T. Liskiewicz, C. Paulin

LTDS, CNRS, Ecole Centrale de Lyon, Ecully 69134 Cedex, France

Received 27 November 2006; received in revised form 10 January 2007; accepted 10 January 2007
Available online 23 May 2007

Abstract

An Archard wear formalism is considered and adapted to formalize the abrasive wear responses of hard coating interfaces against an alumina ball under oscillating sliding conditions. Archard wear coefficients are defined and compared versus the respective coating hardnesses. It is shown that for the Ti–V–C system a near linear decrease of the wear rate versus the hardness can be defined. By contrast, the Ti–V–N system promotes significant debris transfer onto the alumina counterbody. The previous two-body abrasion process is then replaced by a three-body abrasion mechanism which significantly modifies the damage phenomena. The coating hardness–wear rate correlation is therefore no longer verified. It is moreover shown that a local approach, focusing on wear depth analysis, is required to predict interface durability. A FEM investigation integrating the wear surface extension demonstrates that the wear depth kinetics can be predicted by considering the accumulated Archard factor density. Simplified analytical formulations are then introduced to generalise this local analysis. Justifying the global–local application of the Archard wear approach, it suggests that interface durability can be related to a single Archard capacity variable (ϕ) defined as the maximum accumulated Archard factor density which can be dissipated in the interface before contact failure.

Keywords: Fretting; Reciprocating sliding; Wear modelling; Hard coating; Coating durability

1. Introduction

The term fretting denotes a small oscillatory movement between contacting surfaces which invariably occurs in engineering assemblies subjected to vibrations. Depending on the loading conditions (relative displacement amplitude, normal loading), fretting may cause damage by surface fatigue involving crack nucleation and crack propagation and/or wear induced by debris formation [1,2]. It has been shown that the fretting damage is directly connected to the stabilized fretting sliding condition (Fig. 1).

For the smallest displacement amplitudes, the contact stabilizes at the so-called partial slip condition. The contact then displays a composite structure of sticking and sliding zones [3,4]. The fretting loop, defined by the tangential force evolution (Q) versus the applied displacement (δ), is characterized by a closed elliptic shape. This sliding condition mainly favours crack nucleation and crack propagation.

For higher displacement amplitudes, the sticking zone no longer exists, and the entire contact is subjected to full reciprocating sliding. The friction dissipation actives wear mechanisms involving debris formation and debris ejection. The fretting loop is then characterized by a rectangular shape with a maximum tangential force amplitude (Q^*) verifying Ammonton's principle ($Q^* = \mu.P$). A fretting map strategy has been introduced to format this fretting damage evolution [5–8].

Due to its dramatic impact on structural integrity, fretting cracking has been extensively investigated during the past decades [8–14]. Fretting crack nucleation and crack propagation can now be predicted, while fretting fatigue endurance can be formalized. The situation is less advanced as regards wear processes [15]. This is revealed by the great number of wear models, and the difficulty in predicting the evolution of wear with loading parameters like pressure, sliding or friction coefficient. There is, nevertheless, increasing interest in formalizing wear better [16–21]. In the present work, global and local approaches have been developed to quantify the fretting wear processes. Although the analysis focuses on gross slip fretting conditions, it must be outlined that the methodology set out here can be extended to plain reciprocation conditions. Focusing on ceramic interfaces

* Corresponding author. Tel.: +33 4 72 18 65 62; fax: +33 4 78 43 33 83.
E-mail address: siegfried.fouvry@ec-lyon.fr (S. Fouvry).

0043-1648/$ – see front matter
doi:10.1016/j.wear.2007.01.072

Nomenclature

a_H half width of the Hertzian contact (μm)
$a_{(i)}$ half width of the contact at the *i*th fretting cycle (μm)
a_{ft} half width of the contact related to the activation of a flat distribution of the wear kinetics (μm)
$e_{(i)}$ contact exposure parameter at the *i*th fretting cycle
Ed dissipated friction energy (J)
$h(x)$ wear depth at the *x* position of the interface (2D contact) (μm)
$h_{(i)}(x)$ wear depth at the *x* position of the interface (2D contact) at the *i*th fretting cycle (μm)
K_h Archard wear coefficient related to the wear depth analysis ($\mu m^3\,(N\,m)^{-1}$)
K_v Archard wear coefficient related to the wear volume analysis ($\mu m^3\,(N\,m)^{-1}$)
L axial length of the cylinder/plane contact (mm)
N_{ft} fretting cycle related to the activation of a flat distribution of the wear kinetics
Nc fretting cycle related to the coating failure
P normal force (N)
$P_{(i)}$ normal force during the *i*th fretting cycle (N)
P_L normal force per unit of axial length (2D contact) (N/mm)
$p_{0E(i)}$ elliptical approximation of the maximum pressure at the *i*th fretting cycle (MPa)
p_{0H} Hertzian maximum pressure (MPa)
Q tangential force (N)
Q^* tangential force amplitude (N)
te effective worn coating thickness (μm)
tn nominal coating thickness (μm)
V wear volume (μm^3)
$W_{(i)}$ Archard factor dissipated during the *i*th fretting cycle (N m)
$W_{L(i)}$ linear Archard loading factor dissipated in the interface during the *i*th fretting cycle (2D contact) (N m/mm)
$W_{(i)}(x)$ Archard factor density dissipated at the *x* position (2D contact) during the *i*th fretting cycle (N m/μm^2)
$W_{(i)}(0)$ Archard factor density dissipated at the center of the interface ($x=0$, 2D contact) during the *i*th fretting cycle (N m/μm^2)
$W_{E(i)}(0,0)$ elliptical approximation of the Archard factor density dissipated at the center of the interface ($x=0$, $y=0$, 3D contact) during the ith fretting cycle (N m/μm^2)
$W_{F(i)}(0)$ flat approximation of the Archard factor density dissipated at the center of the interface ($x=0$, 2D contact) during the *i*th fretting cycle (N m/μm^2)
$W_{F(i)}(0,0)$ flat approximation of the Archard factor density dissipated at the center of the interface ($x=0$, $y=0$, 3D contact) during the ith fretting cycle (N m/μm^2)
$W_H(0)$ Hertzian approximation of the Archard factor during the *i*th fretting cycle (N m/μm^2)
$\bar{W}_{(Nc)}(0,0)$ averaged Archard factor density associated to the coating failure which is dissipated at the center of the interface ($x=0$, $y=0$, 3D contact) (N m/μm^2)
ΣW (accumulated) Archard factor (N m)
$\Sigma W(x)$ (accumulated) Archard factor density dissipated at the *x* position (2D contact) (N m/μm^2)
$\Sigma W(0)$ (accumulated) Archard factor density dissipated at the center of the interface ($x=0$, 2D contact) (N m/μm^2)
$\Sigma W(0,0)$ (accumulated) Archard factor density dissipated at the center of the interface ($x=0$, $y=0$, 3D contact) (N m/μm^2)

Greek symbols
δ displacement (μm)
δ^* displacement amplitude (μm)
δg sliding amplitude (μm)
$\delta g_{(i)}$ sliding amplitude during the *i*th fretting cycle (μm)
ϕ Archard wear capacity (N m/μm^2)
μ coefficient of friction
$\bar{\mu}$ mean friction coefficient

for which the damage process is mainly controlled by abrasion wear processes, the present work will examine the following aspects:

- How can the general wear response of ceramic tribocouples be formalized by applying a conventional Archard description, and can the coating hardness–wear coefficient relation be justified?
- How can the local wear depth kinetics be predicted, and which parameters control the surface profile evolution?
- How can the surface durability be predicted, and how can it be formalized through a local Archard capacity variable (ϕ)?

2. Experimental procedure

2.1. Test procedure

To investigate oscillating wear phenomena, a meso reciprocating contact (i.e. for normal loading comprised between 10 and 500 N) was considered (Fig. 2a) [22–24]. Various contact geometries like cylinder/plane, sphere/plane and plane/plane configurations can be adjusted to investigate the effect of contact on the stability of the wear laws. The normal force (P) is