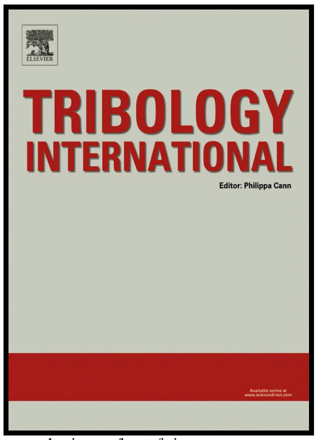

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PII: S0301-679X(16)30334-6
DOI: http://dx.doi.org/10.1016/j.triboint.2016.09.022
Reference: JTRI4369

To appear in: *Tribiology International*

Received date: 21 June 2016
Revised date: 6 September 2016
Accepted date: 17 September 2016

Cite this article as: P.J. Ashton, A.M. Harte and S.B. Leen, Statistical grain size effects in fretting crack initiation, *Tribiology Internationa* http://dx.doi.org/10.1016/j.triboint.2016.09.022

Statistical grain size effects in fretting crack initiation

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Abstract

A crystal plasticity computational framework is developed and validated to investigate the microstructure sensitivity of crack initiation in fretting. Randomly distributed microstructure geometries are incorporated into a partial-slip finite element fretting model. The number of cycles to fretting crack initiation is shown to be sensitive to average grain size and microstructure morphology. Scatter in the number of cycles to crack initiation is shown to increase as the number of grains across the contact width decreases due to statistical size effects. Average number of cycles to crack initiation is shown to increase with decreasing number of grains in the contact. Microstructure morphology is shown to have a negligible influence on the effect of stroke for the partial slip cases considered here.

Keywords: Fretting, Crystal plasticity, Size effects, Fatigue

1. Introduction

Fretting-induced relative slip is typically in the range 5 to 100 μm, for macroscale applications such as splined couplings [1], bolted connections [2] and biomedical hip implants [3]. This length-scale is directly comparable to key microstructural dimensions (e.g average grain size) of commonly-used metallic alloys, as shown schematically in Fig. 1. Relative slip is well known to play a key role in determining fretting fatigue life and can be divided into three regimes; partial slip, mixed slip, and gross slip [4]. The sliding regime is, generally-speaking, determined by tangential displacement, coefficient of friction and normal load. Gross slip occurs when the tangential force is large enough to overcome the resisting frictional force. Partial slip occurs when the tangential load is not large enough to cause gross slip but large enough to cause slip at the edge of the contact region. Mixed slip combines both conditions.

Contact width, another key parameter in fretting fatigue, is also typically of the same order of magnitude as metallic grain size. A number of authors [5-8] have observed a contact size effect in fretting fatigue and shown that a critical contact size exists below which fatigue life increases dramatically. This effect has been attributed to the presence of a key microstructure feature (e.g a grain boundary) in the critically stressed region, which is arguably less likely to arise as contact size is reduced due to smaller stress fields. Nominally, classical macro-scale elastic-plastic finite element fretting models are unable to predict this effect. However some authors [6],[7] have introduced length- or volume-averaging procedures in fretting fatigue calculations to account for such size effects. The averaging dimension of the same order of metallic grains has been shown to give good results. In the current work a microstructure-sensitive crystal plasticity (CP) methodology is explored, which is potentially capable of capturing size effects without the need for such averaging procedures.