MODELING FRETTING FATIGUE IN MULTIAXIAL AND VARIABLE LOADING CONDITIONS

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Abstract

Predicting fretting-fatigue life under multiaxial and variable loading conditions requires taking into account the effects of stress gradients and the fact that stress concentration areasn where cracks may intiate, are mobile and move, along with the contact front, when the normal load varies. This paper proposes a model, analogous to linear fracture mechanics approaches, to take into account the gradient effects around the contact front through intensity factors and to describe the displacement of the contact front and the non-linear behaviour of the contact partial slip region with an incremental model based on these intensity factors.

1. Introduction

A new method was proposed by C. Montebello (2015) to account for the stress gradient effect in fretting-fatigue. It was later extended by G. Rousseau (2020) to predict the life in fretting-fatigue in multiaxial and non-proportional loading conditions of contacting parts with elastically similar materials and is now extended to elastically dissimilar materials by P. Lare and tested in variable normal and shear loadings conditions by F. Da Rocha Chaves.

This approach consists of representing the movement in the vicinity of a contact front by using a set of intensity factors and their associated reference spatial fields in a reference framed attached to the contact front. The decomposition into intensity factors and spatial reference fields was performed using a proper orthogonal decomposition techniques (Karhunen-Loeve transform). The intensity factors incorporate the gradients by construction and can be used to construct “non-local” initiation and lifetime criteria.

$$\boldsymbol{v}(P,t)_{R'} = \underbrace{\dot{I}_I \boldsymbol{\varphi}_I(\boldsymbol{P}) + \dot{I}_{II} \boldsymbol{\varphi}_{II}(\boldsymbol{P}) + \dot{I}_{III} \boldsymbol{\varphi}_{III}(\boldsymbol{P})}_{\text{"linear terms"}} + \underbrace{\dot{I}^c_{II} \boldsymbol{\varphi}^c_{II}(\boldsymbol{P}) + \dot{I}^c_{III} \boldsymbol{\varphi}^c_{III}(\boldsymbol{P})}_{\text{"non linear"}} \quad (1)$$

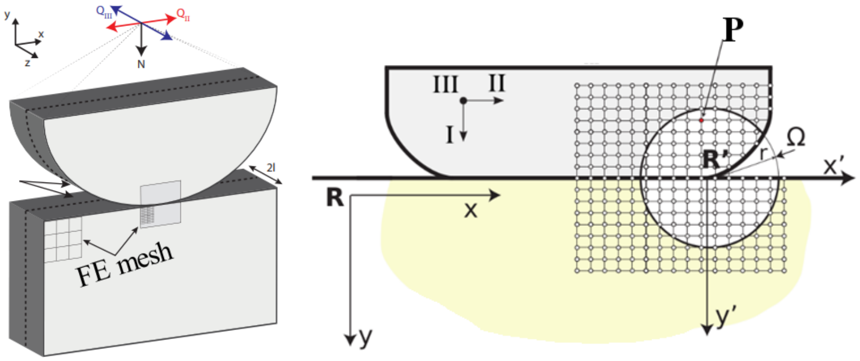
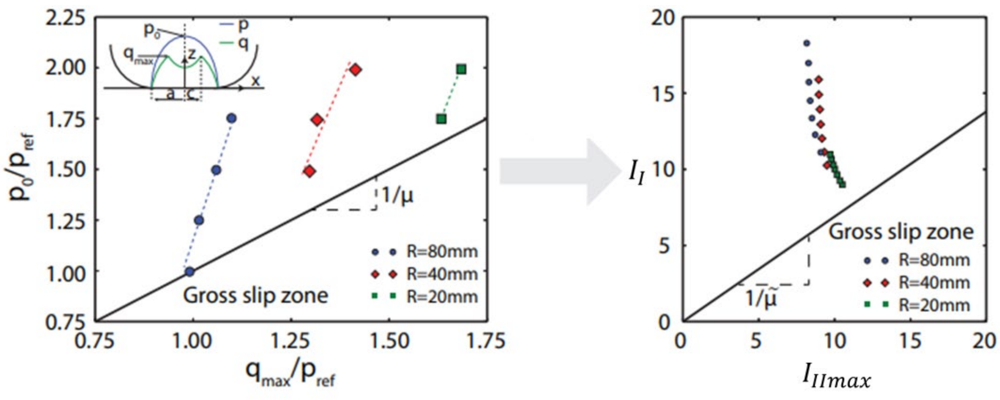


Fig.1 – Reference frame related to the contact front and loading modes.

3D finite element analyses were conducted, first to build the framework of this approximation, second to qualify its accuracy for elastically similar of dissimilar contacting parts and finally to determine the non-linear response of a contact in multiaxial fretting-fatigue conditions. An incremental constitutive model was developed to predict this non-linear response. It consists of a set of constitutive equations providing the évolutions of (I^c_{II}, I^c_{III}) and the displacement of the contact edge as a function of the evolution of (I_I, I_{II}, I_{III}). The predictions of the model were compared to the results of finite elements analyses. Finally, these non-local intensity factors are used to set up crack initiation and fretting fatigue life criteria. Then, fretting fatigue crack initiation thresholds and lives are compared to available experimental data.

Results

a. It was first shown that a very small number of intensity factors is required to accurately describe the mechanical problem. With 3 “linear” intensity factors (I_I, I_{II}, I_{III}) and two “non-linear” ones (I_{II}^c, I_{III}^c), the displacement field can be approximated with less than 5% of error.
b. The reference fields $\boldsymbol{\varphi}_I(\boldsymbol{P}), \boldsymbol{\varphi}_{II}(\boldsymbol{P})$ *and* $\boldsymbol{\varphi}_{III}(\boldsymbol{P})$ were shown to be quasi-identical to mode I, mode II and mode III linear elastic fracture mechanics displacement fields solutions.
c. Provided that the area of interest Ω (Fig. 1) is small compared to the radii of the contacting bodies, the reference fields are independent of these radii.
d. The gross slip conditions $Q = \mu N$ is transposed into $I_{II} = \tilde{\mu} I_I$ where $\tilde{\mu} \approx \frac{3}{2}$
e. The huge gradient effect observed when the initiation thresholds in fretting fatigue for cyclinder-plane fretting fatigue experiments with pads of different radii is plotted in terms of the maximum normal and shear stresses (Fig.2a) disappears when the initiations frontiers are plotted in terms of (I_I, I_{II}). The thresholds found for R=20 mm, 40mm or 80 mm are then identical (Fig. 2b).
f. 3D FE simulation compare satisfactory to the predictions of the incremental constitutive model that was developed by G. Rousseau to predict the évolutions of (I_{II}^c, I_{III}^c) and the displacement of the contact edge as a function of the evolution of (I_I, I_{II}, I_{III}).



(a) (b)

Fig.2 – Initiation thresholds in fretting fatigue found by Amargier et al for cylinder-plane fretting fatigue experiments with pads of radii R=20, 40 and 80 mm, plotted in terms of local normal and shear stresses (a) or in terms of the intensity factors (I_I, I_{II}) for fretting-fatigue first introduced by Montebello et al (b).

2. Conclusions and prospects

This approach allows for the efficient analysis of contacts of various geometries by integrating gradient effects at the base and the incremental model allows for the prediction of lifetimes under variable loading. Recent work by P. Lare shows that the approach can be extended to contacts between components with different elasticity constants. Complex fretting fatigue tests are underway to validate the incremental approach..

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