A MIXED MODE FATIGUE CRACK GROWTH MODEL APPLIED TO ROLLING CONTACT FATIGUE

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ABSTRACT

Extended finite element method simulation were conducted in order to evaluate mode I and II stress intensity factors (SIFs) for cracks under cyclic contact rolling and rolling-sliding conditions. The crack propagation mode and direction were investigated using criteria.

INTRODUCTION

The improvement of the prediction of the fatigue life under rolling contact fatigue is a significant challenge that requires a combined theoretical and experimental approach. Twin disc experiments show clearly a 3D crack network development [1]. This rolling contact loading induces in the neighborhood of the contact zone a multiaxial non proportional stress field with furthermore steep gradient.

The influence of this rolling contact spans from the crack initiation, its early growth to its macroscopic growth, until the crack has propagated beyond the influence of the contact, the propagation being propelled by stresses caused by a far field loading. Under such a loading, crack faces experience very complex open and closure sequences as well as stick and slip ones. An utmost care must be devoted to the determination of these contact conditions along crack faces as they governed the SIF values at crack tips and thus the SIF ranges that are the key parameters under Linear Elastic Fracture Mechanics.

This study aims to develop a 3D fatigue crack model that addresses frictional contact problem encountered along crack faces submitted to non proportional multi axial steady state loading. The first step is the development of 2D approach. It has been performed using the extended finite element method (XFEM) [2]. This new numerical method overcomes the major finite element methods difficulties, i.e. remeshing during the crack growth process, and field projections from a mesh to another one.

CONTACT MODEL AND CALCULATION PROCEDURE

The previously X-FEM and contact algorithms [3] have been revisited and adapted to analyze fatigue crack growth under any contact loading. The 2D fatigue crack growth model is based on a combination of the following points:

(i) use of X-FEM for crack modeling that alleviates the mesh generation: no explicit crack meshing and no re-meshing on crack propagation simulation are required,
(ii) iterative solution of the non linear problem (frictional contact) according to the Large Time Increment method [4],
(iii) steady state formulation of the loading during cycles,
(iv) use of incremental Coulomb’s law for frictional cracks,
(v) criteria for the crack propagation onset, the direction of extension and propagation laws.

The problem statement and complete fatigue crack growth model are presented in [5], [6]. The loading used is representative of a fatigue contact loading, i.e. a travelling rolling, rolling-sliding or sliding load over the body surface described by several cycles. This loading is thus described by two time scales: a scale linked to cycle numbers and an other linked to load steps. At each load step, the iterative solver for the contact problem solution is set up.

The energy release rate $G$ and the SIFs in mode I and II, $K_I$ and $K_{II}$ respectively, are evaluated at each load step of a fatigue cycle. $G$ is evaluated through the J-integral method and the virtual extension field method [7] which gives a path independent domain integral. Since the expression given by Palmer and Rice [8] for contact problem and the relation between $J$-integral and SIFs, the extraction of mixed-mode SIFs is performed thanks to a so-called interaction integral developed for 2D problems [9].
but also for 3D planar or non-planar cracks [10]. More details are given in [6].

The crack propagation direction is then determined at the end of the cycle thanks to different criteria. The mixed mode loadings involve branching kink (un phénomène de branche- ment) (crack propagation angle \( \theta_0 \) different from its original direction). This direction is usually compute by the Erdogan and Sih’s criterion [11], implicitly criterion for proportional loading. For non-proportional loadings (principal stresses ratio is unconstan- dard during a cycle), the Hourlier and al.’s criteria [12], which define maxima on space and time, are used: - criterion 1: \( \theta_0 \) is such as \( k_1^i(\theta, t) \) achieves its absolute maximum (space and time), - criterion 2: \( \theta_0 \) is such as \( \Delta k_1^i(\theta) = \max k_1^i(\theta, t) - \min k_1^i(\theta, t) \) is maximum on space, with \( k_1^i(\theta, t) \) SIF at the tip of a crack extension infinitesimal length obtained from the SIFs of initial crack tip [13].

**NUMERICAL RESULTS**

The model has been validated by comparing the SIFs ob- tained under rolling contact fatigue with those obtained with a fa- tigue crack model based on the distributions of dislocations [14]. Some results shown the capability of our X-FEM model to manage contact conditions in mixed mode (I+II) and emphasize difficulties connected to this multiscale problem. This aspects will be detailed in next paper. Figure 1. (a) Erdogan and Sih criterion for different steps (b) Hourlier and al. criterion

In figure , criterion 1 and 2 are used to determine the propa- gation direction from \( K_I \) and \( K_{II} \) variations at crack tip during a cycle estimated for a 2D surface breaking crack, length \( h = 0.1 \text{mm} \), perpendicular to the surface traversed by a parabolic Hertzian load of variable half-width \( a = 1 \text{mm} \) and maximum pressure \( P = 97 \text{N/mm} \). Friction coefficient are considered: on the contact surface, \( \mu_S = 0.15 \), and between the crack faces, \( \mu_C = 0.1 \). The crack propagate in the shear mode with \( \phi = -70^\circ \), whereas Erdogan and Sih’s criterion give different angles, figure . A 2D inclined crack propagation under loading cycles has been performed, and the next steps will be devoted to 3D simulations.

**REFERENCES**


