Contact Fatigue Damage Mechanisms in Machine Elements

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The aim of this work is to simulate and provide a better understanding of the mechanisms governing crack initiation in bearings using crystal plasticity finite element (CPFE) method. Materials microstructure is explicitly considered and its effect on fatigue crack nucleation is studied. Various criteria are investigated to capture the onset of crack initiation in characteristic rolling contact fatigue (RCF) multiaxial and non-proportional stress and strain fields. The predictive power of microstructurally-based fatigue indicators, such as the stored energy density is investigated.

Keywords: rolling contact fatigue, bearings, crack initiation, microstructure, crystal plasticity finite element (CPFE) modelling.

1. Introduction

Rolling contact fatigue (RCF) is one of the major failure modes of bearings and often results in severe life reduction. In modern industries, when rolling element bearings are properly installed and lubricated, subsurface-initiated cracks, albeit rare, constitute the predominant mechanism of RCF in bearings.

Due to Hertzian contact theory, there is a maximum orthogonal shear stress at a grain-scale depth below the contact surface, which can be associated with subsurface-initiated cracks. Hence, material microstructure and pre-existing material imperfections play a key role in RCF crack initiation. Modelling studies have shown that many factors, such as morphology and orientation of grains may strongly affect the initiation of fatigue cracks.

To understand the mechanism of crack initiation of bearings under RCF, crystal plasticity finite element method (CPFE) is utilized in this study[1-4], which enables the study of microstructurally-based mechanisms. The model considers stress distribution, plastic strain accumulation, dislocation density evolution etc. during the rolling process. Hence, fatigue crack initiation criteria, based *e.g.* on stored energy density, can be used to determine the onset of crack nucleation.

2. Methods

A rate-dependent CPFE modelling is utilised in the study with consideration of evolution of geometrical necessary dislocations (GNDs) and statistically stored dislocations (SSDs) density. The crystal plasticity equations are implemented into user material subroutine UMAT by using Abaqus analysis. The deformation gradient F can be decomposed into elastic and plastic tensors, shown as:

$$F = F^e F^p \quad (1)$$

with the rate of plastic deformation $\dot{F^p}$ represented as:

$$\dot{F^p} = \sum_\alpha \dot{\gamma_p^\alpha} (s^\alpha \otimes n^\alpha) \quad (2)$$

where $\dot{\gamma_p^\alpha}$ is the plastic shear strain rate of a given slip system α, and s^α and n^α are corresponding slip direction and plane normal direction. The shear strain rate can be expressed as a function of the mobile dislocation density[2] and a dislocation-based strain hardening rule is employed, which incorporates the intrinsic critical resolves shear stress and follows the evolution of dislocations based on the accumulated plastic strain rate. In this study, a polycrystalline model is developed in the commercial finite element package ABAQUS with Voronoi tessellation (Fig.1). FCC polycrystalline structures are studied here and a set of random Euler angles are assigned to define to orientation of each grain.

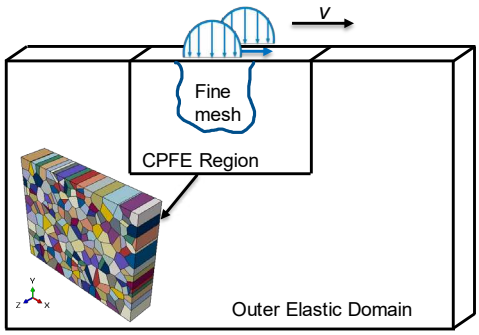

Figure 1: Grain domain for RC crystal plasticity model.

3. Discussion

It is shown that differences in grains' shape and orientation lead to important changes in localized stresses and plastic strain localisation. The computed stored energy density is shown to provide accurate predictions in differentiating between potential crack nucleation sites.

4. References

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