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Numerical prediction of fretting fatigue crack trajectory in a railway axle using XFEM

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Abstract: In this paper, we present for the first time the application of a fretting fatigue crack propagation predictive technique to a railway axle subjected to bending fatigue loading condition. We also present the first numerical study on predicting fatigue crack trajectory in an axle and wheel model of a railway axle. The technique is based on combining the eXtended Finite Element Method (XFEM) with two fatigue crack growth criteria, namely Maximum Tangential Stress (MTS) and minimum shear stress range. In the implementation of XFEM, enrichment functions, shifted formulation and overlay elements are adopted. The element crack closure is taken into account using the punctual restriction criterion. To calculate MTS criterion, the stress intensity factors are extracted using interaction integral method, in which mode I and mode II can be separated. The implementation is validated using a complete contact problem and experimental data from literature. It is found the minimum shear stress range criterion provides crack paths closer to the experimental results than those obtained using MTS criterion. The technique is further applied to a Chinese railway axle and the results are compared to the available experimental data. Good agreement between the numerically predicted and experimentally measured crack trajectory in the railway axle is found.

Keywords: Fretting fatigue, finite element analysis, fatigue crack propagation, XFEM.

1. Introduction

Fatigue is an issue to be taken into account at the moment of designing a mechanical structure or machine. The fatigue failure can be divided into two main stages, namely a former stage of crack initiation and a later stage of crack propagation [1]. The former stage consists of the formation of a very small crack, and it usually occurs in material discontinuities or high stress zones. To avoid these, designers tend not to use stress raisers like fillets, keyways, screw threads, and abrupt changes of section. These measures have been proved to be successful in flat homogenous surfaces. With these design conditions the presence of contact and small slip amplitude between two bodies have shown to be a preferred crack initiation zone over a free surface. This phenomenon is known as fretting.

Fretting occurs whenever a coupling between two contact elements is under an oscillating force, and this oscillating force generates a relative tangential displacement over at least part of the interface. Fretting differs from sliding contact in that the tangential force does not result in global relative motion of contact surface, i.e., it results in partial slip. The contact zone can be divided into a micro-slip zone (25-100 µm) and a region with no relative motion (stick zone) [2-6]

The initiation process in fretting contact is a mixture of wear, corrosion, and fatigue phenomena. This initiation process can be divided into three stages [7]. The first stage involves the removal of the thin oxide layer covering the surface of the pieces through wear processes. As the oxide layer is