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Fretting fatigue life prediction using the extended finite element method

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ABSTRACT

In this work, an efficient procedure to predict fatigue lives in fretting fatigue problems is presented. This is accomplished by means of a combined initiation–propagation approach in which the extended finite element method (X-FEM) is used. The procedure is verified by modelling several fretting fatigue tests available in the literature. The application of the X-FEM enables to numerically evaluate the stress intensity factors (SIFs) for cracks of different lengths emanating at the end of the contact zone and to estimate the propagation life corresponding to each of the tests. This propagation life is combined with the initiation life calculated using a multiaxial fatigue criterion (Fatemi–Socie). The predicted lives are then compared with the reported experimental lives, showing that the consideration of the crack–contact interaction through the numerical models tends to improve the life estimation when compared with a fully analytical approach. The procedure can be applied to more general fretting problems for which analytical solutions are not available.

1. Introduction

Fretting problems are originated by the presence of two or more contacting bodies under compressive loads that undergo small relative displacements of small amplitude, such as those caused by vibrations [1]. In addition, it is often found that one or more of the components are subjected to cyclic stresses producing fatigue crack growth. The combination of both situations is termed fretting fatigue, in which the stress concentration caused by the contact stresses promotes a relative rapid crack initiation [2]. Such problems can be found in bolted, riveted or clamped joints, spline couplings in shafts and fir-tree roots of turbine blades, etc., leading to a substantial reduction of the service life of these components.

In the analysis of the fretting fatigue life and other fatigue problems, two stages are usually distinguished: crack initiation and its subsequent propagation. In recent years, methods have been proposed to predict the total life as a combination of the life spent during the initiation phase and the life associated with the propagation phase. The point at which the initiation phase finishes and the propagation phase begins cannot be precisely defined and some authors propose a certain transition crack length on a rather heuristic basis. In this work, we use a variable initiation length model proposed in [3,4], in which the transition length is not previously fixed, but it depends on the particular load conditions and material properties of the analyzed problem.

The initiation life can be estimated by means of multiaxial fatigue criteria, such as the McDiarmid or the Fatemi–Socie criteria, which are reported to give good results [4]. The propagation life can be analyzed using a crack growth law of the type $da/dN=f(\Delta K)$, e.g. Paris law or other variations based on linear elastic fracture mechanics assumptions (LEFM). The correct calculation of the stress intensity factors (SIFs) plays a crucial role when predicting the life associated with the crack propagation stage. This can affect the estimated total life, especially for problems in which the propagation life is a significant part of the total life, for example in certain fretting problems in which the steep gradients in the vicinity of the contact induce a rapid crack initiation.

On the other hand, the propagation stage in a fretting fatigue problem is substantially different from that of plain fatigue only during the phase in which the crack length is approximately less than the characteristic dimension of the contact zone. Analytical approaches have been used [3] based on the weight function method for estimating the SIF. However, these methods do not take into account the influence of the crack–contact interaction (i.e. alteration of the contact stress and strain fields due to the crack presence) which can be important at the beginning of the propagation stage [5].

For extracting realistic values of the SIFs that take into account the crack–contact interaction, the numerical modelling of the problem becomes necessary and the finite element method (FEM)

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