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Fatigue crack growth simulation in coated materials using X-FEM

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ABSTRACT

In the present work, the eXtended Finite Element Method (XFEM) is used to study the effect of bi-material interfaces on fatigue life in galvanised panels. X-FEM and Paris law are implemented in ABAQUS software using Python code. The XFEM method proved to be an adequate method for stress intensity factor computation, and, furthermore, no remeshing is required for crack growth simulations. A study of fatigue crack growth is conducted for several substrate materials, and the influence of the initial crack angle is ascertained. This study also compares the crack growth rate between three types of bi-materials alloys zinc/steel, zinc/aluminium, and zinc/zinc. The interaction between two cracks and fatigue life, in the presence of bi-material interface, is investigated as well.

1. Introduction

Due to the increase in material costs, many steel manufacturers start to protect steel against corrosion in order to extend its life and to provide more reliable and enduring products. For this purpose, several protection categories are used. The best option in terms of quality/price ratio is the utilisation of galvanised steel plates for car bodies. The galvanising process consists in dipping the steel sheets in a hot bath of zinc for a sufficient time to allow a metallurgical reaction between the steel surface and the molten zinc. Indeed, a protective layer of zinc covers both sides of the galvanised steel and drastically reduces corrosion. In addition, the plates of the vehicles are subjected to complex and cyclic loading combinations due to severe operational conditions. These combinations are at the origin of the starting and the propagation of cracks in these parts, which can lead to fracture [1,2]. For this reason, it is very interesting, through a numerical modelling based on a coupling of X-FEM and Paris law, to describe the fatigue crack growth behaviour in automobile parts. The fatigue crack growth phenomenon has been studied from different points of view by several authors. Paris and Erdogan [3] established an empirical relation between the crack propagation rate and applied stress intensity factors range for crack growth analysis called Paris law. Walker [4] modified the Paris law equation by considering the mean stress effect. Elber [5] used an equivalent stress intensity factor to take into account crack closure under compression. A homogenised XFEM approach has been proposed by [6] to evaluate the fatigue life of an edge crack plate in the presence of discontinuities. Chan [7] has developed a fatigue crack initiation model based on microstructure, which includes explicit crack size and microstructure scale parameters. Fatigue life prediction and crack growth simulation have been studied by the extended finite element method [8–11].

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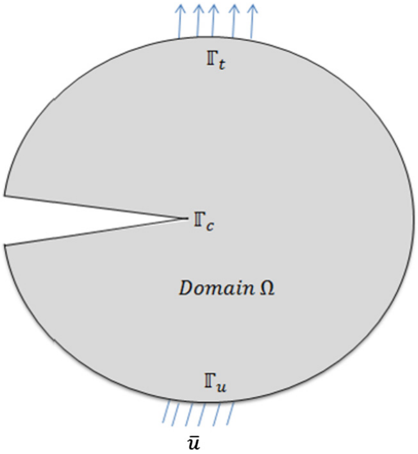

Fig. 1. Description of the problem.

Pathak et al. [9] coupled the Paris law and the element-free Galerkin method to simulate the fatigue crack growth of homogeneous and bi-material interfacial cracks. Ritchie [12] examined the mechanisms of fatigue crack propagation in ductile and brittle solids.

Mazière and Fedelich [13] simulated 2D fatigue crack propagation using the finite element method and implementation of the strip-yield model. Shi and Zhang [14] simulated the interfacial crack growth of fiber-reinforced composites under tension–tension cyclic loading using the finite element method. In their model, the energy release rate is calculated and utilised in the Paris law in order to calculate crack growth rate.

Moreover, an accurate evaluation of stress intensity factor (SIFs) is quite essential for the prediction of failure and crack growth. To evaluate the stress intensity factor of a cracked component, numerical tools such as finite element method (FEM) [15], boundary element method [16], and extended finite element method (XFEM) [16–18] are available. Out of these numerical methods, the extended finite element method has been found to be the most successful and powerful numerical method for solving variety of engineering and science problems. In this method (XFEM), standard finite element approximation is enriched locally with some additional functions [19], which are obtained from the theoretical background of the problem. In this method, a crack can be modelled independently of the finite element mesh. To track a moving discontinuity (crack growth) the level set method is proposed by [20] and was first applied in XFEM by [20,21]. The interaction between bi-material interface with a crack was modelled by the XFEM method [22–24] and examined by several authors [25–28]. The extended finite element method for fracture problems is implemented in ABAQUS software [29] by UEL subroutine.

The present paper focuses on the study of interface effects on the fatigue crack growth in galvanised panels. To this aim, an extended finite element method is coupled with the Paris Law and implemented in ABAQUS software [30] using the Python code.

The paper is organised as follows: Section 2 highlights the discretisation and governing equation of linear elasticity. The fatigue life calculation and the formulation XFEM are also recalled in this section. In the last sections, the numerical method is validated and used to study the effect of interfaces and mechanical properties of substrate on the fatigue crack growth. The interaction between two cracks and inclined crack effect are also touched upon.

2. Numerical formulation

2.1. Discretisation and governing equations

Considering a body Ω with the boundary Γ show Fig. 1. The partial differential equation and boundary conditions for a linear solid mechanics problem can be written as follows [31–33]:

$$\nabla \cdot \sigma + b = 0 \quad \text{in } \Omega \tag{1}$$

$$\sigma \cdot n = \bar{t} \quad \text{on } \Gamma_t \tag{2}$$

$$u = \bar{u} \quad \text{on } \Gamma_u \tag{3}$$

$$\sigma \cdot n = 0 \quad \text{on } \Gamma_c \tag{4}$$

where σ is Cauchy stress tensor, n is the unit outward normal to Ω, $\bar{u}$ and $\bar{t}$ are the prescribed displacements and tractions, respectively, and Γ_t, Γ_u and Γ_c are the traction, displacement and crack boundaries, respectively, and b is the body force.

Based on Eqs. (1)–(4), the variational form of the equilibrium equation can be written as:

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