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Mesh sensitivity effects on fatigue crack growth by crack-tip blunting and re-sharpening

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Abstract

Crack-tip blunting under tensile loads and re-sharpening of the crack-tip during unloading is one of the basic mechanisms for fatigue crack growth in ductile metals. Based on an elastic–perfectly plastic material model, crack growth computations have been continued up to 700 full cycles by using remeshing at several stages of the plastic deformation, with studies of the effect of overloads or compressive underloads. Recent published analyses for the first two cycles have shown folding of the crack surface in compression, leading to something that looks like striations. The influence of mesh refinement is used to study the possibility of this type of behaviour within the present method. Even with much refined meshes no indication of crack surface folding is found here.

Keywords: Crack growth; Plasticity; Large strains; Remeshing; Fatigue

1. Introduction

A basic mechanism for the understanding of fatigue crack growth in ductile metals is that of crack-tip blunting and re-sharpening (Laird and Smith, 1962; Pelloux, 1970; Suresh, 1991). This model gives part of the explanation for crack growth under cyclic loading, but does not account for other important crack growth mechanisms, such as effects of corrosion, debris, damage evolution, etc.

Detailed numerical studies of crack-tip blunting under cyclic loading have been carried out in the last few years (Gu and Ritchie, 1999; Tvergaard and Hutchinson, 2002), using finite strain plasticity to model the large deformations around the crack-tip. These analyses have shown crack growth, and it has been found that the purely ductile growth mechanism can fit into the Paris power law for characterizing fatigue crack growth (Paris and Erdogan, 1963). However, it was only possible to study the first two or three full load cycles, due to very strong mesh distortion in front of the crack-tip. Therefore, the numerical model has been extended by incorporating remeshing techniques (Tvergaard, 2004), and thus crack growth by the

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blunting mechanism has been simulated through several hundred load cycles. It has been found that the crack-tip opening displacement, CTOD, shows a transient behaviour, such that for many cycles initially there is no crack closure at the tip when the minimum load is reached in each cycle, but subsequently the growth pattern develops towards a steady-state, where closure occurs in each cycle. This adds to the understanding obtained in earlier analyses of the possibility of crack closure during fatigue crack growth (Fleck and Newman, 1988; Roychowdhury and Dodds, 2002). The remeshing technique has subsequently been used to study the effect of overloads and the effect of compressive underloads (Tvergaard, 2005, 2006).

In the present paper results for much finer meshes are shown to be able to discuss the mesh sensitivity of the crack growth predictions by crack-tip blunting and re-sharpening. This relates to recent results of Levkovitch et al. (2005), who also used remeshing techniques for a material described by crystal plasticity. Only the first two cycles were analysed by these authors, but the interesting difference is that they found surface folding under compression, leading to something that looks like initiation of striation. It will be shown here that even for the finer meshes applied no surface folding was predicted.

2. Method of analysis

The specimen analysed is a center cracked plate (Fig. 1) subjected to a load at the ends with intensity q. By using this full specimen, rather than conditions of small scale yielding, the solution automatically represents the fact that the mode 1 singularity field develops around the crack-tip when the crack opens, while when the crack closes under compressive loading the stress state switches to uniaxial plane strain compression. The initial crack length is $2a$, the initial width is $2w$, the initial height is $2h$, and the plate, with plane strain conditions applied, has load-free sides. Due to symmetries only one quarter of the plate needs to be analysed numerically; i.e. the region $-a \leqslant x^1 \leqslant w - a$ and $0 \leqslant x^2 \leqslant h$. The crack surface $-a < x^1 < 0$ is traction free, $T^1 = T^2 = 0$, as long as the crack is open ($u^2 > 0$ on the surface). However, if contact occurs at a point of the crack surface, $\dot{u}^2 < 0$ for $u^2 = 0$, these conditions are replaced by the contact condition that the displacement normal to the crack surface is zero, $u^2 = 0$, and the tangential traction on the crack surface is zero, $T^1 = 0$. The traction free

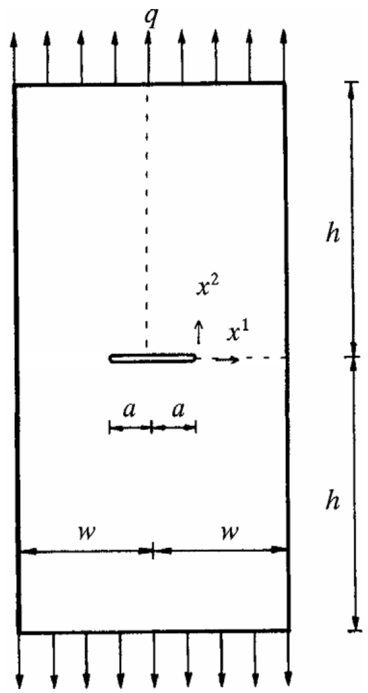

Fig. 1. Plane strain center cracked panel.