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Technical Note

Effect of micro-cavities on different plastic zones at the fatigue crack tip of a compact tension specimen

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ABSTRACT

Knowledge of cyclic plastic deformation response at the fatigue crack tip is crucial to understand the nature of cyclic damage acting on the crack tip. Interaction between crack and defect is equally important to understand the cyclic damage progression at crack tip; however isotropic hardening model was adopted in all existing literatures. Isotropic hardening model is suitable to model only the monotonic plastic zone and unable to model the cyclic/reverse plastic zone. Kinematic hardening model is suitable to model the key cyclic plastic deformation responses like Bauschinger effect, ratcheting, and mean stress relaxation. A non-linear kinematic hardening (Chaboche) model is used in this present investigation to represent the material's cyclic stress–strain response accurately.

Effect of micro-cavity positions (angle and distance from crack tip) and sizes on plastic zones near a crack tip is investigated in this study by two dimensional plane strain finite element model of a compact tension specimen. It is observed that the size and shape of the monotonic and cyclic plastic zones are affected by position and size of the micro-cavity. During asymmetric loading condition, the ratcheting strain accumulation direction is also affected by the position of micro-cavity.

1. Introduction

Progression of plastic deformation and damage at the crack tip is commonly used to study the fracture behaviour of ductile materials. Similarly, advancement of cyclic plastic deformation and damage at the fatigue crack tip is generally used to investigate the fatigue fracture behaviour. Normally three zones are present at the fatigue crack tip: cyclic/reverse plastic zone, monotonic plastic zone and elastic zone. The cyclic plastic zone is surrounded by monotonic plastic zone and these two plastic zones are further surrounded by elastic zone. Among those three zones, cyclic plastic deformation and damage take place only in the cyclic plastic zone. Therefore, size, shape, deformation and damage modes in the cyclic plastic zone always become important in fatigue crack growth study.

Recently number of experimental [1] and numerical [2–5] investigation has conducted to understand the cyclic deformation and damage modes in the cyclic plastic zone. Tong et al. [1–4] have concluded from continuum, visco-plastic and crystal plasticity based finite element analysis that ratcheting takes place in the cyclic plastic zone. Ratcheting can be defined as the progressive accumulation of permanent strain during asymmetric stress cycling. Paul and Tarafder [5] have also reported that accumulation of ratcheting strain in the cyclic plastic zone for R ratio $\neq -1$ (R ratio is the ratio of minimum

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and maximum stress or stress intensity factor). Recently Paul [6] has reported that low cycle fatigue (LCF) takes place in the cyclic plastic zone for R ratio = −1 and ratcheting for R ratio ≠ −1. Similarly, the effect of applied loading condition on size and shape of cyclic plastic zone also has been studied in details by Paul [6].

The fatigue crack growth and its mechanism are essentially influenced by the presence of micro-defects that are inherent to the materials such as micro-cavities. This type of problem has been investigated by several authors [7–12]. However, most authors have considered an elastic or isotropic hardening behaviour of materials. Bouiadjra et al. [13,14] have conducted non-linear finite element investigation and noticed that the size and shape of crack tip plastic zones are significantly affected by the presence of micro-cavity. On the contrary, Bouiadjra et al. [13,14] have used isotropic hardening law to model cyclic plastic deformation. However, kinematic hardening model is suitable to represent the cyclic plastic deformation behaviour of materials [15]. Basic cyclic plastic response of the material like Bauschinger effect, ratcheting and mean stress relaxation cannot be simulated by isotropic hardening model [15,16], on the other hand kinematic hardening model can simulate successfully those key cyclic plastic deformation responses. The cyclic/reverse plastic zone cannot be modelled by isotropic hardening model, as it is unable to describe the Bauschinger effect. Therefore, the effect of micro-defect presence near fatigue crack tip on the plastic zone sizes should be relooked by advanced kinematic hardening model to properly understand it. Thus, Chaboche kinematic hardening model is used in the present work to understand the effect of micro-defects near fatigue crack tip.

2. Finite element analysis

Commercial finite element package ABAQUS [17] is used in this study. Implicit finite element analysis is conducted in the present investigation on a 2D plane strain full compact tension (C(T)) specimen (width (W) = 62.5 mm, height = 60 mm and thickness (B) 20 mm). A stationary fatigue crack with length of 25 mm (notch length 20 mm and 5 mm stationary crack) is considered for the present study (Fig. 1(a)). The semicircular crack tip (Fig. 1) is considered to model crack tip. Similar shape of crack tip is frequently used by number of researchers [18–20]. A 2D finite element mesh is shown in Fig. 1(b), where the meshes are refined in near-tip region to capture the large strain gradients due to the presence of the crack. The 2D plane strain model is meshed by 4-noded quadrilateral element (CPE4R) with reduced integration and enhanced hourglass control to prevent both shear locking and hourglass mode during the analysis. The refined meshes near the crack tip are shown in

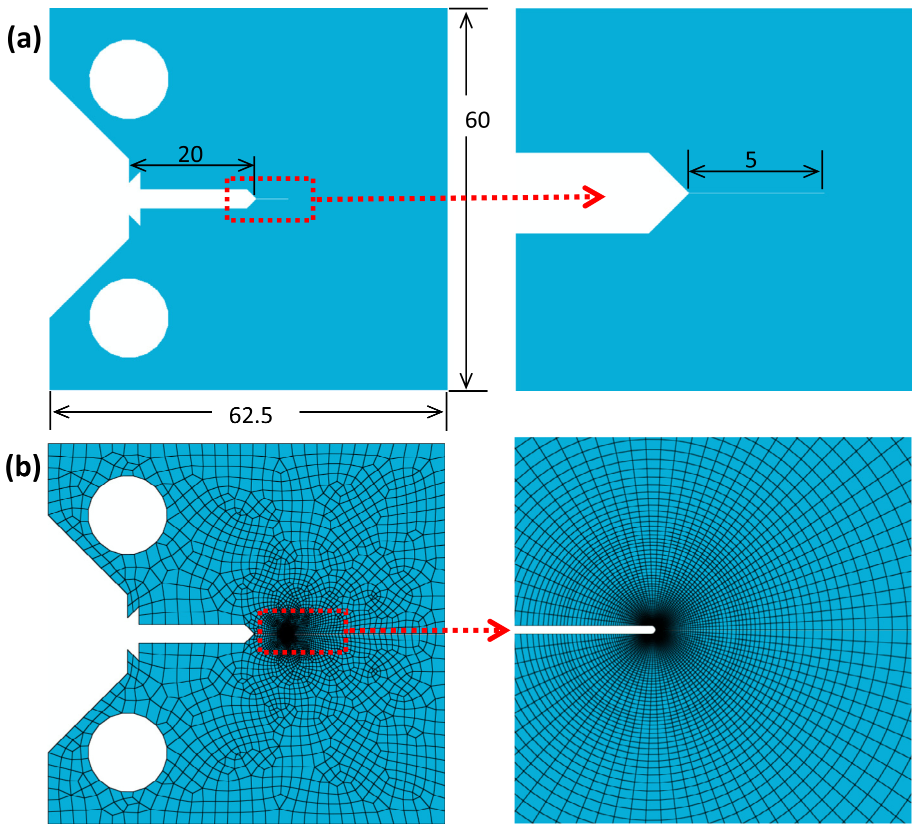

Fig. 1. A full C(T) specimen (right hand side pictures are the zoomed version of left hand side pictures near crack tip): (a) stationary fatigue crack dimensions (all dimensions are in mm) and (b) meshing.