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Some solutions to crack growth effects in metallic materials - crack shape progress and plasticity induced crack closure simulation

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1. Introduction

One of the main contemporary challenges being pertinent to the subject given is the prediction of fatigue crack propagation components made of ductile metallic matter. Owing to the high stresses round the crack tip, strips of constantly deformed material occur along the opposite crack faces in the course of the crack growth [1]. These strips contact each other through portion of the loading cycle, yielding a wedge result known as Plasticity Induced Crack Closure (PICC). It is a basic aspect of the mechanics of propagating cracks that clarifies diverse effects referred to the fatigue crack propagation, such as the effect of stress ratio, mean stress and specimen thickness. Moreover, PICC affects the crack shape evolution (CSE), causing a larger growth retardation (wedging effect) close to face surfaces. The matter is an independent analysis of both events PICC and CSE.

2. Motivation

PICC was studied for established crack shapes, either straight or curved. Among others, elastic-plastic material simulations were considered and followed the strategy that comprises the successive release of nodes after attaching specific load cycles. This tactics permits to develop the plastic wake as the crack grows and to stipulate the crack opening load or stress (P_{op}/P_{max}, S_{op}/S_{max}) which can be employ for estimating the value of a crack driving force such as the effective stress intensity factor extent ($\Delta K_{eff} = K_{max}\,(1–P_{op}/P_{max})$).

The objective of this research is to develop and validate a methodology for the modelling plasticity induced crack closure and crack form evolution rested on elastic-plastic fracture parameters. In this treatise, the plastic crack tip opening displacement extent ($\Delta CTOD_p$) is choosen as the crack driving force, since its relationship with the fatigue crack growth rate is linear and so that, the fatigue CSE and PICC can be predicted along the crack without experimental profile of the crack growth ratio.

3. Methodology

The intended methodology permits to model PICC and CSE concurrently by solving iteratively an elastic-plastic finite simulation which retains the load history information by remeshing and mapping methods and carries out the crack increase by node releasing. The principal phases of the methodology are demonstrated in the flow diagram presented in Fig. 1.

Above all, the linear elastic qualities and hysteretic conduct of the material must be explained. In this work the Von Mises yield criterion was employed together with the

Chaboche hardening law that is correct for symbilizing metals which show kinematic hardening

$$\mathrm{d}\mathbf{X} = C_x \left[X_{\text{sat}} \frac{\boldsymbol{\sigma}' - \mathbf{X}}{\bar{\sigma}} - \mathbf{X} \right] \mathrm{d}\bar{\varepsilon}^{\mathrm{p}} \tag{1}$$

X is the backstress tensor and $\sigma^{\prime}$ is the deviatoric component of the Cauchy stress tensor ε^p and σ are the equivalent plastic strain and the equivalent stress, respectively, whereas C_x and X_{sat} are fitting parameters that can be stipulated by the optimization algorithm.

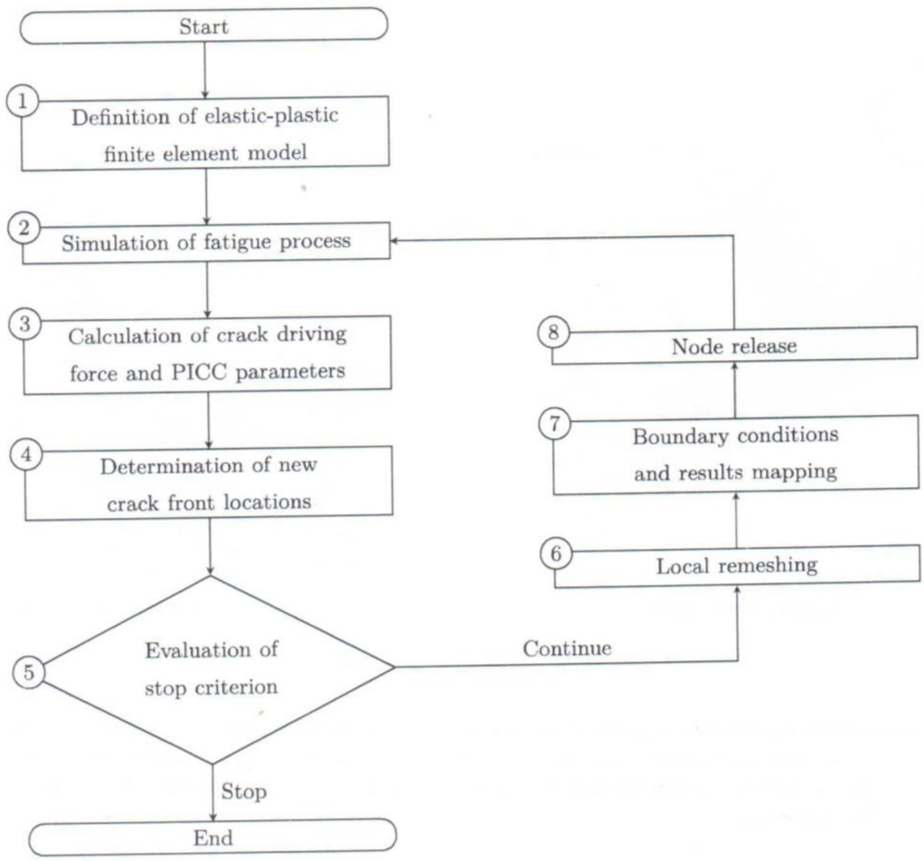

Fig. 1. Flow diagram of the intended methodology [1]

4. Modelling fatigue process

The loading history is now modelled by using the boundary conditions and cyclic loading in question (Fig. 2). Typically, several cycle should be modelled so that to consolidate the material response and get stationary values of the studied variables ($\Delta CTOD_p$ and P_{op}/P_{max}). The optimal number of cycles is still indistinct, because it can be inferred from the different values acquired in the literature, and is often limited by the available computer capacities.

5. Crack driving force and PICC parameters calculation

CTOD is explained as the vertical displacement of the immediate vicinity node behind each crack-front node (Fig. 3), whereas the mesh dependence brought in by such definition can be prevented by consistent in the alternative of the same crack-tip element dimension in description and prediction crack compositions. Δ $CTOD_p$ is taken out from the last loading ramp before the note releases. So as to, the initial elastic region portion is identified, a linear fit is carried out to get the elastic constituent and the difference between complete CTOD and elastic CTOD is received at maximum load. This simple procedure confronts with energetic methods applied for calculating stress intensity factors that mean the evaluation of domain integrals over contours of elements round the crack front.

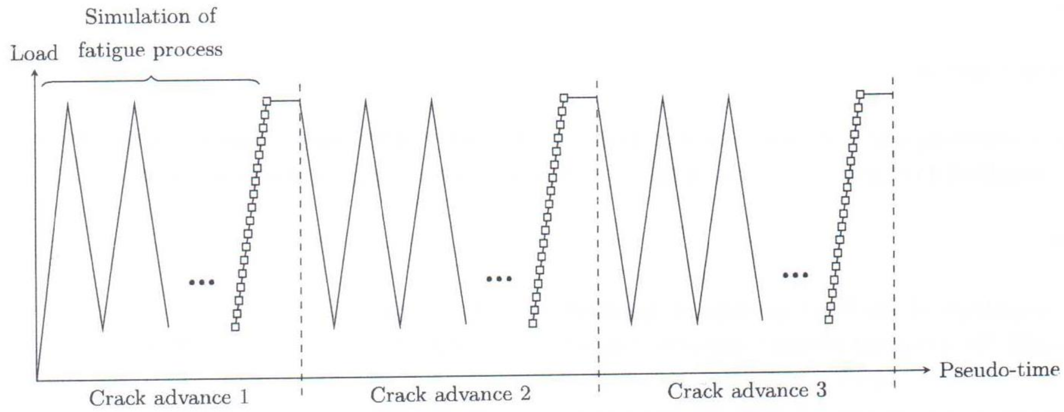

Fig. 2. Schematic example of the applied load cycles [1]

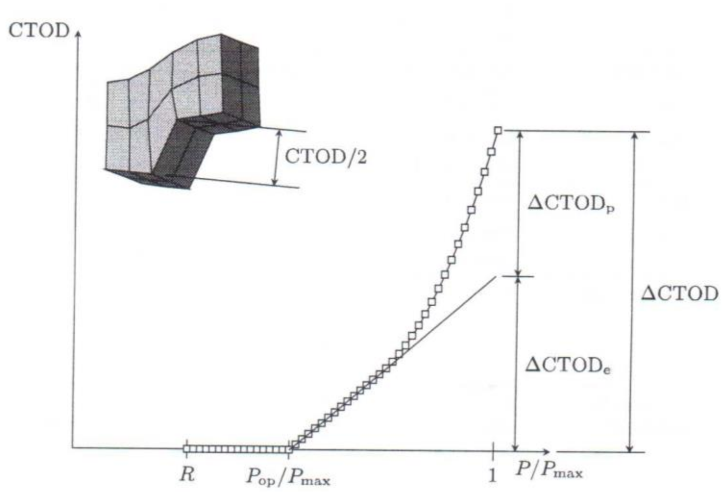

Fig. 3. Crac tip opening displacement measured in the firs node behind the crack front in the last loading ramp

6. Conclusion

It is relevant to compare the results gained in the analysis given with the tendencies watched for other driving forces, such as ΔK_{eff}, that was employed by several authors to do simultaneous modelling PICC and CSE.

For example, Gardin et al [2] modelled the growth of an initially straight through-crack in a compact tension sample, by though about – fixed straight and evolving curved forms.

Shifting to the crack opening load (P_{op}/P_{max}) Branco et al discovered that the crack closure developed next to the surface resulted in an increase of the crack opening load as the crack grows. The principal newness was the using an elastic-plastic fracture parameter rather than the broadly employed effective stress intensity factor range (ΔK_{eff}) what means two pertinent advantages: (a) a lower numerical endeavour, (b) a wider suitability, as large scale yielding scenarios may be analyzed.

It was inferred:

- The suggested methodology is valid, founded on the good numerical – experimental correlation of crack forms and the high arrangement between the watched fracture and PICC tendencies and the literature.
- Δ $CTOD_p$ is an effective crack driving force, since it allows to predict crack forms accurately.
- Δ $CTOD_p$ is an efficient crack driving force, because it demonstrates faster convergence with attached load cycles than the crack opening load. In actual fact, only one cycle has to be attached between note releases so that to stipulate the realistic crack form evolution.

Acknowledgement

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