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DEVELOPMENT AND VERIFICATION OF FE MODEL FOR FATIGUE CRACK GROWTH SIMULATION UNDER MIXED MODE CONDITIONS

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ABSTRACT

From the point of view of physical principles cracks propagation phenomenon is extremely complex process that makes its exact mathematical description very difficult or impossible. Empiric formulas based on experimental works are often used instead. Application of these formulas is usually connected with particular material, from which experimental specimens were manufactured, and sometimes with loading procedure as well. New pieces of knowledge have been observed in a field of fatigue cracks initiation and propagation under complex loading conditions and complex geometry. Classical approaches based on linear and elastic fracture mechanics are not fully valid in many cases. It may be caused by plastic zone at the crack tip (if its size is indispensable in comparison with crack length), and/or by significant constraint influence due to complex geometry.

In this paper, the possibilities of K-T two-parameter fracture mechanics theory implementation into FE simulations of fatigue cracks propagation are discussed. Attention is focused on quantification of a T-Stress influence on the fatigue crack behavior (growth rate and direction of propagation). T-Stress (fracture-mechanics quantity) represents a second non-singular term of the William's expansion, which describes an elastic stress and/or strain field around the crack tip. It represents stress parallel to the crack face and its value is a measure of a crack tip constraint as well. Methodology based on comparison of experimentally determined crack shapes and growth rates with results of FE simulation was employed to validate some crack propagation formulas.

Numerical simulations were carried out for simple test specimens that were utilized in experimental measurements. Special control script code (in programming language Python) is being developed in FME CTU in Prague to simulate fatigue (stable) crack propagation in 2D bodies with general shape and loading using commercial FE code ABAQUS [1, 2]. This control script allows automatic FE model creation, computation of the stress and strain field and fracture parameters (K1, K2, T-Stress and J-integral)

including evaluation of crack propagation direction and remeshing in the domain of crack growth. Crack growth rate was determined using classic Paris law and its modification [3, 4]. The direction of propagation was determined both according to criterion of maximal tangential stress (1) and according to modified criterion respecting T-stress influence (2).

$$\theta = \arccos\left(\frac{3K_{II}^2 + \sqrt{K_I^4 + 8K_I^2 K_{II}^2}}{K_I^2 + 9K_{II}^2}\right), \tag{1}$$

$$K_I \sin\theta + K_{II}(3\cos\theta - 1) - \frac{16T\sqrt{2\pi \cdot r_c}}{3}\sin\frac{\theta}{2}\cos\theta = 0 \Rightarrow \theta \tag{2}$$

where T is T-Stress and θ is predicted crack growth angle.

Experiments were performed using high frequency electro-magnetic loading machine AMSLER. Digital camera with microscopic objective was utilized to monitor the crack propagation during the experiment. Digital pictures were processed with LuciaNet software to determine crack increment (both size and direction) dependency on number of cycles.

Computations and experiments have shown that simple Paris formula can not respect influence of complex geometry and constraint effect. Modification of Paris law is necessary for numerical prediction of crack growth rate [3, 4]. From the point of view of prediction of crack propagation direction was found, that under linear and elastic fracture mechanics conditions both relation (1) and (2) can be used. In cases, where crack tip loading increase due to e.g. stress concentration, more accurate results were achieve using relation (2).

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