COMPUTATIONAL MECHANICS 2018
34th conference with international participation
Srní
October 31 - November 2, 2018

Numerical modelling of plasticity induced crack closure

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Plasticity-induced crack closure (PICC) is the phenomenon discovered by Elber [1] in 1970. Since then, additional closing mechanisms have been introduced, but the plasticity remained the most significant mechanism under various loading conditions. As the crack is loaded, tensile strains are developed near the crack tip, but they are not fully reversed with unloading. Propagating crack than leaves behind so called plastic wake, which is formed by the residual plastic deformations in the direction normal to the crack propagation, causing the crack faces come to the contact before the crack is actually closed. Employing finite element (FE) methods on PICC phenomenon provides closer insight into the closure mechanics, leading to improving the physical background and ability to develop accurate models for fatigue life prediction.

For the purpose of the study, MT specimen with dimensions $2L = 200$ mm, $2W = 60$ mm, $2h = 5$ mm was used (Fig. 1). Specimen was made of steel EA4T (σ_Y = 611 MPa and σ_{UTS} = 727 MPa). Specimen was cyclically loaded with various stress intensity factor range ΔK and also various crack lengths, both following experimentally measured results [2].

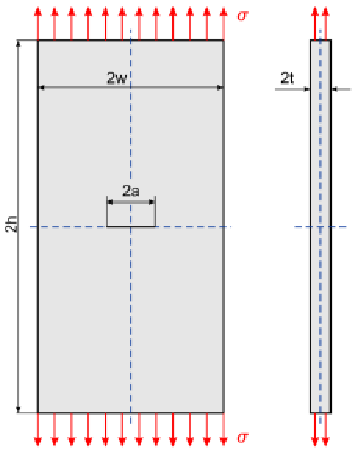

Fig. 1. MT specimen dimensions

Wide research of crack closure aspects in finite element modelling have been published. PICC is a complex problem and FE results depend on many different preprocessing inputs, where finite element mesh is typical example. Most of the researchers prefer linear elements to quadratic, which may create artefacts of residual stresses around the crack tip and edges might have different stiffness due to the middle node. Element size is estimated in connection with the forward plastic zone size r_p, where suggested is to use at least 10 elements through the plastic zone. Important is also the ratio of the element's edges, which should be ideally equal [3].

In order to create plastic wake, it is necessary to introduce cyclic loading followed by crack propagation. Crack growth usually doesn't follow physical laws (Paris law), which is not in the area of interest in this case, but one crack increment is equal to the element size. Therefore, the easiest and most common way of crack propagation is the debonding of constrained nodes. Moment when the node is released differs. Closest to the physical basis is releasing nodes when the load reaches maximum value, although some authors tried to release nodes in different cycle stages. Crack is recommended to let grow at least through the initial plastic zone size, although in some cases solution needs more cycles to reach convergency [3, 4].

Crack closure itself offers also many options how to be determined. Elber noticed the sudden change in geometry stiffness while unloading, which he assigned to the crack faces closure. Based on this, experimentally measured closure uses this technique up today. FE modelling offers apart from the stiffness change, Fig. 2, also another options. Most common is to evaluate the closure by the monitoring of the displacement sign change of the first node behind the crack tip. When the sign changes from positive to negative, crack is closed and the closing force can be estimated, Fig. 3. In order to capture correct closing force, it is essential to use reasonable amount of substeps in each iteration cycle. Similar approach is the monitoring of stresses sign change right on the crack tip. Other possibility is to check contact pressure on the crack faces.

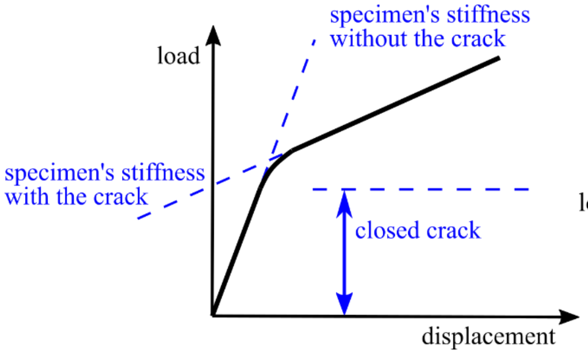

Fig. 2. Stiffness change when the closure occurs

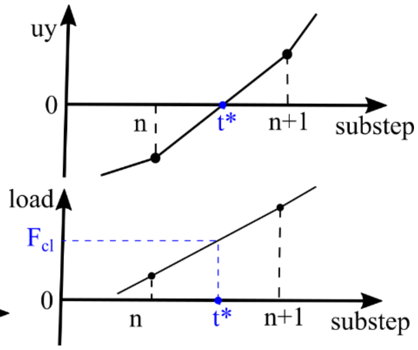

Fig. 3. Closure determination by first node displacement monitoring

These are most significant inputs which have significant impact on the crack closure determination. Most of researchers put their effort into the clarification of these relations in terms of finite element modelling only (e.g. mesh refinement in order to obtain converged solution). However, wide confrontation with experimental results is missing. Presented research aims for finding optimal finite element model configuration, which takes into account agreement with experimental results. Results presented can help to clarified methodology of plasticity induced crack closure numerical simulations.

Plasticity induced crack closure was numerically estimated on two-dimensional FE models. Different methods of determinations were compared and discussed. Optimal FE model configuration was defined, particularly in connection with experimental results. This could be a first step for full three dimensional model of the crack to determined plasticity induced crack closure.

Acknowledgements

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the project m-IPMinfra (CZ.02.1.01/0.0/0.0/16_013/0001823) and specific research project FSI-S-17-4386 of the Faculty of Mechanical Engineering, BUT.

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