Correlation between the pivot node concept and fatigue crack closure

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ABSTRACT

The study of fatigue crack growth has been commonly done by means of bi-dimensional models and assuming a homogeneous behaviour through the thickness. According to the specimen thickness, a state of plane stress or plane strain is presumed. However, recently, it has been shown that thickness effects influence considerably the crack tip behaviour. Tri-dimensional studies present a higher computational cost but the current computational capabilities has triggered their use. These works have revealed a series of effects along the thickness with a strong influence on the crack front growth: plastic zone size, crack closure or stress intensity factor distribution [1-6].

One of the experimental evidences that can be explained as a direct consequence of these effects is the curvature of the crack. It is observed that when the crack advance, the crack front changes adopting a curved shape, growing faster at the interior than at the exterior. Two mechanisms can explain this effect: the first one is related to the crack closure effect near the surface, it would imply a smaller effective ΔK close to the surface, and therefore a slower crack growth rate. The second one, related to the plastic zone size decrement observed in a small region close to the surface, is due to ΔK being smaller near the surface than in the interior. Both mechanisms are difficult to evaluate separately. A series of works were devoted to study these effects.

A research line has been focused in the analysis of the stress intensity factor distribution along the thickness [4-6]. These works evaluate the finite element model (FEM) of an Al 2024-T35 compact tension specimen with no plastic wake effect introduced, according to the methodology developed by the authors. The three-dimensional behaviour in the vicinity of the crack front is simulated through numerical analysis with ANSYS code and J-integral method is used to determinate the curves of K evolution along the thickness. The main finding of these studies is that the distribution of K is not homogeneous, it presents a variable profile through the thickness. The overall values for the whole model accurately agree with the nominal K applied.

The K profiles along the thickness are characterized by a series of parameters that allow us to analyze the distribution of K in terms of the expected K_{nom} against variations of geometrical (thickness) and external (applied load) factors. We can observe three different zones limited by two characteristic points, one which separates the results according to whether they are higher or lower than K_{nom} (denoted Do) or the point (called Da) corresponding to a distributed load state similar to the middle plane of the specimen. Results for different thicknesses (b = 3-9 mm) and loads applied (K_{nom} = 9-30 MPa·m$^{1/2}$) were studied. For all these cases the abrupt drop in the results was maintained in an area close to the outside of the specimen.

One of the most relevant finding was the identification of a point at a certain distance of the external surface where the value obtained of K was constant regardless the load applied. This point was called pivot node and presents advantages for the correlation of numerical and experimental studies. The significance of this finding is that the SIF remains independent of the load range. This suggests the hypothesis that

differences found on K at the interior or the exterior of this pivot node would lead to differences on crack growth rates that will shape the curvature of the crack, however the overall crack growth rate would be dominated by the K_{nom} defined at this point.

Another important issue was that when evaluating the influence of the thickness, the position of the pivot node is related with the absolute distance to the surface instead to an equivalent dimensionless distance for each thickness. The position of the pivot node was in the range 0.36-41 mm from the surface, for all the thicknesses and load levels studied.

As the dependence of the binomial maximum load - thickness disappears in this narrow region of the thickness, this becomes an ideal zone to correlate results (experimental or numerical). It was observed that these results agreed with previous experimental results where numerical crack closure prediction were validated with experimental crack growth data [1].

Crack opening and closure values, obtained for 3D finite element model with constant amplitude load, were evaluated along the thickness and used to evaluate their correlation with different experimental crack growth data with different R. The correlation coefficients were used to identify the position of the thickness for maximum correlation. When the results were plotted in terms of the absolute distance to the exterior, it was found that the maximum values were present in the same area, ranging from 0.2 to 0.4, coincident with the region of the specimen correspondent to the pivot node.

The present paper look into the relation between fatigue crack closure estimation and the significance of the pivot node concept. The previous correlation was made in terms of a constant K_{nom}. In the present work, K values necessaries to obtain ΔK_{eff} are updated according to the SIF distribution along the thickness obtained with the fracture simulations (without plastic wake). Correlations confirms the previous conclusion regarding the significance of the pivot node position.

REFERENCES

[1] Gonzalez-Herrera A, Zapatero J. Tri-dimensional numerical modeling of plasticity induced crack closure. Eng Fract Mech 75:4513–28 (2008).

[2] Camas, D., Garcia-Manrique, J., Gonzalez-Herrera, A. Numerical study of the thickness transition in bi-dimensional specimen cracks. Int J Fatigue 33:952- (2011).

[3] Camas, D., Garcia-Manrique, J., Gonzalez-Herrera, A. Crack front curvature: Influence and effects on the crack tip fields in bi-dimensional specimens, Int J Fatigue 44:41-50. (2012).

[4] Garcia-Manrique, J., Camas, D., Lopez-Crespo, P., Gonzalez-Herrera, A. Stress intensity factor analysis of through thickness effects. Int J Fatigue 46:58-66. (2013).

[5] Garcia-Manrique, J., Camas, D., Gonzalez-Herrera, A., Study of the stress intensity factor analysis through thickness: Methodological aspects, Fatigue Fract. Eng. Mater. Struct. 40:1295-1308. (2017).

[6] Garcia-Manrique, J., Camas-Peña D., Lopez-Martinez J., Gonzalez-Herrera A. Analysis of the stress intensity factor along the thickness: The concept of pivot node on straight crack fronts. Fatigue Fract Eng Mater Struct. (2017). (in press)