3-D CONSTRAINT EFFECTS IN SUBSIZE SE(B) SPECIMENS OF NFA-14YWT WITH TRANSVERSE DELAMINATION

Claudio Ruggieri[1]*

[1]*University of São Paulo, São Paulo, SP, Brazil*
* *Presenting Author email: claudio.ruggieri@usp.br*

Abstract
This investigation addresses a numerical investigation of the crack front fields and effects of crack-tip constraint in subsized SE(B) specimens with transverse delamination. Nonlinear numerical analyses of very detailed 3-D finite element models of SE(B) fracture specimens for nanostructured ferritic alloy (NFA) material enable assessing the effects of prescribed delamination cracks on the crack front fields with increased deformation levels as characterized by the *J*-integral. Overall, the present analyses reveal important features of 3-D crack front fields in fracture specimens with transverse delamination that have a direct bearing on the often observed toughness increase in fracture testing of materials with through-thickness anisotropy in mechanical properties.

1. Introduction

The rapidly increasing demand for energy has stimulated renewed interest in alternative energy sources, including nuclear fission and specifically nuclear fusion power reactors. However, the development of nuclear fusion as a viable energy source represents perhaps one of the most difficult and complex scientific and engineering challenges. In particular, the use of advanced structural materials capable of assuring safe and reliable operation under extreme and hostile conditions plays a key hole in structural integrity analysis of nuclear fusion power reactors. These demands have prompted the development of nanostructured ferritic alloys (NFA) made of an ultrahigh density of nm-scale Y-Ti-O rich oxide nanofeatures (NFs) that provides outstanding combination of high strength, ductility and fracture toughness. Possibly the most notable characteristic of the NFA material is the high fracture toughness properties and very low transition temperatures associated with delamination cracking in the transverse (L-T or T-L) direction as demonstrated in the experimental studies of Alam et al.[1]. Here, the development of delamination cracks affects the macroscopic fracture behavior by changing the crack front (through thickness) constraint and, at the same time, providing an additional contribution to the total work of fracture.

2. Results

The numerical solutions to analyze delamination cracking effects on fracture behavior described next utilize a conventional elastic-plastic constitutive model with conventional Mises plasticity in large geometry change (LGC) setting. The finite element code WARP3D provides the numerical solutions for the 3-D analyses reported here. Figure 1(a) shows the 3-D finite element model for a 20% side-grooved SE(B) specimen with a/W=0.5. The transverse delamination process is modeled by introducing a delamination crack in the specimen center-plane region with a prescribed lenght, ℓ_D, and height, h_D, at the onset of loading as depicted in Fig. 1(b). The highly refined finite element mesh shown in Fig. 1(c) defines the delamination crack region to accurately resolve the near-tip stress and strain fields, in which the size of the square elements within the thin slab is 0.025 mm.

Figure 2(a-b) shows the development of near-tip opening stresses, σ_{yy}, and out-of-plane stresses, σ_{zz}, with increased levels of deformation, as characterized by K_J, for the analyzed SE(B) models with a transverse delamination crack of ℓ_D=0.50 mm and h_D=0.25 mm. Clearly, the introduction of a delamination crack creates a stress-free surface at the center plane thereby relaxing the through-thickness constraint and, at the same time, shifting the near-tip highly stressed region to the middle portion of the remaining thickness ligament (this corresponds approximately to $Z/(B/2)\approx 0.4\sim 0.5$). Here, the opening stresses at the nearest

[1] M. E. Alam, N. J. Cunningham, D. Gragg, K. Fields, G. R. Odette, V. Hoelzer, S. A. Maloy, Mechanical properties characterization of a larger best practice heat of 14YWT NFA1, Tech. Rep. DOE/ER-0313/56, Department of Energy (DOE) (2014).

layer to the specimen center plane fall rapidly to values of $\approx 1.2\sigma_{ys}$ for $r/(J/\sigma_{ys})\geq 1$ whereas the σ_{zz}-stresses vanish at $Z/(B/2)=0$ and $Z/(B/2)=1$.

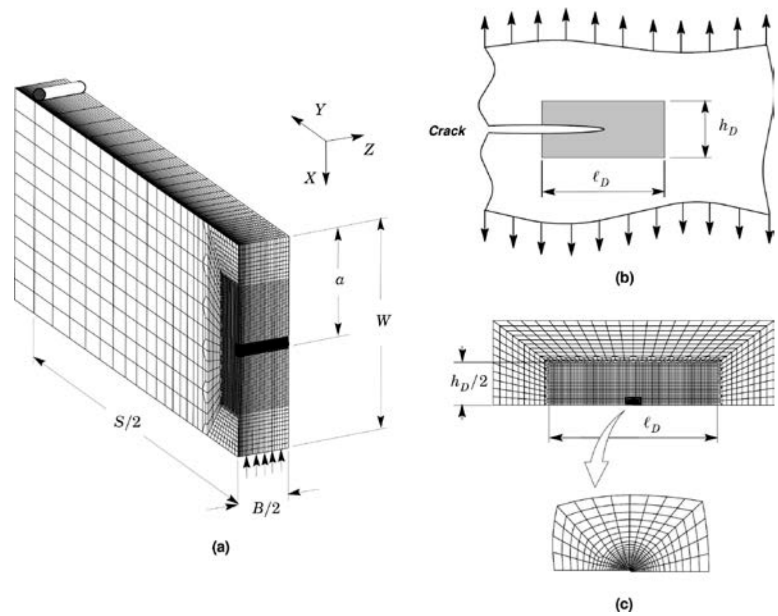

Fig. 1- (a) Quarter-symmetric finite element model used in the 3-D analyses of the tested SE(B) specimen with *a/W*=0.5. (b) Schematic for the adopted geometry of the transverse rectangular delamination; (c) Finite element model of the transverse rectangular delamination including the near-tip mesh detail.

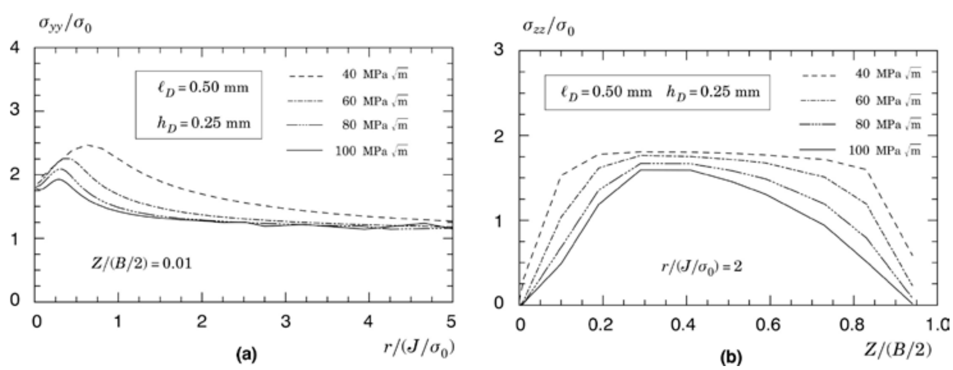

Fig. 2 - Development of near-tip opening stresses, σ_{yy}, and out-of-plane stresses, σ_{zz}, with increased levels of deformation for the analyzed SE(B) models with a transverse delamination crack.

3. Conclusions

The 3-D numerical analyses show that formation of a crack-divider delamination creates a stress-free surface at the center plane thereby relaxing the through-thickness constraint and, at the same time, shifting the near-tip highly stressed region to the middle portion of the remaining specimen thickness ligament. More importantly, though, the onset of a transverse center-plane delamination crack effectively divides the bulk of the specimen so that only a reduced portion of the crack front is subjected to high levels of crack-tip loading (as measured by J or K_J) thereby potentially enhancing macroscopic fracture toughness behavior.

Acknowledgements

The author acknowledges the many useful discussions and contributions of his colleagueProf. Robert G. Odette (University of California at Santa Barbara).