DELAMINATION MODELING IN A DOUBLE CANTILEVER BEAM USING S-VERSION FINITE ELEMENT METHOD AND COHESIVE ZONE MODEL

Wei Xie

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, Shaanxi, China, nwpuxiewei@ nwpu.edu.cn

Keywords: Adhesive joint, Cohesive zone model, S-version finite element method, Delamination

ABSTRACT

Structural adhesive joints are being widely used in aerospace, automotive, biomedical, microelectronics and reliable methods are needed for predicting joint strength. Analytical solutions for the prediction of adhesive joint strength are limited in their ability to predict damage and failure as they are mostly applicable to simple geometries and may not consider the complex stress states experienced in service environments. Numerical techniques, specifically those based on the finite element method, have provided a means for analyzing and predicting the failure of adhesive joints under various loading conditions. Failure prediction may be classified as methods based on strength of materials, fracture mechanics, and damage mechanics [1].

Therefore, the use of adhesive joints in critical structural applications necessitates the developments of robust integrity assessment methodologies and testing procedures in order to tackle fracture events. A valuable approach for analyzing the fracture properties of adhesive bonded joints is represented by the Virtual Crack Closure Technique (VCCT) [2], or using cohesive finite elements [3-7]. Delamination growth is predicted when a combination of the components of the energy release rate is equal to a critical value. There are some difficulties when using the VCCT in the simulation of progressive delamination. The calculation of fracture parameters requires nodal variables and topological information from the nodes ahead and behind the crack front. Such calculations are tedious to perform and may require remeshing for crack propagation. The use of cohesive finite elements can overcome some of these above difficulties. Cohesive finite elements can predict both the onset and the non-self-similar propagation of delamination. However, the simulation of progressive delamination using cohesive elements poses numerical difficulties related to the proper definition of the stiffness of the cohesive layer and a very fine mesh to avoid spurious oscillations in the load-displacement curve [8,9], which make analysis very time consuming and computationally expensive.

A less expensive method in terms of the CPU time requirement for studying adhesive joints and crack propagation of aircraft structures is the s-vision finite element method. As one of the mesh refinement technique, the s-version finite element method was firstly proposed by Fish [10]. The idea of this method is to overlay a fine local mesh into the concerned area, which is discretized as a rough global mesh. A re-meshing process is not needed by introducing the superimposed finite element method, and the performance is similar to a fine mesh. Due to this advantage, this method is applied to various fields such as laminated composites [11], elasto-dynamic problems [12], crack propagation [13], etc. Recently, an efficient superimposed finite element method has been proposed by Park et al. [14]. As the boundary in the global mesh coincides with the boundary in the local mesh, computational cost is reduced. This method is applied to adhesive joints for an efficient generation of a fine mesh in the thin adhesive layer. An initial global mesh is generated in the substrate. Then, a fine local mesh is overlaid on the global mesh located at the interface between the adhesive and the substrate. Finally, cohesive elements are generated in the adhesive layer using the global nodes and local nodes at the interface.

In the present study, CZM has been used in order to investigate fracture behaviour in a pre-cracked double cantilever beam (DCB). In particular, finite element implementation of eight nodes cohesive elements is accomplished using the three dimensional s-version finite element method. The sensitivity of the cohesive zone parameters (i.e. fracture strength and critical energy release rate) in

predicting the overall mechanical response is first examined; subsequently, these parameters are tuned comparing numerically simulated load-displacement curves with experimental.

In the study of the adhesively bonded DCB of aircraft structures using the s-version finite element method, it was observed that both the global and the global–local models produced very similar deformations in the area of the interest for every step of the total deformation. Considering the total degrees of freedom associated with every model, the data library size required to store the output file, and the CPU time required to simulate the model, the s-version method showed a considerable improvement over the global analysis. More than 80% data storage space and more than 65% CPU time requirement could be saved using the s-version method.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support by National Natural Science Foundation of China (No.11672238), the Natural Science Basic Research in Shaanxi Province of China (No. 2017JM1027). Wei Xie would like to thank Prof. Masanori Kikuchi for assistance with the s-FEM.

REFERENCES

[1] Da Silva, L. F. M. and Campilho, R. D. S. G., *Advances in Numerical Modelling of Adhesive Joints*, Springer, Berlin, 2012.

[2] Krueger R, The virtual crack closure technique: history, approach and applications, *NASA/Contractor Report-2002-211628*, 2002.

[3] Alfano G, Crisfield MA, Finite element interface models for the delamination analysis of laminated composites: mechanical and computational issues, *Int J Numer Methods Engng*, 77, 2001, PP.111–70.

[4] Camanho PP, Da ́vila CG, de Moura MF, Numerical simulation of mixed-mode progressive delamination in composite materials, *J Compos Mater*, 37, 2003, PP.1415–38.

[5] Goyal-Singhal V, Johnson ER, Da ́vila CG, Irreversible constitutive law for modeling the delamination process using interfacial surface discontinuities, *Compos Struct*, 64, 2004, PP.91–105.

[6] Turon A, Camanho PP, Costa J, Da ́vila CG, An interface damage model for the simulation of delamination under variable-mode ratio in composite materials, *NASA/Technical Memorandum* 213277, 2004.

[7] Turon A, Camanho PP, Costa J, Da ́vila CG, A damage model for the simulation of delamination under variable-mode loading, *Mech Mater*, 38, 2006, PP.1072–89.

[8] A. Turon, C.G. Davila, P.P. Camanho, J. Costa, An engineering solution for mesh size effects in the simulation of delamination using cohesive zone models, *Engineering Fracture Mechanics*, 74, 2007, PP.1665–1682.

[9] Mohammad M. Islam, Rakesh K. Kapania, Global-Local Finite Element Analysis of Adhesive Joints and Crack propagation, *Journal of Aircraft*, 51, 2014, PP. 310-319.

[10] Fish J, The s-version of the finite element method, *Comput Struct*, 43, 1992, PP. 539–47.

[11] Fish J, Guttal R, The s-version of finite element method for laminated composite, *Int J Numer Method Eng*, 39, 1996, PP.3641–62.

[12] Yue Z, Robbins Jr. DH, Adaptive superposition of finite element meshes in elastodynamic problems, *Int J Numer Method Eng*, 63, 2005, PP. 1604–35.

[13] Lee SH, Song JH, Yoon YC, Zi G, Belytschko T, Combined extended and superimposed finite element method for cracks, *Int J Numer Method Eng*, 59, 2004, PP. 1119–36.

[14] Park JW, Hwang JW, Kim YH, Efficient finite element analysis using mesh superposition technique, Finite Elem Anal Des, 39, 2003, PP. 619–38.