REDUCTION OF TRANSVERSE SHEAR STIFFNESSES OF TRANSVERSELY CRACKED LAMINATES

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Abstract

Transverse matrix cracking has been investigated extensively. One of the key issues in studies on this subject is stiffness reduction of laminate due to the existence of transverse cracks in the laminate. Most accounts in the literature examine the in-plane stiffnesses [1-7] with few capable of predicting the bending stiffnesses [8-10]. There has been no account available in the literature, to the best of the authors' knowledge, dealing with the reduction of transverse shear stiffnesses of transversely cracked laminates.

While enjoying numerous advantageous characteristics, laminated composites suffer from their low transverse stiffnesses and strengths. This makes the consideration of transverse shear deformation in laminate analyses essential. Laminated composites are also susceptive to damage of various types, transverse cracking being one of them, resulting from lateral impacts, for instance. Transverse cracks in laminated composites undermine not only the in-plane and bending stiffnesses of the laminate, but also the transverse shear stiffnesses. Given the generic weakness of laminated composites in transverse shear stiffnesses, the reduction of transverse shear stiffnesses due to damage constitute a severe consideration in the application of laminated composites designed to tolerate a level of damage in form of transverse matrix cracks. The present paper is devoted to the prediction of reduction of transverse shear stiffnesses due to the presence of transverse cracks in some of the laminae of the laminate.

Various approaches can be found in the literature for the analysis of transversely cracked laminates, e.g. shear lag [1,2], variational approach [3,4], stress transfer [5], continuum damage mechanics [6], finite elements [7] and finite strips [8]. Most of them are generically restrictive and hence impossible to accommodate the mechanism of transverse shear deformation as described in a laminate theory, e.g. Reissner-Mindlin type. The present work extends the finite strip method as developed by one of the authors previously [8] which was based on a generalized plane strain condition so that both in-plane and bending deformation can be incorporated while keeping the presentation of the problem two-dimensional. In order to incorporate also transverse shear deformation, the generalized plane strain problem has to be generalized further. This has been presented in the paper. The new generalized plane strain problem remains 2-D in presentation. Boundary conditions are derived based on the assumption that cracks in the laminate are regularly spaced.

The finite strip method is then applied to the new generalized plane strain problem for the discretization of cracked laminates in the direction through the thickness, resulting in a set of simultaneous ordinary differential equations. Instead of further discretizing the problem in the remaining in-plane coordinate using Fourier series as was done in the previous approach in order to transform the problem into a set of simultaneous algebraic equations [8], the mathematical software, Matlab, is employed to solve the simultaneous ordinary differential equations directly after imposing appropriate boundary conditions.

With the mathematical power of Matlab, an improved finite strip analysis has been achieved before being extended to incorporate transverse shear. The results have been validated against those obtained previously.

Detailed analyses of the transverse shear deformation in cracked laminates have been performed and results obtained and discussed. Due to the lack of results in the literature on this subject for comparison and validation of the present analysis, possible experiments have been proposed.

References

[1] Garrett,K.W. and Bailey,J.E. Multiple transverse fracture in 90° cross-ply laminates of a glass fibre-reinforced polyester. *J. Mater. Sci.* Vol. 12, pp 157-168,1977

[2] Highsmith,A.L. and Reifsnider,K.L. Stiffness-reduction mechanisms in composite laminates. *Damage in Composite Materials*. ASTM-STP-775, pp 103-117, 1982

[3] Hashin,Z. 1985 Analysis of cracked laminates: a variational approach. *Mechanics of Materials*. Vol.4, pp121-136

[4] Nairn J.A. and Hu S., Matrix microcracking, *Damage Mechanics of Composite Materials*, ed. R. Talreja, Elsevier, Amsterdam, pp187-243, 1994

[5] McCartney L.N., Theory of stress-transfer in a 0°-90°-0° cross-ply laminate containing a parallel array of transverse cracks, *J. Mech Phys. Solids*, Vol. 40, pp27-68, 1992

[6] Talreja R., A continuum mechanics characterization of damage in composite materials, *Proc. R. Soc. Lond.* A339, pp195-216, 1985

[7] Herakovich, C.T., Aboundi, J., Lee, S.W. and Strauss, E.A. Damage in composite laminates: effects of transverse cracks. *Mechanics of Materials*. Vol.7, pp91-107, 1988

[8] Li S., Reid S.R.and Soden P.D., A finite strip analysis of cracked laminates, *Mech. of Mater*., Vol.18, pp289-311, 1994

[9] Smith P.A.and Ogin, S.L. Characterisation and modelling of matrix cracking in a (0/90)2s GFRP laminate loaded in flexure, *Proc. Roy. Soc. Lond*. A456, pp2755-2770, 2000

[10] Kuriakose S. and Talreja R. Variational solutions to stresses in cracked cross-ply laminates under bending. *Int. J. Solids Struct.*, Vol. 41, pp2331-2347, 2004