Modal Analysis of Delaminated Composite Laminates Using Interlaminar Stress Continuity Theory

蔡其宏、李春穎

E-mail: 9314607@mail.dyu.edu.tw

ABSTRACT

The strength of composite laminates is weak in the lateral direction, especially in the interlaminar interfaces. Therefore, the interlaminar stress between adjacent laminates has been the focus of the analysis of composite laminates. Delamination damage often occurs when the interlaminar interfaces are subjected to severe loading. In this study, an interlaminar stress continuity theory incorporating linear interfacial slip is used to derive a theoretical model of composite laminated structure subjected to cylindrical bending. The Hamilton ’ s Principle is also applied to set up a finite element model. As the displacement field of generalized interlaminar stress continuity theory satisfies all the interlaminar stress continuity conditions, all three stress components can be obtained directly by the constitutive equations. The validity of the proposed theory is demonstrated first by comparing the simulation with the closed form solution. Then numerical results disclose the effects of ship constant and location of the delaminated interface on the first three modes ’ resonance frequencies. It is shown that the delaminated interface has higher influence on the decrement of the resonance frequency of higher order modes. In additionally the delamination at the mode of the mode shape has more pronounced effect on the reduction of that particular mode.

Keywords : Interlaminar Stress, linear interfacial slip,Interlaminar Stress Continuity Theory

Table of Contents

較低 44 圖4.27 為取自圖4.25之第二模態頻率與完美接著之比較 44 圖4.28 為取自圖4.25之第三模態頻率與完美接著之比較 45 圖4.29 為將完美接著與分別在各個元素依序具有瑕疵知構件作比較，可知完美接著結構之靜態剛性皆較有瑕疵情況者為佳 45 表目錄 表1 複合材料應用例 4 符號說明

REFERENCES

[1]梁雅卿， http://www.tmmfa.org.tw/magazine/出版刊物/第21期/2112.htm [2]W. J. Cantwell, and J. Morton,“ The Significance of Damage and -Defects and Their Detection in Composite Materials: A Review, ”-Journal of Strain Analysis, 1992, Vol. 27, No. 1, pp.29-42.
[3]E. Carrera,“ A Priori vs A Posteriori Evaluation of Transverse -Stresses in Multilayered Orthotropic Plates, ” Composite -Structures, 2000, Vol.48, pp.245-260.
[4]T. Kant and K. Swaminathan,“ Estimation of Transverse/ -Interlaminar Stresses in Laminated Composites – Selective -Review and Survey of Current Development, ” Composite -Structures, 2000, Vol.49, pp.65-75.
[5]J. N. Reddy, Mechanics of Laminated Composite Plates – Theory -and Analysis, CRC Press, 1997.
[6]H. Murakami,“ Laminated Composite Plate Theory with -Improved In-Plate Response, ” Journal of Applied Mechanics, -1986, Vol.53, pp.661-666.
[7]M. DiSciuva,“ A General Quadrilateral Multilayered Plate -Element with Continuous Interlaminar Stresses,“ Computers and -Structures, 1993, Vol.47, No.1, pp.91.
[8]C.Y. Lee and D. Liu,“ An Interlaminar Stress Continuity Theory -for Laminated Composite Analysis, ” Computers and Structures, -1992, Vol.42, pp.59-78.
[9]C. Y. Lee and C. H. Shu,“ Layer Reductio n Technique in the -Interlaminar Shear Stress Analysis of Laminated Cylindrical -Shells ”, The Journal of the Chinese Society of Mechanical -Engineers, 1998, Vol.19, No.4, pp.433-439.
[10]C. Y. Lee and J. M. Chen,“ Interlaminar Shear Stress Analysis of -Composite Laminate with Layer Reduction Technique, ”-International Journal for Numerical Methods in Engineering, -1996, Vol.39, pp.847-865.
[11]D. Liu, L. Xu, and X. Lu,“ Stress Analysis of Imperfect -Composite Laminates with an Interlaminar Bonding Theory, ”-International Journal of Numerical Methods in Engineering, -1994, Vol.37, pp.2819- 2839.
[12]T. O. Williams, and F. L. Addessio,“ A General Theory for -Laminated Plates with Delaminations, ” International Journal of -Solids and Structures, 1997, Vol. 34, No. 16, pp.2003-2024.
[13]A. Needleman,“ An Analysis of Decohesion along An Imperfect -Interface, ” International Journal of Fracture, 1990, Vol. 42, -pp.21-40 [14]張石平、李春穎、劉達新， ”層間應力連續理論用於脫層積層 板之圓柱彎曲分析 ”， 2003，中華民國第二十七屆全國力學會 議論文集 ，論文編號E178。
[15]N. J. Salamon,“ An Assessment of the Interlaminar Stress -Problem in Laminated Composites, ” Journal of Composite -Materials Supplement, 1980, Vol. 14, pp.177-194.
[16]R. S. Sandhu, W. E. Wolfe, R. L. Sierakowski, C. C. Chang, and -H. R. Chu,“ Finite Element Analysis of Free-Edge Delamination -in Laminated Composite Specimens, ” U.S. Air Force Wright -Laboratory Report, 1991, WL-TR-91-3022.
[17]N. J. Pagano,“ Influence of Shear Coupling in Cylindrical -Bending of Anisotropic Laminates, ” Journal of Composite -Materials, 1970, Vol. 4, pp.330-343.
[18]R.B. Pipes,“ Interlaminar Stresses in Composite Laminates, ”-Technical Report, 1972, AFML-TR-72-18.
[19]S. Tang,“ A Boundary Layer Theory – Part I: Laminated -Composites in Plane Stress, ” Journal of Composite Materials, -1971, Vol.9, pp. 33-41.
[20]S. Tang and A. Levy,“ A Boundary Layer Theory – Part 2: -Extension of Laminate Finite Strip, ” Journal of Composite -Materials, 1975, Vol. 9, pp. 42-52.
[21]A. S. Wang, and F. W. Crossman,“ Edge Effects on Laterally -Thermally Induced Stresses in Composite Laminates, ” Journal of -Composite Materials, 1977, Vol. 11, pp.300-312.
[22]A. S. Wang, and F. W. Crossman,“ Some New Results on Edge -Effect in Symmetric Composite Laminates, ” Journal of -Composite Materials, 1977, Vol. 11, pp.92-106.
[23]C. T. Herakovich, A. Nagarkar, and O. D. A. Brien,“ Failure -Analysis of Composite Laminates with Free Edge, Modern -Development in Composite Materials and Structures, ” in Vinson, -J. R. Ed., American Society of Mechanical Engineers , 1979 -pp.53-66.
[24]I. S. Raju, and J. H. Jr. Crew,“ Interlaminar Stress Singularities at -a Straight Free Edge in Composite Laminates, ” Computers and -Structures, 1981, Vol. 14, pp.21-28.
[25]I. S. Raju, J. D. Whitcomb, and J. G. Goree,“ A New Look at -Numerical Analysis of Free-Edge Stresses in Composite -Laminates, ” 1980, NASA TP-1751.
[26]R. B. Pipes, B. E. Kaminski, and N. J. Pagano,“ The Influence of -the Free-Edge upon the Strength of Angle-Ply -Laminates, ” ASME STR-521, The Test Methods for High -Modules Fibers and Composites, 1972, pp.218-228.

[27]C. Kassapoglou, and P. A. Lagace, “ Closed Form Solutions for -the Interlaminar Stress Field in Angle-Ply and Cross-Ply -Laminates, ” Journal of Composite Materials, 1987, Vol.21, -pp.292-308.
[28]P. R. Heyliger, and J. N. Reddy, “ Reduction of Free-Edge Stress -Concentration, ” Journal of Applied Mechanics, 1985, Vol.52, -pp.801-805.
[29]W. E. Howard, T. Gossard, and R. M. Jones, “ Composite -Laminate Free-Edge Reinforcement with U-Shape Caps, Part I: -Stress Analysis , ” 1989, AIAA Journal, pp.610-616.