Finite element modeling of composite plates with internal delamination

K. Alnefaie

Mechanical Engineering Department, King Abdulaziz University, P.O. Box 80248, Jeddah 21589, Saudi Arabia

A R T I C L E   I N F O

Article history:
Available online 27 January 2009

Keywords:
Laminated composites
Plates
Finite element model
Internal delamination
Natural frequencies

A B S T R A C T

A three-dimensional (3D) finite element model of delaminated fiber-reinforced composite plates is developed to analyze their dynamics. Natural frequencies and modal displacements are calculated for various case studies with different dimensions and delamination characteristics. Numerical results showed a good agreement with available experimental data. A new proposed model shows enhancement of the accuracy of the results. This study also introduces a method for detecting delamination in composite plates.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

The use of laminated composite materials in space vehicles and various machine components has increased considerably over the past decades. In fact, a monograph written four decades ago showed very limited number of publications on laminated plate vibration. There is evidence that vibration of laminated plates was the subject of more than a 1000 publication in the last decade [1,2]. Researchers show significant interest in determining the natural frequencies of such important structures. Qatu published results for the frequencies of laminated plates having rectangular shapes under different boundary conditions [3,4] and triangular shapes [5].

Under repeated or impact loads these materials are subjected to various forms of damage, mostly delaminations and cracks [6–11]. Such damage becomes an obstacle to the more extensive usage of composite materials. Therefore, the monitoring of internal or hidden damage in composite material is critical in engineering practice [12]. The use of vibration based techniques as non-destructive testing methods for damage monitoring of laminated composite panels is a field attracting the interest of many researchers [13–19].

The effective damage monitoring for this kind of material or structure depends largely on the accurate prediction or estimation of mechanical or dynamic behaviors of both intact and damaged composite panels [20]. It is difficult to obtain accurate exact solutions for multi-layered panels having arbitrary lamination sequence and/or boundary conditions. This difficulty increases considerably when such structures are delaminated. Thus, computational approaches like finite element methods play an important role in detecting damage for laminated composites. There are numerical and experimental investigations of delaminated multi-layered composites [19–26].

Sankar [27] modeled a delaminated beam as two sublaminates by offsetting beam finite elements. Rikards [28] developed a model of finite superelements for sandwich composite beam and plate without delamination, each layer being considered as a simple Timoshenko beam. Later, Gadelrab [8] discussed the modal variation of delaminated beam under different boundary conditions. Ousset and Roudolff [9] analyzed the delaminated multi-layer composite plate based on Mindlin Reissner plate model. Zak et al. [29] and Ousset and Roudolff [9] developed models of finite elements for beams and plates with boundary delamination.

Among most of the publications the prediction of material mechanical or dynamic behaviors is based on the classical laminated plate theory [3,30]. In this theory, the transverse shear deformation effect is ignored. Subsequently, this theory cannot provide accurate results for moderately thick laminated plates, for which the inplane elastic modulus is much higher than the transverse shear modulus [3,31]. Besides, the Poisson's effect is significant for angle-ply laminated plates. Therefore, three-dimensional layer-wise theory is needed in order to obtain an accurate prediction of the dynamic response of multi-layered composite panels. In addition, potential dangers are often induced by hidden or internal delaminations in the in-service laminated composites. However, there is a lack of both numerical and experimental investigations on internal delaminations with different geometries in laminated composites. Yam et al. [34] discussed the relation between the strain mode and the displacement mode for vibrating elastic structure. They claimed modal strain analysis can be used for investigation of local variation of structural parameters.

In this paper, a three-dimensional finite element model for multi-layered composites with internal delamination is established, and the fiber orientations of individual lamina as well as the transverse shear effect are taken into account. Numerical calculations