Mechanics Research Communications 73 (2016) 117–126

Contents lists available at ScienceDirect

Mechanics Research Communications

journal homepage: www.elsevier.com/locate/mechrescom

A refined hyperbolic shear deformation theory for thermal buckling analysis of cross-ply laminated plates

Mokhtar Bouazza [a,b,*], Abdelaziz Lairedj [c], Noureddine Benseddiq [d], Smaine Khalki [a]

[a] Department of Civil Engineering, University of Bechar, Bechar 08000, Algeria
[b] Laboratory of Materials and Hydrology (LMH), University of Sidi Bel Abbes, Sidi Bel Abbes 2200, Algeria
[c] Department of Mechanical Engineering, University of Bechar, Bechar 08000, Algeria
[d] Mechanics Laboratory of Lille, CNRS UMR 8107, University of Lille 1, 59655 Villeneuve d'Ascq, France

ARTICLE INFO

Article history:
Received 12 August 2015
Received in revised form 13 February 2016
Accepted 24 February 2016
Available online 8 March 2016

Keywords:
Cross-ply laminated plates
Thermal buckling
Hyperbolic shear deformation theory

ABSTRACT

Analytical solution of refined hyperbolic shear deformation theory is developed to obtain the critical buckling temperature of cross-ply laminated plates with simply supported edge. Derivations of equations are based on novel refined theory using a new hyperbolic shear deformation theory. Unlike other theories, there are only four unknown functions involved, as compared to five in other shear deformation theories. The theory presented is variationally consistent and strongly similar to the classical plate theory in many aspects. It does not require the shear correction factor, and gives rise to the transverse shear stress variation so that the transverse shear stresses vary parabolically across the thickness to satisfy free surface conditions for the shear stress. The validity and high accuracy of the current exact solution are evaluated by comparing the present results with their counterparts reported in literature.

1. Introduction

Fiber-reinforced composite laminates due to their high specific strength and stiffness are increasingly used in weight-sensitive applications such as aircraft and space vehicles. Most of these vehicles have to operate in hostile thermal environments; as a result, the structural components of these vehicles are subjected to thermal loads. In certain cases, the thermal load turns out to be the primary load, and the thermal stability of composite laminates is one of the factors governing their design.

Numerous studies, based on deterministic analysis, have been performed on modeling and analysis of mechanical and thermal buckling of laminated plates. For examples, Tauchert [1,2], Noor and Burton [3,4], Noor and Jeanne [5], Thornton [6], Leissa [7], Bargmann [8], Chandrashekara [9], Ganapathi and Touratier [10], Chen et al. [11], Chen and Chen [12], Huang and Tauchert [13], Shimpi [14], Shimpi and Patel [15], Girish and Ramachandra [16], Ferreira et al. [17], Shufrin and Eisenberger [18,19], Kim et al. [20,21], Thai and Kim [22], Gossard et al. [23], EL Meiche [24], Mechab [25], Whitney and Ashton [26], Singh et al. [27], Bourada et al. [28], Meyer and Hyer [29], Prabhu and Durvasulu [30], Matsunaga [31], Shu and Sun [32], Sun and Hsu [33] Bednarczyk and Richter [34], Pandey et al. [35], Carrera [36,39], Murakami [37], Toledano and Murakami [38], Boley [40], Batra and Wei [41], Jones [42], Shi et al. [43], Ferreira et al. [44], Yang and Sheih [45], Thangaratnam et al. [46], Mathew et al. [47], Shiau et al. [48], Mossavaral and Eslami [49], Fares et al. [50], Klosner and Forray [51], Kari et al. [52], Fazzolari and Carrera [53], Klosner and Forray [54], Biswas [55], Ounis et al. [56], Lee [57], Nali and Carrera [58], Fazzolari and Carrera [59], Khdeir and Reddy [60], etc.

Recently, Venkatachari et al. [61] examined buckling characteristics of curvilinear fiber composite laminates exposed to hygrothermal environment. The formulation is based on the transverse shear deformation theory and it accounts for the lamina material properties at elevated moisture concentrations and thermal gradients. A 4-noded enriched shear flexible quadrilateral plate element is employed for the spatial discretization. Kulikov and Plotnikova [62] proposed the application of the method of sampling surfaces (SaS) to three-dimensional (3D) steady-state thermoelasticity problems for orthotropic and anisotropic laminated plates subjected to thermal loading. The SaS method can be applied efficiently to the 3D stress analysis of cross-ply and angle-ply composite plates with a specified accuracy

* Corresponding author at: Department of Civil Engineering, University of Bechar, Bechar 08000, Algeria. Tel.: +213 662137302.
E-mail address: bouazza_mokhtar@yahoo.fr (M. Bouazza).

http://dx.doi.org/10.1016/j.mechrescom.2016.02.015

Table 1
The shape function $\Psi(z)$ describing the shear deformation according to different plate theories.

Plate theory	Function $\Psi(z)$
Classical thin plate theory (CPT)	$\Psi(z)=0$
First-order shear deformation plate theory [74–76]	$\Psi(z)=z$
Higher-order theories	
Reddy [77]	$\Psi(z)=z(1-4z^2/3h^2)$
Touratier [78]	$\Psi(z)=(h/\pi)\sin(\pi z/h)$
Karama et al. [79]	$\Psi(z)=ze^{-2(z/h)^2}$
Aydogdu [80]	$\Psi(z)=z\alpha^{-2\frac{(z/h)^2}{\ln\alpha}}, \alpha=3$

utilizing the sufficient number of SaS. Peng et al. [63] studied the buckling problem of bilayer composite plates under non-uniform uniaxial compression via the nonlocal theory. Sabik and Kreja [64], an interesting FEM model for multilayered composite plates and shells under the temperature influence. The multilayered shell body was considered as an Equivalent Single Layer with the average resultant stiffness of the multilayered cross-section, whereas the First Order Shear Deformation theory kinematic assumptions were taken into account. Hai et al. [65] analyzed the thermal buckling of cross-ply laminated beams using two-dimensional (2-D) thermo-elasticity theory. Sreehari and Maiti [66] developed a finite element formulation for handling buckling and post buckling analysis of laminated composite plates subjected to mechanical and hygrothermal loads using the Inverse Hyperbolic Shear Deformation Theory. Li et al. [67] studied the effects of non-uniform thermal field on plate structure were mostly focused on the conditions that the temperature varies along the thickness direction. Using the genetic algorithm the optimal fiber distribution is obtained for an eight-layer symmetrical panel. Panda et al. [68] investigated the combined influences of delamination and hygrothermal atmospheres on buckling response of industry-driven bidirectional composite flat panels.

Duran et al. [69] analyzed the thermal buckling of square composite laminates with variable stiffness properties using classical lamination theory and the finite element method. Fiber angles vary spatially and result in material properties that are functions of position. Moita et al. [70], presented finite element model is presented for buckling and geometrically nonlinear analysis of multilayer sandwich structures and shells, with a soft core sandwiched between stiff elastic layers. D'Ottavio and Polit [71] proposed a global and local buckling of sandwich panels under uniaxial compression in the framework of classical linearized stability analysis. Murugesana and Rajamohana [72] investigated the interlaminar shear stresses in laminated composite plates under thermal and mechanical Loading using the commercially available software package MSC NASTRAN/PATRAN. Zhen and Lo [73] studied the Hygrothermomechanical effects on laminated composite plates in terms of a higher-order global-local model (HGLM), etc.

In the present work, thermal buckling analysis of cross-ply composite multilayered plates under uniform temperature rise is investigated using a hyperbolic shear deformation theory. This theory is that it accounts for a quadratic variation of the transverse shear strains across the thickness, and satisfies the zero traction boundary conditions on the top and bottom surfaces of the plate without using shear correction factors. The results of the present theory are compared with the known data in the literature. Finally, based on the results obtained, some useful conclusions are presented.

2. Theoretical formulation

2.1. Higher-order plate theories with five unknown functions

The displacements of a material point located at (x, y, z) in the plate may be written as

$$\begin{aligned} U(x,y,z) &= u_0(x,y) - z\frac{\partial w_0}{\partial x} + \Psi(z)\theta_x \\ V(x,y,z) &= v_0(x,y) - z\frac{\partial w_0}{\partial y} + \Psi(z)\theta_y \\ W(x,y,z) &= w_0(x,y) \end{aligned} \tag{1}$$

where U, V and W are the displacements in the x, y, and z directions, u_0, v_0 and w_0 are the midplane displacements, θ_x and θ_y are the rotations of the yz and xz planes due to bending, respectively. $\Psi(z)$ represents shape function determining the distribution of the transverse shear strains and stresses along the thickness. Table 1 presents the function $\Psi(z)$ according to different plate theories [80].

2.2. Present new hyperbolic shear deformation theory

Unlike the other theories, the number of unknown functions involved in the present refined hyperbolic shear deformation theory is only four, as against five incase of other shear deformation theories [36–39]. The theory presented is variationally consistent, does not require shear correction factor, and gives rise to transverse shear stress variation such that the transverse shear stresses vary parabolically across the thickness satisfying shear stress free surface conditions.

2.2.1. Assumptions of the present plate theory

Assumptions of the present theory are as follows:

(i) The displacements are small in comparison with the plate thickness and, therefore, strains involved are infinitesimal.
(ii) The transverse displacement W includes two components of bending w_b and shear w_s. Both these components are functions of coordinates x and y.