Theoretical & Applied Mechanics Letters 8 (2018) 184-192

Contents lists available at ScienceDirect

Theoretical & Applied Mechanics Letters

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

Letter

Nonlinear thermo-structural behavior of sandwich panels with truss cores under through-thickness gradient temperature field

Wu Yuan[a,b], Hongwei Song[a,b,*], Chenguang Huang[a,b]

[a] *Key Laboratory for Mechanics in Fluid Solid Coupling Systems, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China*
[b] *School of Engineering Science, University of Chinese Academy of Sciences, Beijing, 100049, China*

HIGHLIGHTS

- A theoretical model for sandwich panels with truss core under through-thickness gradient heating is proposed.
- Gradient shear and bending stiffness due to non-uniform temperature is considered.
- Nonlinear thermal bending in fixed inside surface temperature and thermal post-buckling in fixed temperature difference are analyzed.

ARTICLE INFO

Article history:
Received 18 October 2017
Received in revised form 18 January 2018
Accepted 5 February 2018
Available online 6 February 2018
*This article belongs to the Solid Mechanics.

Keywords:
Sandwich panel with truss core
Thermal protection system
Thermo-structural response
Nonlinear bending
Post-buckling

ABSTRACT

A theoretical analysis is presented to predict the nonlinear thermo-structural response of metallic sandwich panels with truss cores under through-thickness gradient temperature field, which is a common service condition for metallic thermal protection system (TPS). The in-plane temperature distribution is assumed to be uniform, and through-thickness temperature field is determined by heat conduction. Two typical conditions are analyzed: nonlinear thermal bending in fixed inside surface temperature, and thermal post-buckling in fixed temperature difference between two surfaces. Temperature-dependent mechanical properties are considered, and gradient shear stiffness and bending stiffness due to non-uniform temperature is included. Results indicate that the temperature-dependent material properties obviously affect bending resistance; however, the effect is negligible on post-buckling behavior. Influences of geometric parameters on the thermo-structural behavior of the sandwich panel according to the present theoretical model are discussed.

©2018 The Authors. Published by Elsevier Ltd on behalf of The Chinese Society of Theoretical and Applied Mechanics. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Sandwich panels are mechanically efficient lightweight structures that are composed of two thin and stiff face sheets and a relatively thick and lightweight porous core. Recently sandwich panels with truss cores (SPTCs) have been received considerable attention [1-12]. This type of structure has achieved significant success in various practical fields, such as heat insulation, energy absorption, noise reduction, and electromagnetic wave shield [2, 5, 13-15]. When being used in a thermal protection systems (TPS) of high-speed flight, the outside surface is typically subjected to intense aerodynamic heating, whereas the inside surface is approximated to an adiabatic boundary condition. Therefore, SPTCs constantly experience a through-thickness gradient temperature field due to heat conduction. One of the undesirable effects of SPTCs under such loadings is thermal stress, which may lead to premature failure at temperatures below those that substantially impair material properties [16]. Nonlinear thermal bending and thermal post-buckling are two main failure mechanisms in these conditions.

Ansari et al. [17] analyzed the nonlinear bending of a microplate based on Mindlin's strain gradient elasticity and first-order shear deformation plate theory. Le-Manh et al. [18] presented an analytical solution for the nonlinear bending behavior of a composite plate with variable thickness. For sandwich panels,

* Corresponding author.
E-mail address: songhw@imech.ac.cn (H.W. Song).

http://dx.doi.org/10.1016/j.taml.2018.03.007
2095-0349/© 2018 The Authors. Published by Elsevier Ltd on behalf of The Chinese Society of Theoretical and Applied Mechanics. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Rezaeifard et al. [19] investigated the bending behavior of sandwich beams with elastic-plastic cores. Several studies have focused on the bending of plate structures subjected to thermal loadings. Suresh and Mortensen [20] considered the large deformation analysis of graded multi-layered composites. They found that the nonlinear strain-displacement relation should be applied when thermal loading reaches a high level. Shen [21, 22] analyzed the nonlinear thermal bending response of functionally graded material plates by using a two-step perturbation method. Dong and Li [23] developed a unified model for bending, buckling, and vibration for temperature-dependent functionally graded rectangular plates subjected to thermal loadings. Aside from theoretical analysis, numerical studies, such as those that use the weak form quadrature element method [24], the meshless method [25], and the element free Galerkin method [26], have also been conducted to investigate the bending response of thin-walled structures.

Cetkovic [27] investigated the critical thermal buckling behavior of laminated plates by using the layerwise displacement model. Yuan et al. [12] obtained the critical buckling temperatures of SPTCs under fully clamped boundary conditions based on the Ressiner model, later on they built failure maps considering thermal buckling as one of the failure modes [9]. For thermal post-buckling response, Mossavarali and Eslami [28] studied the thermal post-buckling behavior of thin plates with initial flaws. Nikrad and Asadi [29] provided a theoretical solution for the thermal post-buckling behavior of delaminated composite plates based on the minimum potential energy principle. Shen [30] investigated the thermal post-buckling behavior of a functionally graded plate based on high-order shear deformation theory. Yuan et al. [10] studied the thermal post-buckling behavior of SPTCs under uniform thermal loadings.

Few studies have examined the thermo-structural response of SPTCs when experience through-thickness gradient temperature field, which is a typical thermal loading condition for TPS during service. In the present work, the nonlinear thermal bending and thermal post-buckling behavior of SPTCs under through-thickness gradient temperature field are investigated. Through-thickness heat conduction and temperature-dependent material properties are considered, and gradient shear stiffness and bending stiffness due to non-uniform temperature is incorporated in the theoretical model.

Theoretical model. As shown in Fig. 1(a), a rectangular simply supported metallic SPTC is considered. The length, width, and thickness of the SPTC are a, b, and h_p, respectively. The thickness of the truss core is h_c. The angle between the core member and the face sheet is ω. A uniform heat flux due to aerodynamic heating is loaded onto the outside surface, and the inside surface approximates to an adiabatic boundary condition, as shown in Fig. 1(b). The in-plane temperature distribution is assumed to be uniform, and through-thickness temperature field is determined by heat conduction. Two cases of thermal boundary conditions are considered.

Case 1. The temperature of the inside face sheet T_i is assumed to be constant. In this case, the temperature difference between the two face sheets increases when it heated. Therefore, thermal bending is observed as the main failure mode.

Case 2. The temperature difference between the outside and inside face sheets $T_o - T_i$ is assumed to be constant. The thermal bending moment remains unchanged when the temperature of

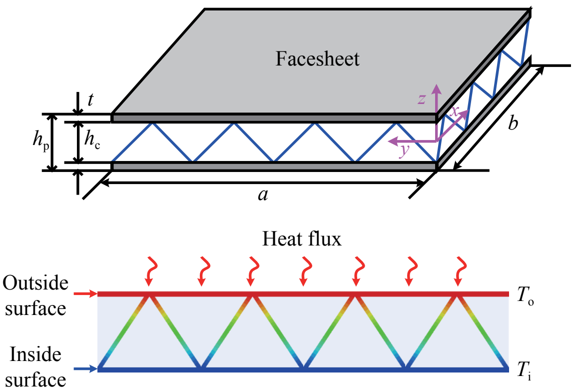

Fig. 1. Schematic of SPTCs under through-thickness gradient temperature field.

the SPTC varies. Hence, thermal post-buckling is the main failure mode.

The through-thickness gradient temperature distribution can be obtained by solving a steady-state heat transfer equation as follows:

$$-\frac{\mathrm{d}}{\mathrm{d}Z}\left(k\frac{\mathrm{d}T}{\mathrm{d}Z}\right)=0. \tag{1}$$

The temperature distribution along the thickness of the face sheet is assumed to be uniform due to low thickness. Then, the temperature along the lengthwise direction of the truss member is solved by imposing the boundary conditions $T = T_i$ at $Z = -h_c/2$ and $T = T_o$ at $Z = h_c/2$ as follows:

$$T=\frac{T_i-T_o}{l_c}l+T_o. \tag{2}$$

The nonlinear equilibrium equations for SPTCs can be obtained by using the minimum potential principle, which can be expressed as

$$\frac{\partial N_X}{\partial X}+\frac{\partial N_{XY}}{\partial Y}=0, \tag{3}$$

$$\frac{\partial N_{XY}}{\partial X}+\frac{\partial N_Y}{\partial Y}=0, \tag{4}$$

$$\frac{\partial Q_X}{\partial X}+\frac{\partial Q_Y}{\partial Y}+\frac{\partial}{\partial X}\left[N_X\frac{\partial(W+W_0)}{\partial X}+N_{XY}\frac{\partial(W+W_0)}{\partial Y}\right]+\frac{\partial}{\partial Y}\left[N_{XY}\frac{\partial(W+W_0)}{\partial X}+N_Y\frac{\partial(W+W_0)}{\partial Y}\right]=0, \tag{5}$$

$$\frac{\partial M_X}{\partial X}+\frac{\partial M_{XY}}{\partial Y}-Q_X=0, \tag{6}$$

$$\frac{\partial M_{XY}}{\partial X}+\frac{\partial M_Y}{\partial Y}-Q_Y=0. \tag{7}$$

The temperature-dependent material properties of the SPTC are considered, which can be written as

$$E=E(T), \tag{8}$$

Download English Version:

https://daneshyari.com/en/article/7196429

Download Persian Version:

https://daneshyari.com/article/7196429

Daneshyari.com