Composite Structures 117 (2014) 333–345

Contents lists available at ScienceDirect

Composite Structures

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

Eccentric impact analysis of pre-stressed composite sandwich plates with viscoelastic cores: A novel global–local theory and a refined contact law

M. Shariyat [a,b,*], S.H. Hosseini [a]

[a] Faculty of Mechanical Engineering, K.N. Toosi University of Technology, Tehran 19991-43344, Iran
[b] Center of Excellence in Smart Structures and Dynamical Systems, Tehran 19991-43344, Iran

ARTICLE INFO

Article history:
Available online 9 July 2014

Keywords:
Double-superposition global–local theory
Low-velocity eccentric impact
Sandwich plate
Viscoelastic core
Pre-load
Integro-differential equations

ABSTRACT

A novel double superposition power-exponential global–local theory and a refined contact law are developed to investigate eccentric low-velocity impact responses of rectangular sandwich plates with viscoelastic cores. The continuity conditions of the transverse normal and shear stresses at the interfaces between layers is satisfied a priori. Stiffness of the underneath layers is considered in the contact law as well, for the first time. The non-linear integro-differential governing equations are solved by a second-order finite element and a special numerical time integration procedure. Effects of the pre-stresses on the indentation and contact force are investigated for the first time. Moreover, effects of the eccentricity on the impact responses of the sandwich plates are discussed in detail, for the first time. Verification of the results is accomplished through comparing present results with experimental results of a known reference. Results show that in the eccentric impacts, the contact force and the absorbed energy increase. Therefore, the failure occurrence can be more likely in the eccentric impacts. Furthermore, by utilizing a viscoelastic core, the apparent stiffness of the contact region increases and consequently the impact force and the absorbed energy increase. Biaxial tension increases the impact force and consequently, leads to premature failures.

1. Introduction

Due to some unique characteristics, such as lightness and gathering layers with severe differences in the material properties in a single construction, nowadays the composite sandwich plates have extensively been used in marine, aerospace, civil, automotive, and even conventional structures. Although almost all materials exhibit viscoelastic behaviors, materials employed in the engineering sandwich plates, such as polymeric fibers, resins, and PVC or foam cores, often manifest remarkable viscoelastic behaviors. In many cases, the load carrying sandwich plates are subjected to casual impacts. In such cases, the main loads of the structure may be regarded as preloads. Therefore, accurately modeling of the contact mechanism, viscoelastic nature of the constituent materials, effects of the preloads, and the kinematic nonlinearities is a crucial issue in accurately predicting the impact responses of the viscoelastic composite sandwich plates. Chai and Zhu [1] reviewed the research progress on dynamic response investigation of composite sandwich structures subjected to low-velocity impacts.

Low-velocity impact responses of the sandwich plates have been studied by Lee et al. [2], modeling the face sheets of the sandwich plate as two separate Mindlin plates and considering both transverse shear and normal stiffnesses of the core. Responses of the composite sandwich plates to the low-velocity impact were studied by Palazotto et al. [3] using the classical plate theory and a finite element algorithm. The core was modeled as an elastic–plastic foundation and the contact loading was simulated by a Hertzian pressure distribution. Sburlati [4] studied impact forces and elastic indentations of a sandwich plate, using Hertz's contact law. Using a high-order zigzag plate model, Icardi and Ferrero [5] presented a nonlinear finite element simulation of impacts on sandwich composites with laminated face sheets. As Palazotto [3], the contact radius and force were computed iteratively based on enforcing the impacted top surface to conform to the shape of the indenter. Foo et al. [6] coupled the energy-balance model with the law of conservation of momentum for a composite sandwich structure subjected to a low-velocity impact.

---

* Corresponding author at: Faculty of Mechanical Engineering, K.N. Toosi University of Technology, Tehran 19991-43344, Iran. Tel.: +98 9122727199.

E-mail addresses: m_shariyat@yahoo.com, shariyat@kntu.ac.ir (M. Shariyat), hosseini_seyedhossein@yahoo.com, s.h.hosseini@mail.kntu.ac.ir (S.H. Hosseini).

URL: http://wp.kntu.ac.ir/shariyat/publications.html (M. Shariyat).

http://dx.doi.org/10.1016/j.compstruct.2014.07.003
0263-8223/© 2014 Elsevier Ltd. All rights reserved.

Since the overall thickness of the sandwich plates and shells is often greater than the laminated composite plates and shells [7] and the transverse distribution of the material properties commonly experiences serious jumps at the interfaces between the layers, the equivalent single layer global theories may not lead to accurate results in many cases, including cases wherein the core is fabricated from very soft materials or foams or when number of the layers of the face sheets is large [8]. To overcome these shortcomings, some layerwise plate theories [9–13] have been proposed to account for local variations of the displacement components. The main two usual disadvantages of these theories are ignoring the transverse stress continuity condition at the interfaces between the layers and the growth of the number of the unknown displacement parameters with number of the layers. To retain advantages of the equivalent single-layer as well as layerwise theories, various zigzag theories have been proposed [14–16]. Bhaskar and Varadan [17] adopted superposition of the piecewise linear local and higher order global fields for the in-plane displacements. Cho and Parmerter [18] combined Reddy's higher-order theory [12] with the layerwise zigzag theory. Recently, Iurlaro et al. [19] presented a comparative study for assessment of the refined zigzag theories. Liu [20] extended concepts of the zigzag theory through introducing the double superposition concept. Shariyat [21–25] has presented the global–local theory that is suitable for inherently non-linear analyzes of the plates and shells, for the first time. The resulting global–local theory satisfied the continuity condition of the transverse stresses at the interfaces between the layers.

Very limited researches have investigated influence of the initial stresses on the low-velocity impact responses of the rectangular [26,27] or circular [28] composite plates. Shariyat and Farzan [27] and Shariyat and Jafari [28] investigated effects of the preloads on the impact responses of the rectangular/circular FGM plates; nevertheless, due to using the first-order plate theory, their results have some limitations and some inaccuracies. In the same context, Heimbs et al. [29] reported several experimental and LS-DYNA finite element results for the rectangular plates.

Although the low-velocity impact of the single-layer functionally graded viscoelastic plates has recently been investigated by the Shariyat and Farzan Nasab [30] (using the first-order shear-deformation theory); to the best of authors' knowledge, low-velocity impact of the viscoelastic laminated or sandwich composite plates has not been performed so far. However, some algorithms have been developed for vibration analysis of the viscoelastic plates. Cupial and Niziol [31] studied vibration of a three layered composite plate with a viscoelastic mid-layer. Vangipuram and Ganesan [32] investigated buckling and vibration of rectangular composite viscoelastic sandwich plates under thermal loads. Zheng and Deng [33] studied free vibration of the multi-layer viscoelastic composite plates. Kim et al. [34] investigated dynamic behavior of multi-layer viscoelastic composite plates undergoing large deformations, using the finite element method. A numerical algorithm to analyze dynamic response of composite plates with anisotropic viscoelastic materials was developed by Yi et al. [35]. Meunier and Shanoi [36] investigated dynamic response of sandwich plates with viscoelastic PVC foam cores. Araujo et al. [37] presented a finite element model for analyzing sandwich plates with viscoelastic cores and multi-layer face sheets. Recently, Shariyat [38,39] presented general numerical algorithms for dynamic analysis of sandwich plates whose layers exhibit viscoelastic behaviors, employing high-order global–local plate theories.

In the present research, a nonlinear eccentric low-velocity impact analysis of rectangular sandwich plates with composite face sheets and hierarchical viscoelastic cores subjected to biaxial preloads is accomplished for the first time. In this regard, a novel enhanced double-superposition global–local sandwich plate theory with interlaminar stress continuity and a refined contact law are proposed and employed. The non-linear governing equations are solved by a second-order finite element technique in the space domain and the resulting time-dependent integro-differential equations are solved based a special procedure. Effects of the eccentricity and the pre-stresses on the impact responses are discussed in the present paper, for the first time. Many novelties are included to present more accurate and general results. Majority of the results contain practical tips that are observed and reported for the first time.

2. The governing equations of the low-velocity impact of the sandwich plate

2.1. The displacement field description based on the proposed sandwich plate theory

The main distinguishing factor of all the available plate theories, is the form of the chosen interpolation functions of the displacement components in the transverse direction. Some researchers employed a single interpolation function for the whole thickness, in the polynomial [12], trigonometric [40,41], exponential, hyperbolic [42], and inverse hyperbolic [43] interpolating functions or multiplications of these functions [44,45]. Shariyat and Alipour proved that in contrast to the assumption of these theories, rotation of the core may not only be different from that of the face sheets but also may occur in opposite direction [46–50]; so that using zigzag [51–57] theories with piecewise defined interpolating functions, particularly, global–local theories with double superposition, is generally vital for the sandwich plates.

The global–local sandwich beam theory with interlaminar transverse stress continuity previously developed by the first author of the present paper and his co-authors [58] is extended here to the sandwich plates. The geometric parameters and the chosen coordinate system of the sandwich plate with viscoelastic core are shown in Fig. 1.

According to the present double-superposition global–local theory, the displacement field of the kth layer may be regarded as a superposition of one global and two local displacement fields $(k = 1, 2, 3)$:

$$
\begin{aligned}
u^k(x,y,z,t) &= u_0(x,y,t) - zw_{,x}(x,y,t) + ze^{-2(z/h)^2}[\theta_x(x,y,t) + w_{,x}(x,y,t)] \\
&\quad + \bar{u}_L^k(x,y,z,t) + \hat{u}_L^k(x,y,z,t) \\
v^k(x,y,z,t) &= v_0(x,y,t) - zw_{,x}(x,y,t) + ze^{-2(z/h)^2}[\theta_y(x,y,t) + w_{,y}(x,y,t)] \\
&\quad + \bar{v}_L^k(x,y,z,t) + \hat{v}_L^k(x,y,z,t) \\
w^k(x,y,z,t) &= w_0(x,y,t) + zw_1(x,y,t) + z^2 w_2(x,y,t) \\
&\quad + \sum_{i=1}^{k-1} \psi_i(x,y,t)(z - z_{i+1})H(z - z_{i+1}) \\
&\quad + \sum_{i=1}^{k-1} \Psi_i(x,y,t)(z - z_{i+1})^2 H(z - z_{i+1})
\end{aligned}
\tag{1}
$$

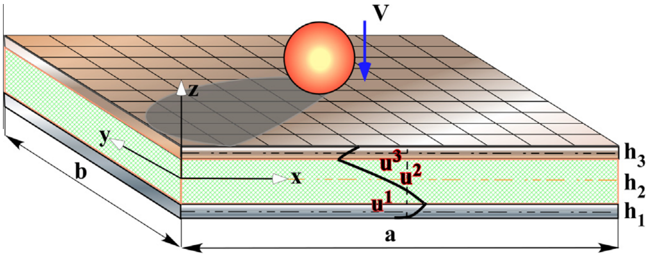

Fig. 1. The geometric parameters and the chosen coordinate system of the consider sandwich plate with viscoelastic core that is subjected to a solid indenter.