Composites: Part B 53 (2013) 308–313

Contents lists available at SciVerse ScienceDirect

Composites: Part B

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

Effect of the root crack on the lateral buckling loads and natural frequencies of sandwich composite beams

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ARTICLE INFO

Article history:
Received 21 July 2012
Received in revised form 4 April 2013
Accepted 12 April 2013
Available online 3 May 2013

Keywords:
A. Laminates
B. Buckling
C. Finite Element Analysis (FEA)
D. Mechanical testing

ABSTRACT

This study aims to examine the effect of interfacial root crack on the lateral buckling and free vibration responses of a sandwich composite beam experimentally and numerically. Lateral buckling loads and natural frequencies in a thin sandwich composite cantilever beam with root crack are determined. The crack with various lengths is opened between the face sheet and foam core, such as 50, 100, 150 and 200 mm. Lateral buckling and free vibration tests of these samples are carried out. For the numerical analysis, ANSYS finite element software is used. Results obtained by numerical analyses and experiments are compared and it is seen that there is a good agreement between them.

1. Introduction

Structural sandwich is a special form of laminated composite, consist of two thin, stiff and strong face sheets bonded together with a relatively thick and weak core. They are widely used in automotive, aerospace and navy industries because of its high specific strengths, high specific energy absorption, thermal insulation, good sound reduction and high bending stiffness which results from the load carrying capacities of faces separated by the core which carries the through thickness shear loads. They have low density, high stability, and low cost [1,2]. Kim and Dharan [3] focused on buckling of the debonded face sheet and extended the delamination buckling model of Vizzini and Lagace [4] to debonded sandwich specimens. Sleight and Wang [5] conducted a buckling analysis of a sandwich column with two symmetrically located through-width debonds using the Vizzini and Lagace model [4], and they also performed finite element analysis.

Wind turbine blades, aircraft structures ships and high speed trains are examples where sandwich structures are used as load-carrying elements [6]. Thin-walled sandwich beams should resist to the stability due to their slenderness. On the other hand, determination of the free vibration response of the composite beams is important in point of vibration based health monitoring studies.

Dynamic responses of the composite structures are frequently used to detect the faults formed during production or operation period. Variation in the fundamental vibration frequency and corresponding mode shape caused by the damage are used to detect the failure in the health monitoring studies of the engineering structures. Therefore, researchers have paid great attention to the determination of natural frequencies of both healthy and damaged composite structures due to the industrial importance of the subject.

The effects of crack ratios and positions on the fundamental frequencies and buckling loads of slender cantilever Euler beams with a single-edge crack are investigated by Karaağaç et al. [7]. The finite element solution was proposed and experiments are carried out in order to verify the results obtained from the proposed numerical method. Birman and Byrd presented the effect of the matrix crack on the stiffness and natural frequencies of a composite beam [8]. They reported that change in the natural frequency is more considerable if the crack propagates into longitudinal layers. Wei et al. implemented the modal analysis in association with the wavelet transform to detect the delamination for multi-layer composites. They compared the natural frequencies, mode shapes, and energy content of wavelet signals for intact and delaminated plates and they reported that the dynamic response analysis provides solutions for detecting the structural anomalies [9]. Ayorinde et al. presented the various structural health monitoring methods for sandwich composite structures. They gave the examples of vibration based and ultrasonic methods for detecting the structural faults [10].

Birman and Simitses presented the solution of the vibration problem for sandwich panels and beams with matrix cracks in transverse layers of cross-ply facings [11]. They investigated the problem of vibration of sandwich beams with matrix cracks in

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http://dx.doi.org/10.1016/j.compositesb.2013.04.060

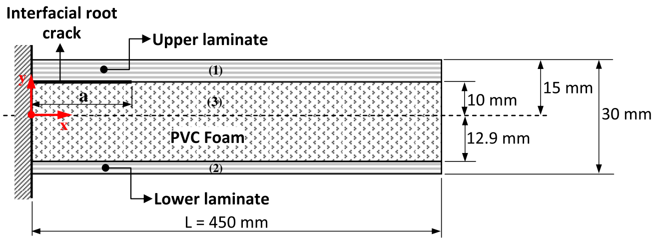

Fig. 1. Sandwich composite beam.

the transverse layers and delaminations generating from the tips of transverse cracks. They reported that the presence of delaminations results in relatively small changes in the natural frequencies than the transverse matrix cracks.

Shu and Della studied the free vibration characteristics of beams with multiple delaminations. They reported that the delamination has considerable effects on the natural frequencies and mode shapes for relatively larger delamination sizes due to the decreasing structural stiffness [12].

Recently, Toygar et al. [13] studied the effect of the interface crack, which was located at the beam free end, on the lateral buckling and free vibration frequencies of a sandwich composite beam both experimentally and numerically. They reported that the buckling load and natural frequencies of the beam decrease as the crack length increases, and the decrease in these parameters is more prominent for bottom crack case.

In this study, the lateral buckling loads and natural frequencies in a sandwich composite cantilever beam with root crack are considered. The crack is opened between the face sheets and foam core. The length of the crack is increased and then the lateral buckling loads and natural frequencies are found using experimental and finite element method. Acceptable results are obtained between two methods. It is seen that the length of the crack has measurable effect on the lateral buckling loads and natural frequencies.

2. Materials and method

In this study, the sandwich composites used in the experiments were manufactured by the manufacturer firm, GCG Marine Inc., Izmir, Turkey. In the manufacturing, glass fiber as reinforced material and vinyl ester as resin were used. In the middle of the the sandwich composite structure, polyvinyl chloride (PVC) foam as core and the upper and lower laminates, as seen in Fig. 1, with different thickness was preferred. The beams with 6 mm thickness were cut from the manufactured sandwich composite in order to use in the lateral buckling and vibration tests with root crack. Interface root cracks were built at the upper and lower side of the beam between laminated structure and PVC foam. The length of the crack ‘a’ was considered as 0 (non-crack), 50, 100, 150, and 200 mm (Fig. 1). Fig. 2 shows the four different specimens used in the lateral buckling tests.

The upper laminate was manufactured by a randomly distributed glass–fiber lamina and four woven laminas. The lower laminate was manufactured by three woven laminas and a randomly distributed lamina. The physical and mechanical properties of upper and lower laminates are given in Table 1. Table 2 presents the physical and mechanical properties of the foam and vinyl ester in the sandwich composite material used in this study.

In this study, the lateral buckling load and the natural frequencies in a thin sandwich composite cantilever beams with root crack are considered.

3. Experimental studies

The sandwich composite beam specimen has a length of 450 mm, 30 mm total height and 6 mm thickness with core depth of 22.9 mm. The facing sheets at the top are 5 mm and the bottom is 2.1 mm. The specimen is clamped at one end shown in Fig. 3.

The lateral buckling tests were done using an universal tensile testing machine, Shimadzu AG-X 100 kN. During these tests, an in-house buckling test mechanism given in Fig. 3 was used. The test apparatus was designed to insure the accurate cantilever boundary condition for one-edge of the beam. Single vertical load was acted at the free end of the beam. During the tests, all specimens were loaded laterally until the first buckling mode was reached, as shown in Fig. 3. Since the sandwich composite beams become unstable as the first buckling mode takes place, other modes are not considered in this study.

Dynamic response of the sandwich composite beam was considered as the impulse response. The experimental fundamental frequencies were extracted from the frequency content of the impulse response of the cantilever beam. Vibration response of the sandwich composite beam was measured using an experimental setup in which a noncontact displacement measurement system

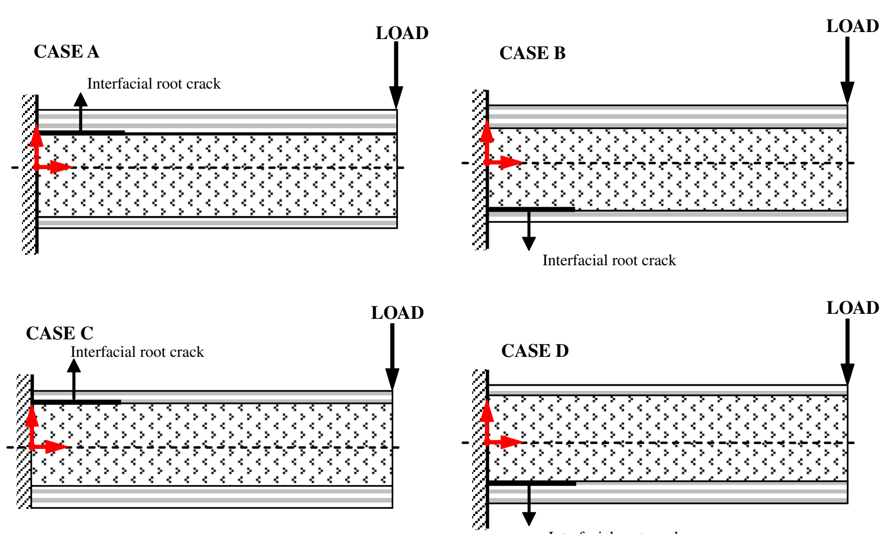

Fig. 2. Four different specimens with root crack.