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EFFECT OF THE ROOT CRACK ON NATURAL FREQUENCIES OF SANDWICH COMPOSITE BEAMS

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Abstract

This study aims to examine the effect of interface crack on the free vibration response of a sandwich composite beam experimentally and numerically. 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. 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.

Keywords: Sandwich composites, Root crack, Natural frequency, Finite element method.

1 Introduction

Sandwich composites are frequently used in the marine industry, aerospace industry, recently in automobiles, and defense industries. They have low density, high stability, and low cost [1]-[2]. Sandwich structures possess a high global buckling resistance when subjected to in-plane compressive loads. These properties make sandwich structures a favorable alternative in applications where weight savings reduction is essential.

Wind turbine blades, aircraft structures ships and high speed trains are examples where sandwich structures are used as load-carrying elements [3]-[4]. 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. [5]. 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 [6]. 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 [2]. 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.

Ayorinde et al. presented the various structural health monitoring methods for sandwich composite structures [7]. They have gave the examples of vibration based and ultrasonic methods for detecting the structural faults.

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 [8]. They investigated the problem of vibration of sandwich beams with matrix cracks in 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 [9].

In this study, the natural frequencies in a thin 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 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 natural frequencies and mode shapes of the sandwich beam.

2 Material and Method

The sandwich composites used in the experiments was manufactured by the manufacturer firm, GCG Marine Inc., Izmir, Turkey. The upper laminate, as seen in Figure 1, was manufactured by a randomly distributed glass–fiber lamina and four woven laminas. The lower laminate (Figure 1) was manufactured by three woven laminas and a randomly distributed lamina. The physical and mechanical properties of the upper and lower laminates and polyvinyl chloride (PVC) foam are given in Table 1. In the manufacturing, glass fiber as reinforced material and vinyl ester as resin were used. In the middle of the structure, polyvinyl chloride (PVC) foam was preferred.

The beams with 6 mm thickness were cut from the manufactured sandwich composite in order to use in vibration tests. Interface root cracks were built between upper laminate and PVC foam. The length of the crack ‘a’ was considered as 0 (non-crack), 50, 100, 150, and 200mm (Figure 1). In this study, dynamic response of the sandwich composite beam is considered as the impulse response. The experimental fundamental frequencies are extracted from the frequency content of the impulse response of the cantilever beam.

Table 1: Material properties.

	Upper Laminate (1)	Lower Laminate (2)
E_x (GPa)	23.2	19.75
E_y (GPa)	9	8.5
E_z (GPa)	9	8.5
ν_{xy}	0.4	0.15
ν_{xy}	0.2	0.2
ν_{xy}	0.4	0.15

	PVC Foam (3)
E (GPa)	0.300
ν	0.38

Vibration response of the sandwich composite beam is measured using an experimental setup in which a noncontact displacement measurement system is employed. The experimental setup for vibration measurement is shown in Figure 2. The beam is subjected to an impact by a standard hammer and the impulse vibration response of the beam is recorded in terms of displacement with a laser displacement sensor. Measurement range of the laser sensor is ±40 mm about the reference location and the resolution of the laser sensor is 0.5 µm. The displacement signal is collected by a laser displacement meter (LDM) at 8 kHz sampling rate. The voltage value produced by the LDM per mm is 0.25 V. Then the voltage signal is sent to the computer through a USB data acquisition card using MATLAB software. Application of the Fast Fourier Transform (FFT) to the vibration displacement data gives the fundamental vibration frequencies of the sandwich composite beam.

3 Result and Discussion

Determination of the natural frequencies of an engineering structure is the fundamental stage for vibration analysis. Variation in the natural frequencies is frequently related to a fault, which is formed by various mechanisms. In this study, natural frequencies of the sandwich composite beam having root crack are calculated numerically by using the ANSYS software.

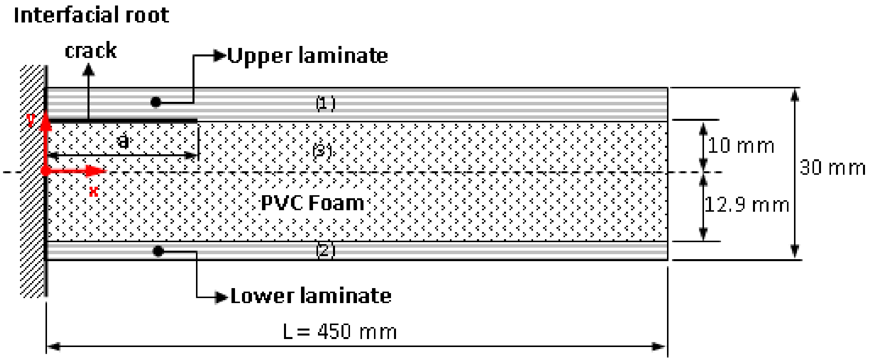

Figure 1: Sandwich composite beam.

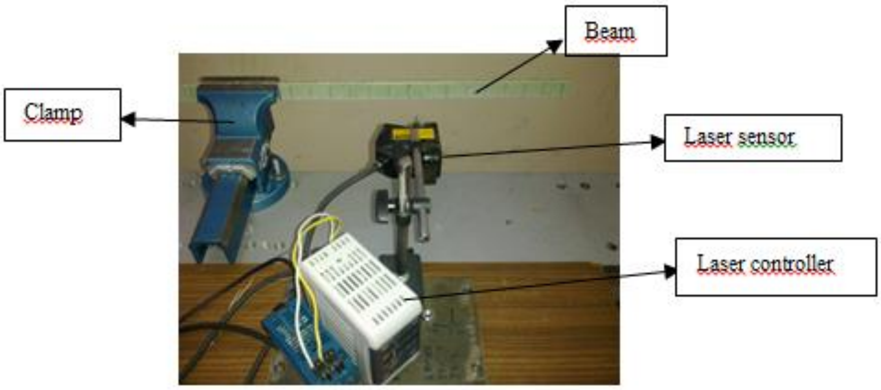

Figure 2: Real view of the experimental setup.

The governing equations of motion for free vibrations of a multi degree of freedom system is expressed in the matrix form as;

$$[M]\{\ddot{q}\}+[C]\{\dot{q}\}+[K]\{q\}=0 \qquad (1)$$

Where q, $\dot{q}$ and $\ddot{q}$ denote the nodal displacement vector, nodal velocity vector and nodal acceleration vector, respectively. M, C and K stand for the mass, damping and stiffness matrices, respectively. Substituting the undamped free vibration response $q(t)=\phi e^{i\omega_n t}$ in Eq. (1) and taking the damping matrix as zero, Eq(1) reduces to a well known eigenvalue problem

$$\left\lfloor K-\omega_n^2 M \right\rfloor \phi = 0 \qquad (2)$$

Where ω_n is the natural frequency and ϕ is the associated non-zero mode shape vector of the structure. The natural frequencies of the structure can be obtained by the solution of the below equation

$$\det\left\lfloor K-\omega_n^2 M \right\rfloor = 0 \qquad (3)$$

In this study, first five natural frequencies of the sandwich beam with and without root crack are calculated by the finite element method using the ANSYS software. The finite element model of the sandwich composite beam is seen in Figure 3. In the finite element model "Layered 46" solid element with eight nodes is used for modal analysis. The finite element model consists of 11475 elements and 16372 nodes. The results of the natural frequency analyses in x-z and x-y planes are given in Table 2.

The results given in Table 2 show that the natural frequency values for bending vibration in x-z and x-y planes for intact beam are less than those calculated for cracked beam. The natural frequency values have a wavy nature for examined crack lengths. The natural frequency values for four vibration modes are greater for 50 mm and 200 mm crack lengths than those obtained for other two crack lengths. The 5th vibration mode in the table belongs to the 1st torsional vibration mode and for this mode the natural frequency decreases considerably as the crack length increases.

For the comparison purpose, the impulse response of the sandwich composite beam is measured in terms of displacement by using a laser displacement measurement system. The natural frequencies of the examined sandwich composite beams are calculated from the impulse response using the FFT analysis.

The impact responses of the composite beam for intact and cracked cases are given in Figures 4-8. Figures 4a and 4b show the impact response and its frequency content of the intact composite beam. First two bending modes in x-z plane are seen in this figure. These frequencies are also seen in Figures 5-8 for the sandwich composite beam having root crack with crack lengths 50 mm, 100 mm, 150 mm and 200 mm.

The numerical and experimental natural frequencies for the first two bending modes in x-z plane are compared in Table 3 and Table 4. As seen from the difference values, there are generally acceptable discrepancies between the experimental and numerical natural frequency values for the measured natural modes.

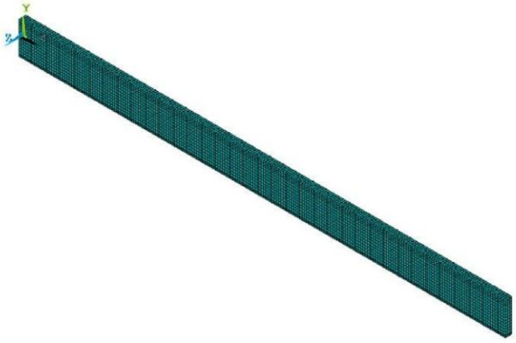

Figure 3: Finite element model of the sandwich composite beam.

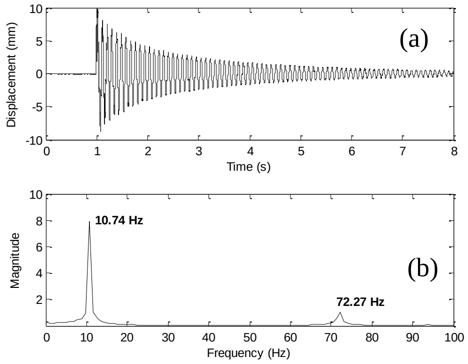

Figure 4: Intact beam a) impulse response b) frequency content.

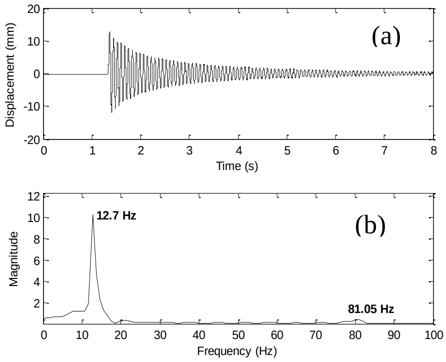

Figure 5: Root crack a=50 mm, a) impulse responseb) frequency content.

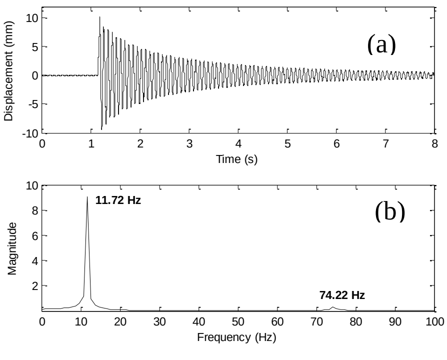

Figure 6: Root crack a=100 mm, a) impulse response b) frequency content.

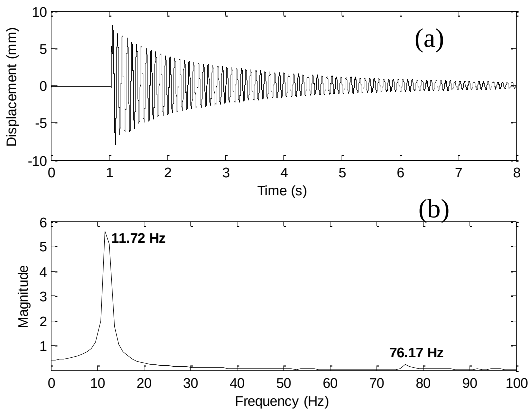

Figure 7: Root crack a=150 mm, a) impulse response b) frequency content.

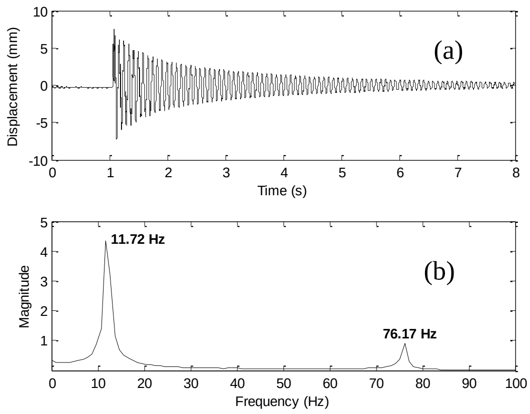

Figure 8: Root crack a=200 mm, a) impulse response b) frequency content.

Table 2: Fundamental vibration frequencies (Hz) of the sandwich composite beam.

Mode Shape	Intact beam	a=50 mm	a=100 mm	a=150 mm	a=200 mm
f_1 	12.443	12.762	12.478	12.498	12.758
f_2 	62.283	63.383	62.260	62.076	62.160
f_3 	77.923	79.930	78.029	78.282	79.905
f_4 	217.970	223.710	218.310	219.120	223.630
 f_5	356.050	352.770	347.530	342.92	307.610

Table 3: First natural frequency (Hz) in x-z plane of the composite beam.

	Numerical (ANSYS)	Experimental	% Difference
Intact Beam	12.443	10.74	13.686
a=50 mm	12.762	12.7	0.486
a=100 mm	12.478	11.72	6.074
a=150 mm	12.498	11.72	6.225
a=200 mm	12.758	11.72	8.136

Table 4: Second natural frequency (Hz) in x-z plane of the composite beam.

	Numerical (ANSYS)	Experimental	%Difference
Intact Beam	77.923	72.27	7.254
a=50 mm	79.930	81.05	-1.401
a=100 mm	78.029	74.22	4.881
a=150 mm	78.282	76.17	2.697
a=200 mm	79.905	76.17	4.674

4 Conclusions

In this study, the effect of the root crack on the natural frequencies of a sandwich composite cantilever beam is investigated both numerically and experimentally. Based on the numerical and experimental frequency values, following conclusions are drawn,

- The existence of the root crack affects the natural frequencies of the sandwich composite beam.
- The natural frequencies for bending modes of the intact beam are less than those obtained for the considered root crack cases. The natural frequencies for bending modes are higher for 50 mm and 200 mm crack lengths. The natural frequencies of the sandwich beam for the crack lengths 100 and 150 mm are less than from other two crack lengths but still higher than the frequencies of the intact beam.
- For the torsional vibration mode, the natural frequency decreases as the crack length increases.
- The numerical and experimental natural frequencies for first two bending modes in x-z plane are in a considerable agreement.

5 References

[1] Shipsha A and Zenkert D, “Compression-after-impact strength of sandwich panels with core crushing damage”, Applied Composite Materials, 12, 149–164, 2005.
[2] Wei Z, Yam LH and Cheng L., “Detection of internal delamination in multi-layer composites using wavelet packets combined with modal parameter analysis”, Composite Structures, 64, 377–387, 2004.
[3] Vinson JR. Sandwich structures. Appl Mech Rev, 54, 201–214, 2001.
[4] Zenkert D, An introduction to sandwich construction. Engineering Materials Advisory Services. Published by Chameleon Press Ltd, 1995, London.
[5] Karaağaç C, Özturk H and Sabuncu M, “Free vibration and lateral buckling of a cantilever slender beam with an edge crack: experimental and numerical studies”, Journal of Sound and Vibration, 326, 235–250, 2009.
[6] Birman V., Simitses GJ, "Vibrations of sandwich panels and beams with matrix cracks in the facings", Composites Science and Technology, 61,1605–1613, 2001.
[7] Ayorinde E., Gibson R., Kulkarni S., D. Feizhong, Mahfuz H., Islam S., Jeelani S.,"Reliable Low-cost NDE of composite marine sandwich structures", Composites Part B: Engineering, 39, 226–241, 2008.
[8] Birman V and Byrd LW., “Matrix cracking in transverse layers of cross-ply beams subjected to bending and its effect on vibration frequencies”, Composites Part B: Engineering, 32, 47–55, 2001.
Shu D and Della CN, “Vibrations of multiple delaminated beams”, Composite Structures, 64, 467–477, 2004.