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The Free Vibration Analysis of Honeycomb Sandwich Beam Using 3D and Continuum Model

G. Şakar, F. Ç. Bolat

Abstract**—**In this study free vibration analysis of aluminum honeycomb sandwich structures were carried out experimentally and numerically. The natural frequencies and mode shapes of sandwich structures fabricated with different configurations for clamped-free boundary condition were determined. The effects of lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness on the vibration characteristics were examined. The numerical studies were performed with ANSYS package. While the sandwich structures were modeled in ANSYS the continuum model was used. Later, the numerical results were compared with the experimental findings.

Keywords**—**Sandwich structure, free vibration, numeric analysis, 3D model, continuum model.

I. Introduction

THE use of sandwich panels has increased in many areas such as aerospace, automotive, wind energy due to high bending stiffness, low weight and good fatigue life. They typically consist of thin face sheets and light-weight cores (Fig. 1). The main duty of face sheets in a sandwich panel is to carry the transverse load or bending moment while the core takes care of separating and fixing the face sheet, carrying the transverse shear load, and providing other structural or functional duties.

In the literature a number of experimental and theoretical investigations have been done to show the importance of the subject. Reference [1] is a comprehensive FEA analysis (finite element) tool for structural analysis, including linear, nonlinear and dynamic studies. Reference [2] investigated the design and analyses of honeycomb structures by replacing the actual honeycomb structure with the orthotropic model. During the finite element analyses, substantial advantages were obtained with regard to ease of modeling and model modification, solution time and hardware resources. Reference [3] studied the effect of delamination on the natural frequencies and corresponding modes of a free-free sandwich beam. Reference [4] explained honeycomb manufacturing methods, materials, cell configuration, terminology and uses. Sandwich beams were studied to reveal the underlying size effects of the periodic core cells for the first time within the framework of free vibration analysis of such an advanced lightweight structure by [5]. Reference [7] presented isoparametric finite element formulation based on a shear deformable model of higher-order theory using a higher order facet shell element for the free vibration analysis of isotropic, orthotropic and layered anisotropic composite and sandwich laminates. Reference [8] studied the natural frequencies of honeycomb sandwich beams having deboning or delamination embedded between the face layer laminates and the honeycomb core are studied theoretically and experimentally. Reference [9] aimed at investigate the vibrations of honeycomb panels. They used ANSYS for analysis. The 3-D model was introduced to validate the continuum model commonly used in studying the vibrational of a honeycomb panel. Reference [10] analyzed the effects of the thickness of the core and face sheets, and delamination on damping. Measurements on honeycomb–foam sandwich beams with different configurations and thicknesses had been performed and the results compared with the theoretical predictions. Reference [11] presented some results from experimental investigation of the dynamic shear property of both Nomex and aluminum honeycomb cores and the damping of composite honeycomb sandwich beams in steady-state flexural vibration. Reference [12] presented a method for the prediction of eigenfrequencies and modes of vibration for rectangular and orthotropic sandwich plates. They calculated the eigenfrequencies using the Rayleigh Ritz technique assuming frequency dependent material parameters. They compared predicted and measured results. Reference [13] presented a semi-analytical method in their paper to evaluate the natural frequencies as well as displacement and stress eigenvectors for simply supported, cross-ply laminated and sandwich plates by using higher order mixed theory. Reference [14] dealt with parameter identification of aluminum honeycomb sandwich panels with the assumption that they can be treated as orthotropic continua. Elastic constants and modal damping ratios were considered as the identified parameters, and the basic equations of Timoshenko beam theory were employed in their paper. The improved Reddy's third-order theory coupled with shear correction factors in predicting free flexural vibration of symmetric honeycomb panels was examined by being compared with the experimental value and the finite element analyses based on three-dimensional models by [15]. The free flexural vibration of symmetric rectangular honeycomb panels having simple support boundary conditions was investigated in their paper using the classical plate theory, Mindlin's improved plate theory, and Reddy's third-order plate theory by [16]. Description was given of the development of a spline finite strip method for predicting the natural frequencies and modes of conventional rectangular sandwich plates by [17]

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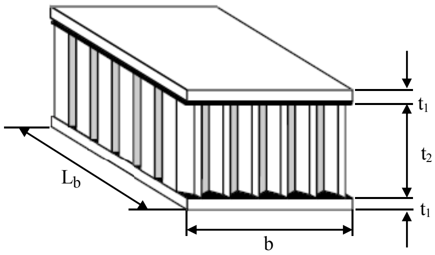
In this study, the free vibration of honeycomb sandwich beams was investigated. The study focused on the effects of lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness on the natural frequencies of the sandwich beam. The vibration analysis was carried out numerically and experimentally.

II. Experimental Procedure

The image and schematic representations of the sandwich beams studied are given in Figs. 1 (a) and (b). The top and bottom face sheets have the same thickness and properties. The length of the beam is L_b, the width b, the core thickness t_2, face sheet thickness t_1.The core material was obtained CELL Company. The face sheets consists of 1050 Aluminum material.

(a)



(b)

Fig. 1 Image (a) and schematic representation (b) of the sandwich beam

III. Finite Element Modelling

The changes in the natural frequencies and corresponding vibration modes with changing lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness were predicted using the ANSYS finite element code. Two different models were used in ANSYS. The models are given in Figs. 2 and 3. In the modeling it was accepted that the face sheets and the core were combined perfectly.

Fig. 4 shows the experimental setup for obtaining the natural frequencies of the sandwich beams. The beams were excited with an impact hammer at the middle of the beam. A laser vibrometer was employed to measure the beam response. The B&K PULSE system was used to analyze the signals with the FFT mode and the natural frequency of the beam was determined directly. The vibration tests were conducted using the clamped-free boundary conditions. Each specimen was tested under vibration test for ten times to reduce scattered values and the measurement errors. In this study only the first mode was measured.

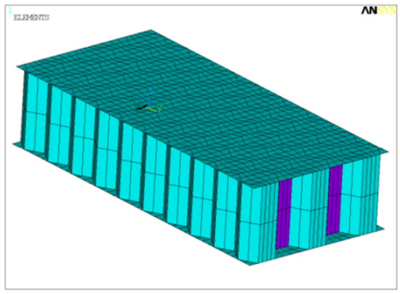


Fig. 2 3-D model of the honeycomb sandwich beam

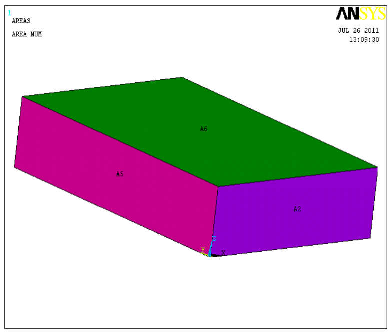


Fig. 3 Continuum model of the honeycomb sandwich beam

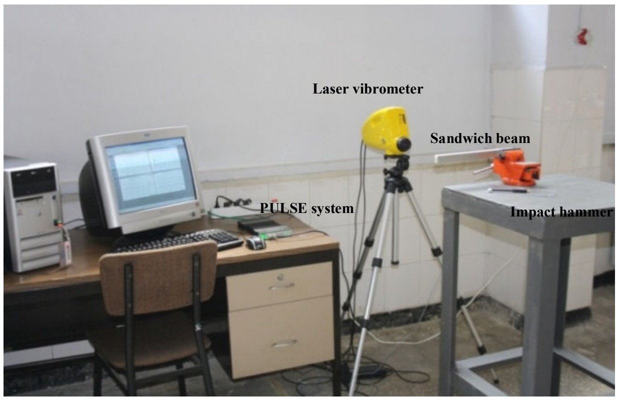


Fig. 4 Experimental Setup

In 3-D model the face sheets and the core of the sandwich beam was represented by eight nodded shell elements, having six degrees of freedom at each node (Translations in nodal x,y,z directions and rotations about the nodal x,y and z axes). In continuum model the face sheets were modeled with Shell 281 element and the core was modeled with Solid 186 element. In the analyses the formulas given by [6] were used to determine properties of honeycomb cores. The geometry of a common honeycomb structure and the depicts of all symbols used in the formulae are given Fig. 4.

IV. Results

In this study experimental and numerical results of natural frequencies of the sandwich beam were given. The comparison between the first mode frequencies of clamped-free specimen was given in Table I. It was seen that the numerical results obtained with 3-D model and continuum model and experimental results were in harmony. Then the first natural frequency variations of the sandwich beam were examined by using the continuum model for the various parameters and the mode shapes for in plane vibrations were obtained. The mode shapes of clamped-free sandwich beam are shown in Fig. 10. In the analyses 33 cell in the W direction and 3 cell in the L direction were taken into account. The length of the sandwich beam was determined according to the cell number.

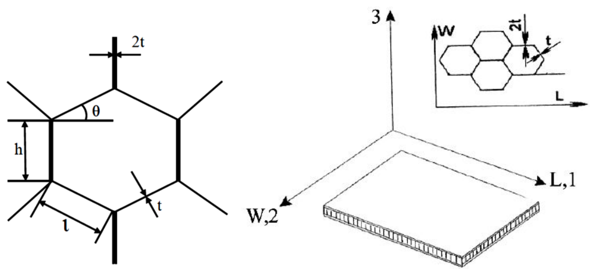


Fig. 5 Honeycomb cell geometry and coordinates

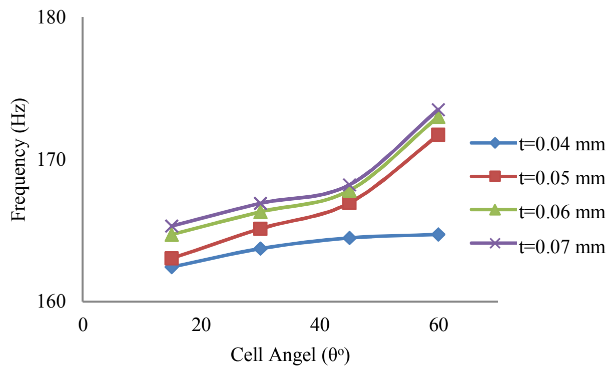


Fig. 6 Influence of the cell angle on the first natural frequency of the sandwich beam t_1=0.5 mm, t_2=6 mm, d=6.35 mm)

Fig. 6 shows the effect of cell angle on the first natural frequency of the sandwich beam. The first natural frequency increases when the cell angle increases. This increase is valid for all foil thicknesses. In Fig. 6 *t* depicts foil thickness.

TABLE I
Comparison of Experimental Natural Frequencies with Numerical Results of the First Natural Frequency of the Sandwich Beam (t_1=0.7 mm, t=0.05 mm)

Core thickness (t_2 mm)	First natural frequency (Hz) of the sandwich beam		
	Experimental	Continuum model	3-D model
6	141	139	139
10	227	222	224
15	288	318	323

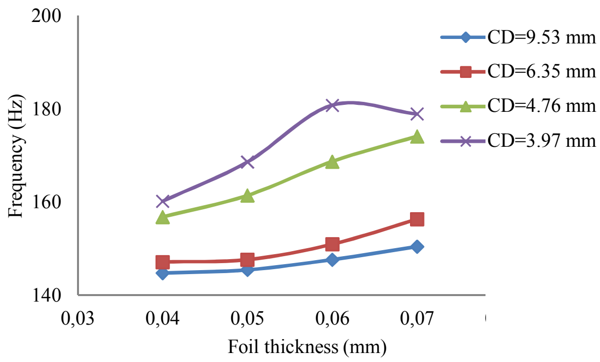


Fig. 7 Influence of the foil thickness on the first natural frequency of the sandwich beam (t_1=0.5 mm, t_2=6 mm, θ=30°)

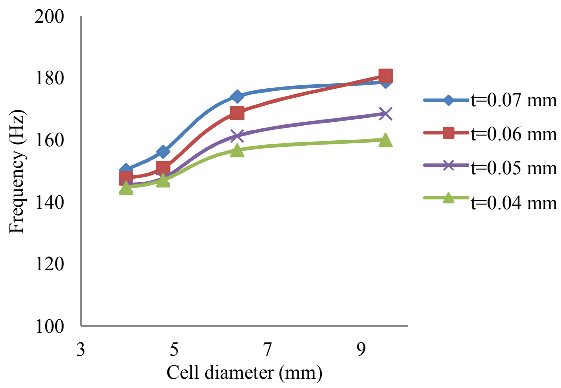


Fig. 8 Influence of the cell diameter on the first natural frequency of the sandwich beam (t_1=0.5 mm, θ=30°)

TABLE II
The Natural Frequencies of Sandwich Beams Having Different Face and Core Thicknesses

Face sheet thickness (t_1 mm)	First natural frequency (Hz) of the sandwich beam		
	t_2=6 mm	t_2=10 mm	t_2=15 mm
0.5	156.7	228.83	324.39
0.7	157.42	230.29	327.13
1	158.12	231.59	329.41
1.2	158.69	232.22	330.53

Fig. 7 shows the effect of foil thickness on the first natural frequency of the sandwich beam. The first natural frequency increases when the foil thickness increases. In Figure CD depicts cell diameter. Fig. 8 shows the effect of cell diameter on the first natural frequency of the sandwich beam. The first natural frequency increases when the cell diameter increases. Fig. 9 shows the effect of core thickness on the first natural frequency of the sandwich beam. The first natural frequency increases when the core thickness increases. This figure was plotted for t_1=0.5 mm face thickness. For the other face thicknesses same situation is valid.

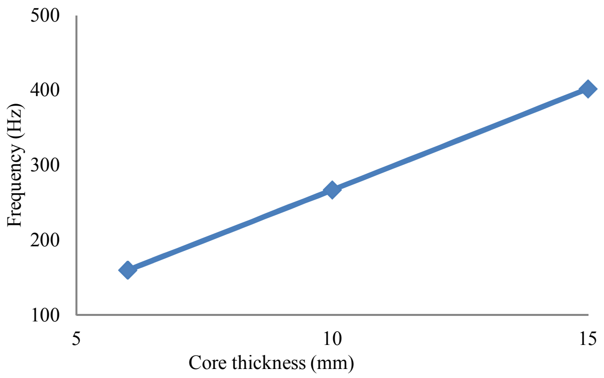
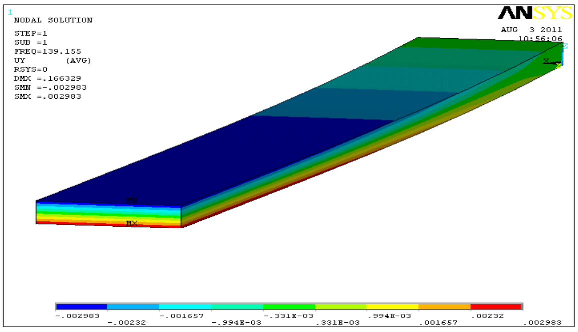
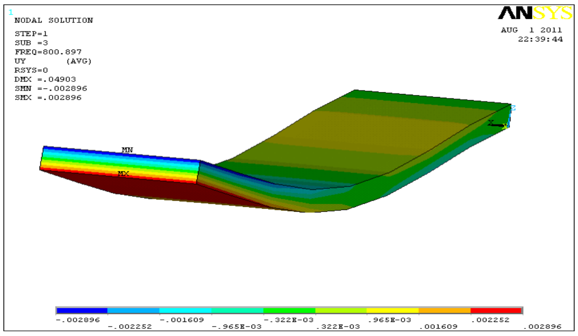


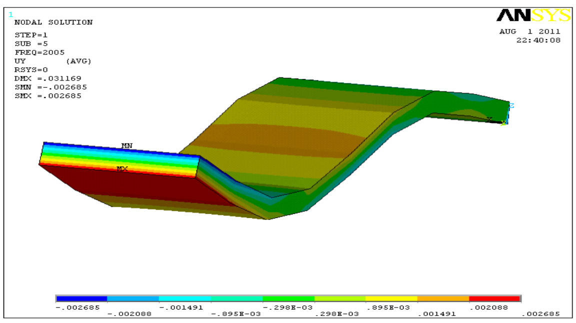
Fig. 9 Influence of the core height on the first natural frequency of the sandwich beam (t=0.04 mm, t_1=0.5 mm, d=3.97 mm, θ=30^o)



(a)



(b)



(c)

Fig. 10 First three mode shapes (a), (b), (c) of the clamped-free sandwich beam

In this study, the free vibration of honeycomb sandwich beams was investigated. The study focused on the effects of lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness on the natural frequencies of the sandwich beam. The vibration analysis was carried out numerically and experimentally. The results obtained numerically and experimentally showed good agreement. In numerical analyses to model honeycomb core the continuum model was used. The mechanical properties of the honeycomb core were obtained by using formulas given by Ashby and Gibson. In the analyses it was observed that when the cell diameter was increased the first natural frequency decreased. The cell angle (θ) has little effect on the first natural frequency. When the foil thickness and core height were increased the first natural frequency was increased. It was determined that the most effective parameter on the natural frequency on the sandwich beam was core height.

ACKNOWLEDGMENTS

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