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Effect of Boundary Conditions on Natural Frequencies of Orthotropic-Cored Composite Sandwich Beams

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Abstract

The influences of different boundary conditions on the free vibration behavior of sandwich beams having an orthotropic core have been investigated. The finite element codes used in the analysis are written via MATLAB and infused into ANSYS software package. The two-dimensional beam is considered to be made of an orthotropic core and two isotropic face sheets which may be homogeneous or heterogenous. The longitudinal dominated natural frequencies are considered and effects of core and face-sheet materials on the natural frequency are also studied. The results show that the order of the natural frequencies from highest to lowest, respectively, is clamped-clamped, clamped-simply supported, simply supported-simply supported and clamped-free for the orthotropic core composite beam. Also, using Al-TiB_2 instead of pure Al layer as well as the increasing the inhomogeneity index decreases the natural frequency.

Keywords: Vibration, Natural frequency, Boundary conditions, Composites beams, Orthotropy

Sınır Şartlarının Ortotrpik Çekirdekli Kompozit Sandviç Kirişlerinin Doğal Frekanslarına Olan Etkisi

Öz

Değişik sınır şartlarının orthotropik çekirdek tabakaya sahip kompozit malzemenden yapılmış olan kirişlerin serbest titreşim davranışları üzerine olan etkisi incelenmiştir. Çözümlemede, sonlu elemanlar paket programı kullanılmış olup kodlar MATLAB ile yazılmıştır. İki boyutlu kirişin bir adet ortotropik çekirdekten oluştuğu ve yüzey tabakasının homojen ya da heterojen olduğu varsayılmıştır. Kiriş boyuna titreşimler dikkate alınmış olup çekirdek ve yüzey tabaklarının malzeme özelliklerinin doğal frekans üzerine etkisi de ayrıca çalışılmıştır. Sonuçlara göre doğal frekanslar yüksekten düşüğe doğru sırasıyla ankastre-ankastre, ankastre-basit mesnet, basit mesnet-basit mesnet ve ankastre-serbest olarak belirlenmiştir. Ayrıca, saf Al tabaka yerine Al-TiB_2 fonksiyonel derecelendirilmiş yüzey tabakası kullanmak ve inhomojenlik katsayısını artırmak doğal frekansı düşürmüştür.

Anahtar Kelimeler: Titreşim, Doğal frekans, Sınır şartları, Kompozit kirişler, Orthotropi

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1. INTRODUCTION

The understanding of vibration behavior of sandwich beams is the important task for the scientists and structural engineers so that they may provide not only the good strength and less weight but also flexibility and thermal insulation.

The recent studies related to the natural frequency of composite beams will be cited hereafter. Salam and Bondok [1] have investigated free vibration behaviors of various sandwich beams such as beam having multi-layer core using finite-element. A novel finite element formulation for the natural frequency of sandwich beam is presented by Sudhakar et. al. [2] where the beam is assumed to be composed of rigid face sheets and flexible core. ANSYS finite-element code using Plane 82 element type is developed by Long et. al. [3] for the plane vibration of partially-cantilevered sandwich beams with soft core. Lou et. al. [4] have investigated the natural frequency of beam with steel face layers and pyramidal truss core. In this work, the beam is considered to be subjected to simply supported boundary conditions. Sabiha et. al. [5] are studied the free vibration of pinned-pinned beam made of steel core and thin composite face sheets. The free vibration response of lattice sandwich beam is analyzed by Lou et. al. [6] considering different boundary conditions where the lattice beam is transformed to homogeneous three-layered beam. Xu and Qiu [7] are presented a parametric study on the natural frequency of lattice-cored composite beam by using combine theory of Euler-Bernoulli and Timoshenko beam. In their work, the governing equation of motion of simply-supported beam is derived with the help of Hamilton's principle. Yang et. al. [8] have examined the plane free vibration of functionally-graded core beam via a mesh-free boundary-domain integral equation method. The composite face layered sandwich beam is analyzed by Tekili et. al. [9] in the terms of natural frequency where the finite-element is solution method. The free vibration of flexible core sandwich beam has been studied by Wang and Wang [10] using extended high-order sandwich panel theory under various boundary conditions. Bensahal and Amrane [11] have performed a finite element study on the free vibration sandwich beam subjected to different boundary conditions. The natural frequencies of polymer honeycomb sandwich cantilever beam have been investigated by Cheng et. al. [12] via a refined sandwich beam theory. The free vibration study based on hyperbolic shear deformation theory is presented by Bouakkaz et. al. [13] where the beam is composed of functionally-graded face layers and isotropic homogenous core. Wang and Liang [14] have investigated the free vibration characteristics of flexible core symmetric sandwich beam using the combine theory of Euler-Bernoulli beam and two-dimensional elasticity. In their work, the primary solution method is harmonic quadrature method and the beam is studied under various so-called boundary conditions. Zhang et al. [15] are presented a finite element solution on the free vibration of honeycomb corrugated hybrid core composite beam. The natural frequency study of metal foam core composite beam is conducted by Wang and Zhao [16] using Chebyshev collocation method. Asgari et. al. [17] have examined the free vibration of three-layered sandwich beam with a flexible core using simply supported boundary conditions. The free vibration study of functionally-graded lattice core sandwich beam has been conducted by Xu et. al. [18] using Rayleigh-Ritz method. Sayyad and Avhad [19] are presented the natural frequency of sandwich beam using Navier's solution technique. In this study, the beam is made of functionally-graded face sheets and isotropic homogeneous core layer and subjected to simply supported boundary conditions. Erdurcan and Cunedioglu [20] have studied the natural frequency of symmetric composite beam with an aluminum core and FGM face layers. In this work, a finite element solution is presented and layerwise model is used to represent the graded behavior of FGM face layers.

The study performed in this paper is to examine the boundary effect on the free vibration characteristics of sandwich beam with two face sheets and a core. The face sheets may be homogeneous or heterogenous and the core is orthotropic. The study is carried out by assuming the two-dimensional beam problem. The laminates are perfectly bonded to each other meaning that there is no delamination. The beam is considered to be subjected to various boundary conditions as clamped-clamped (C-C), clamped-free (C-F), clamped-simply supported (C-S) and fully simply supported (S-S).

2. BEAM AND MATERIAL MODELS

A composite core sandwich beam having a rectangular cross-section is subjected to plane-stress conditions in the x-z plane with length L and depth h. The cartesian coordinate system is oriented to the bottom of the left-end of the beam where the axial coordinate is x and transverse coordinate is z. For the sake of simplicity and preventing the redundancy, the beam geometry is taken as constant where the depth is 0.125 mm and the length is 0.5 mm. The bottom and face layer are identical to each other and the thicknesses of face layer and core are 25 mm and 75 mm, respectively. Two main cases are considered for beam model. The face layer materials are isotropic homogeneous and functionally-graded (FG) for the first and second cases, respectively. In the analysis, Aluminum is selected as the isotropic face sheet material and two different materials as Graphite/Epoxy and Boron/ Epoxy for orthotropic core are considered. The mixture of Aluminum and Titanium Diboride is used for FGM face layers where the bottom of face layer is Aluminum graded smoothly to Titanium Diboride through the top of face layer. The material properties used in this paper are tabulated in Table 1.

The material model obeying the power-law function for the FGM face sheets are given as follows:

$$P(z) = P_b + (P_t - P_b)\left(\frac{z}{h}\right)^{\lambda} \quad (1)$$

where P is the effective material property, namely, Young's Modulus E, Poisson's ratio v and density ρ, b and t, respectively, denote the bottom and top of the face sheet and λ is the inhomogeneity index which is a positive constant.

Table 1. Elastic properties of the material used in the analysis

	Graphite/ Epoxy	Boron/ Epoxy	Aluminum (Al)	Titanium Diboride (TiB_2)
E_1 (GPa)	181	200	70	575
E_2=E_3 (GPa)	10.3	19.6	70	575
V_{12}=V_{13}	0.28	0.28	0.3	0.15
V_{23}	0.6	0.3	-	-
G_{12}=G_{13} (GPa)	7.17	7.2	-	-
G_{23} (GPa)	3	5.5	-	-
$\rho\ (kg\ /\ m^3)$	1600	1967	2707	4520

The FEM model are coded by using MATLAB and implemented to ANSYS Mechanical APDL. The selected element type is PLANE183 which is two-dimensional structural solid element defined by eight-node. The element has two degrees of freedom at each node as translations in the nodal x and z directions. Also, the different element type can be selected to successfully modeling the beam [21]. The FGM behavior for the second case is obtained by slicing the face sheets into numerous homogeneous pieces along the axial coordinate where each slice has constant but different material properties. The nodes are coincident at the interface regions to secure the integrity of beam. The numbers of elements, respectively, are 4200 and 6000 for isotropic and FGM face sheets beams. The number of slices for the FGM face sheets to emulate the graded property of material is defined as 40 where increasing the number of slices does not affect the accuracy considerably but affects the burden of computation. For each case, the beam is investigated under four different boundary conditions as depicted in Figure 1.

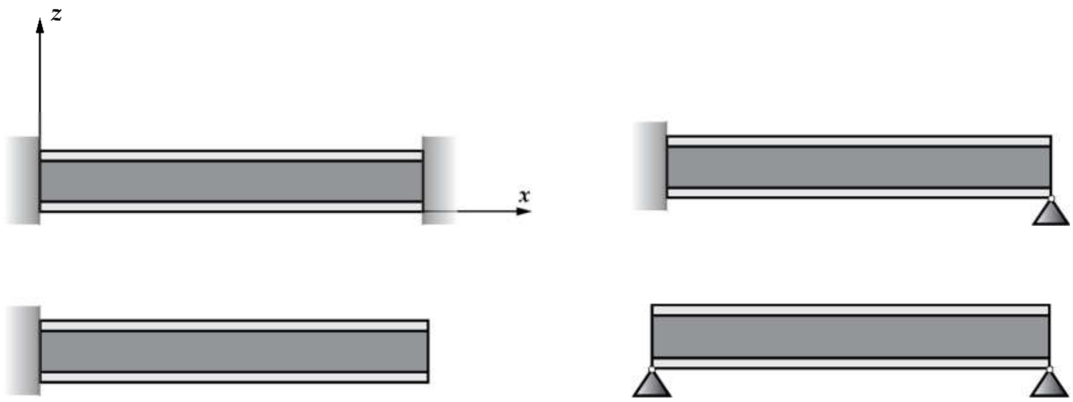

Figure 1. Illustration of composite beam under different boundary conditions

3. RESULTS AND DISCUSSIONS

The validation of three-layered finite element model is acquired by using the data available in literature. In the validation study, the layers of beam are assumed to be made of pure Al and subjected to simply supported boundary conditions. The results are compared with the natural frequencies given by Li [22] for the homogeneous Al beam and a very good agreement is obtained. The validation study results are given in Table 2 where *m* denotes the wave number. The first five fundamental natural frequencies of Al-Glass/Epoxy-Al beam are tabulated in Table 3 where the C-C boundary condition results in highest frequency values. The effects of FGM face sheets and boundary conditions are given in Table 4. It is seen that using graded face layer increases the natural frequency of the orthotropic core beam. In Table 5, the influence of inhomogeneity index can be observed. The natural frequencies for all cases decrease with the increase of inhomogeneity index. As, the trend for the natural frequencies is the same with the Glass/Epoxy core case, only the first fundamental frequency is taken into consideration for Boron/Epoxy core beam which prevents the redundancy for the reader. The results for the Boron/Epoxy case are given in Table 6 and it is observed that using Boron/Epoxy as a core material decreases the natural frequencies. Consequently, the order of natural frequencies from highest to lowest with respect to boundary conditions are C-C, C-S, S-S and C-F, respectively.

Table 2. Comparison of the results with literature for the first 5 natural frequencies (Hz)

m	This Study	Li [22]
1	1053.997959895	1052.9149908
2	3492.041736381	3486.1521552
3	6447.468518035	6430.2687291
4	9561.972670083	9527.8743302
5	12626.44457408	12658.3199622

Table 3. Natural frequencies of Al-Glass/Epoxy-Al composite beam for different boundary conditions

	ω_n			
m	*C-C*	*C-F*	*C-S*	*S-S*
1	1621.296162008	463.6484272879	1363.991387480	1127.705119916
2	3362.649335465	1835.818179267	3197.462877353	3015.929317161
3	5404.302838372	3854.045838799	5221.238110579	5046.922626531
4	7535.117741474	5811.790574542	7366.585773778	7197.829387526
5	9809.631266040	7750.215737570	9637.367271987	9461.696688790

Table 4. Natural frequencies of FGM-Glass/Epoxy-FGM composite beam for different boundary conditions λ=1

	ω_n			
m	*C-C*	*C-F*	*C-S*	*S-S*
1	1882.903604933	641.1609583673	1632.093598501	1433.403188078
2	3963.162911916	2263.455927942	3723.514024429	3488.835152270
3	6430.193977916	4573.625396955	6100.484654716	5794.208113251
4	9147.499073626	6834.709799005	8780.381611912	8396.449820132
5	12136.35720605	9834.292198251	11731.52181127	11292.05341098

Table 5. Natural frequencies of FGM-Glass/Epoxy-FGM composite beam for different boundary conditions λ=2

	ω_n			
m	*C-C*	*C-F*	*C-S*	*S-S*
1	1837.819181339	606.7248083799	1589.132724125	1385.568392257
2	3827.818155314	2182.268202814	3624.857523086	3419.284134759
3	6150.939055781	4429.637909049	5880.258608840	5628.389164980
4	8619.021945353	6574.458352093	8363.451931928	8038.190823994
5	11358.17569294	9387.531766983	10999.30358935	10659.02576944

Table 6. First fundamental natural frequencies of Boron/Epoxy core composite beam for different boundary conditions

	ω_n			
Facesheet	*C-C*	*C-F*	*C-S*	*S-S*
Al	1546.866190789	447.185668403	1303.898483274	1082.292414291
FGM λ=1	1810.093922841	616.3879408418	1567.726822992	1375.456043345
FGM λ=2	1762.054545988	582.4079302594	522.853006857	1327.121281490

4. CONCLUSION

The influences of different boundary conditions on the longitudinal dominated free vibration behavior of three-layered composite beam are examined using finite-element software package. The finite-element codes are written by using MATLAB and implemented to ANSYS Mechanical APDL. The beam with a core having an orthotropic property is assumed to be two-dimensional on the *x-z* plane. It is obtained that the C-C boundary condition leads to highest natural frequency values whereas the C-F boundary condition gives the lowest ones. The effects of face layer material as well as the core material also considered. The replacing pure Al face layer with Al-TiB_2 graded face layer and using Boron/Epoxy core instead of Glass/Epoxy decreases the natural frequency for all boundary conditions.

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