



Free Vibration Analysis of Composite Plate Stiffened by Lattice Structures

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Abstract

Free vibration behavior of laminated composite plates stiffened by different lattice structures is considered. To simulate free vibration, finite element models were created with Ansys Parametric Design Language (APDL). In the models, SHELL181 and BEAM181 elements were used to model laminated composite and lattice structures, respectively. The influence of the different stiffeners lattice structures on natural frequencies of the composite plate is examined for the clamped-free-clamped-free boundary condition. The results showed that the frequency parameters of the stiffened composite structures made of the L2-type lattice are higher than those composed of other lattice types. This study provides an exciting opportunity to advance our knowledge of the usage of lattice structures as stiffener structures for composite plates.

Keywords: Composite, Stiffened plate, Free vibration, Finite element method, Lattice structures.

Kafes Yapılarla Pekiştirilmiş Kompozit Plakanın Serbest Titreşim Analizi

Öz

Farklı kafes yapıları ile pekiştirilmiş tabakalı kompozit plakaların serbest titreşim davranışı incelenmiştir. Serbest titreşimi simüle etmek için, Ansys Parametric Design Language (APDL) ile sonlu eleman modelleri oluşturulmuştur. Modellerde tabakalı kompozit ve kafes yapıların modellenmesinde sırasıyla SHELL181 ve BEAM181 elemanları kullanılmıştır. Farklı pekiştirici kafes yapılarının kompozit plakanın doğal frekansları üzerindeki etkisi, ankastre-serbest-ankastre-serbest sınır koşulu için incelenmiştir. Sonuçlar, L2 tipi kafesten yapılan pekiştirilmiş kompozit yapıların frekans parametrelerinin diğer kafes tiplerinden oluşanlardan daha yüksek olduğunu göstermiştir. Bu çalışma, kafes yapılarının kompozit plakalar için pekiştirici yapıları olarak kullanımına ilişkin bilginizi artırmak için ilgi çekici bir fırsat sunmaktadır.

Anahtar Kelimeler: Kompozit, Pekiştirilmiş plaka, Serbest titreşim, Sonlu eleman metodu, Kafes yapılar.

1. Introduction

Thin-walled structures are broadly used to build aerospace structures in the aerospace industry. To produce thin-walled structures, composite materials are commonly utilized due to their outstanding lightweight and strength. Although the thin-walled composite structures have strong tensile strength, they need reinforcing for shear, compression, and bending loads [1]. Using stiffeners is frequently preferred to reinforce the composite structures in the aerospace industry [2]–[4].

In the design period, predicting the resonance frequencies of any engineering structure is critical to avoid undesirable damages such as crack and fatigue, etc. The free vibration analysis is commonly utilized for calculating the natural frequencies of the engineering structure that may result in resonances. The finite element method is a trustworthy method for predicting dynamic responses for different sorts of engineering structures [5]. In this regard, the present study is concerned with the influences of different stiffeners lattice structures on natural frequencies of the composite plate for the clamped-clamped boundary condition. Therefore, the literature review is summarized in two sections. The first part is regarding the vibration of composite stiffened plates and the second is devoted to lattice structures.

There are numerous research articles concerning stiffened composite plates. Amongst these, Bhar et al. [6] performed finite element analysis of laminated composite stiffened plates. In this study, they used higher-order shear deformation theory and the first-order shear deformation theory to conduct static and free vibration analyses. Huang et al. [7] proposed an effective finite element modeling method for stiffened laminated composite plates. To model stiffeners, a curved beam element compatible with the shell element was introduced in the model. Damjanović et al. [8] performed free vibration analysis of composite stiffened plates using the dynamic stiffness method based on the higher-order shear deformation theory. In another article, the influences of the transverse shear deformation and the rotary inertia are considered for free vibration analysis of stiffened and cracked laminated composite plate assembly [9]. Zhang and Xu [10] calculated the static deformation of eccentrically stiffened plates. The stiffened plates were modelled plate and beam elements that are discretely connected to the plate elements for inquiring the eccentricity. Rajawat et al. [11] carried out the free vibration analysis of stiffened laminated plate using APDL. In the analysis, SHELL181 element was used to model composite plate. The consequences of the eccentricity of the stiffener, the number of stiffeners, and its positions were investigated on natural frequencies in that study. Geng et al. [12] proposed a new numerical scheme to determine the stiffened-plate composite structures' mid-frequency and dynamic response. Balkan et al. [13] examined the nonlinear dynamic behavior of a laminated composite stiffened plate subjected to the non-uniform blast and load. In this study, a composite sandwich beam was used as a stiffener. Sinha et al. [14] determined the effects of numbers, types and orientation of stiffeners, depth of stiffener to the thickness of plate ratio, and aspect ratio and boundary conditions of plates on natural frequencies of the composite stiffened plates. They also established a finite element model of composite stiffened plate for computing natural frequencies. Investigation of composite stiffened plates is still active research area [15]–[18]. In recent years, although much more information has become available on composite stiffened plates, there is limited study

dealing with free vibration analysis of composite plate stiffened by lattice structures to the best of the author's knowledge.

This study intends to analyse the effects of different lattice structures, which are used as stiffeners, for free vibration analysis of composite plate stiffened. Therefore, the literature on lattice structures is summarized as follow. Progression in additive manufacturing technology has brought about lattice structures that have a lightweight and mechanical efficiency ratio [19]–[22]. Most of the published studies have attempted to optimize lattice-structural materials [23], [24]. Azzouz et al. [25] examined the role of the three lattice structures' shapes on the compression, shear and bending strength. Yang et al. [26] provided an analytical method to divine the mechanical properties of sandwich lattice structures. In that study, a finite element model of the sandwich lattice structures was developed by using Timoshenko beam theory to predict deformation patterns. Yang et al. [27] evaluated the use of vibration-based defect recognition composite sandwich panels with corrugated lattice cores. They investigated how effects different sorts of flaws on modal characteristics by developing a finite element model in ABAQUS software. An et al. [28] tested the effectiveness of meta-truss lattice composite structures for providing vibration attenuation.

Thus, this article has aimed to assess the using different lattices as stiffeners for stiffened composite plates and their association with natural frequencies.

2. Finite Element Modeling

In this article, free vibration analysis of laminated composite plates stiffened with three different lattice structures was performed to determine their natural frequencies. The finite element method is a popularly practised technique to predict engineering structures' behaviour. Therefore, to calculate natural frequency, finite element models of stiffened laminated composite plates were generated. In the models, the ANSYS Parametric Design Language platform was used to establish the finite element models. The laminated composite plates and the lattices were meshed using SHELL181 finite elements and BEAM188 finite elements respectively.

To construct the finite element model of stiffened composite plates, firstly, three sorts of lattice structures were created. Figure 1 shows the line models of stiffeners lattices' cell structures, the dimensions are shown that used in the FE model in Figure 2. The lattices' cells were labelled with L_i ($i=1,2,3$).

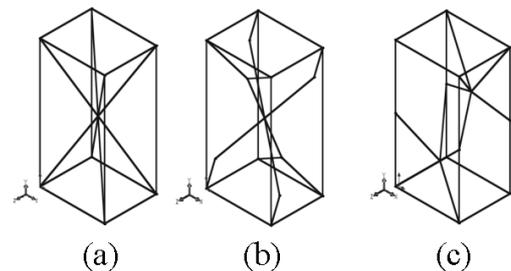


Figure. 1 Lattices' cell structures, (a) L_1 , (a) L_2 (b), L_3 (c).

In Figure 2, “ r ” represents the diameter of the beam of lattices cells, “ b ”, “ h ” and “ t ” indicate the width, height and thickness of the lattices' cells respectively.

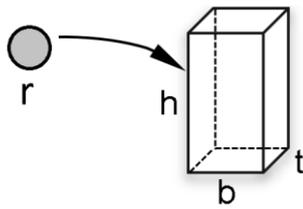


Figure 2. Dimensions of lattices and cross-section of the lattice beam.

The stiffened composite plates models were established as rectangles (see Figure 3). The schematic view of utilized symmetric lay-ups of the composites is illustrated in Figure 4. The ply angles of the composite plates were specified as [90°, -45°, 45°, 90°].

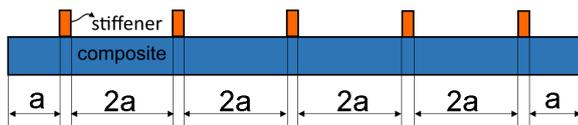


Figure 3. Exemplified illustration of the stiffened composite plates.

In Figure 3, the blue rectangle and orange rectangles illustrate composite plate and lattice structures respectively. Here, the offset between each stiffener, “a”, was described as $a = k_b \cdot b$. The width and length of the composite plate can be calculated as follow $B = 10 \cdot a + 5 \cdot t$ and $H = k_h \cdot h$, respectively.

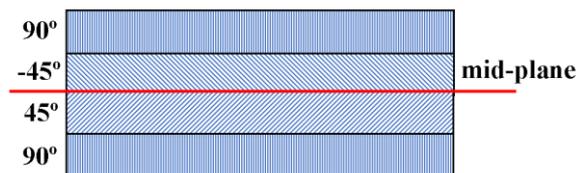


Figure 4. Angular lay-ups of the composite plates.

In the finite element models, stiffeners were constructed by placing “ k_h ” pieces of cells next to each other with the “ h ” side of the cell in the vertical position in the direction of the z-axis. In each finite element model, 5 stiffeners were used (see Figure 5) to construct stiffened composite plates. Simulations were carried out for the clamped-free-clamped-free boundary conditions.

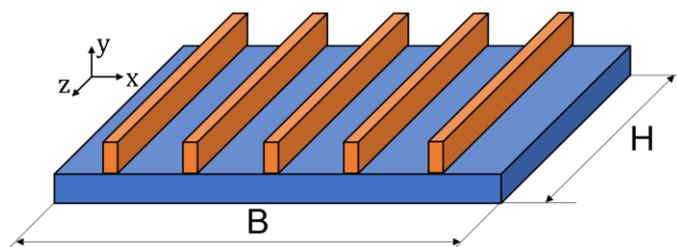


Figure 5. 3D view of the composite plate with the stiffeners.

3. Results and Discussion

Computed natural frequencies are presented by the natural frequency parameter that is defined as follow;

$$\mu_i = \frac{f_i}{m_L} \tag{1}$$

where, “ f_i ” (Hz) and “ m_L ” represent natural frequencies of the stiffened composite plates corresponding to the first three

fundamental bending modes in the x-z plane and the total mass of all stiffeners in the structure respectively.

Material properties of composite plates are $E_1 = 44.9$ GPa, $E_2 = 12.32$ GPa and $\rho_C = 2000$ kgm⁻³. Here, E_1 and E_2 are Young’s modulus along the fibre and Young’s modulus transverse the fibre respectively. The material properties of stiffeners made of Polylactic acid (PLA) are $E_L = 2$ GPa and $\rho_L = 1230$ kgm⁻³.

Dimensions of the lattice cells were specified as $t = 10$ mm, $h = b = 25$ mm, $k_b = 8$ and $k_h = 20$ for the stiffened composite structures.

The effects of the usage of the different lattices' cells the natural frequency parameters are demonstrated in Table 1 and 2. These results are given for the $r = 1$ mm and $r = 2$ mm diameter lattice beam.

Table 1. Natural frequency parameters for $r=1$ mm.

Vibration plane	Lattice type	Natural frequency parameters		
		μ_1	μ_2	μ_3
Bending (x-z)	1	62.54	172.29	338.03
	2	64.86	178.67	350.55
	3	59.02	162.59	319.04

It is observed that all the frequency parameters of the stiffened composite structures built from the L_2 -type lattice are greater than those constructed with other lattice types when Table 1 considered. A similar trend can be seen in Table 2 for the 2 mm diameter lattice beam.

Table 2. Natural frequency parameters for $r=2$ mm.

Vibration plane	Lattice type	Natural frequency parameters		
		μ_1	μ_2	μ_3
Bending (x-z)	1	14.43	39.73	78.01
	2	15.01	41.32	81.12
	3	13.57	37.40	73.43

4. Conclusions and Recommendations

The present study was designed to determine the effect of the different stiffeners lattice structures on natural frequencies of the composite plate to examine for the clamped-free-clamped-free boundary condition.

The results of this study indicate that the frequency parameters of the stiffened composite plates composed of the L_2 -type lattice are greater than those constructed by other lattice types. The results pointed out these designed stiffened composite structures may be used in many sorts of fields such as aeronautics, aerospace, construction and more.

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