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Comparative vibrational behavior study of marine composite panels consisting of bidirectional non-woven and woven fabrics

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Abstract

A wide range of fibres are available for design and use in the construction of composite structures. There are various factors influencing the choice of fibre type such as the type of loading on the structure, and the construction method. Unidirectional or bidirectional non-woven fibres have high in-plane tensile and compressive properties. While woven fibres have lower in-plane tensile and compressive properties than non-woven fibres, they have better in-plane shear properties. Also, the fibre volume fraction is different for various types of fibres in composition with matrix. Therefore, due to different density of fibres and resin, different vibrational behaviours are expected for these two types of fibres. This article compares the vibration behaviour of composite panels for marine structures consisting of bidirectional non-woven as well as woven fabrics. First, the properties of a composite lamina with the same thickness from these two types of fibres are determined, and then their vibration behaviours are compared using the finite element method. By means of modal analysis, the frequencies of the primary vibration modes for panels consisting of two types of woven and non-woven fibres will be extracted and compared. The results show that in spite of low axial elastic modulus for woven fabrics, the panel laminated by woven fibre lamina have the same vibration behaviour as the panel laminated by biaxial non-woven lamina. Also, the first six mode shapes of the two panels consisting of different lamina (woven and biaxial non-woven) are similar.

Keywords: Areal density; Woven fabric; Vibration characteristics; Marine structure.

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1. Introduction

Composite materials are widely used in industries such as marine industry, aerospace and wind turbine blades. The ability to build structures with complex geometric shapes, high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, longer fatigue life and stealth characteristics. Woven fabrics (WF) composites form one of the important classes of textile composites. They offer certain advantages over conventional unidirectional (UD) laminated composites which have made them attractive for structural applications[1].

Some Studies have been done on the vibrations of laminates includes woven fibers, but Comparative studies between the vibrations of structures that laminated using woven or non-woven fibres have not been done. Here some studies mentioned.

Lu et al. investigated the vibration properties of composite materials and structures[2]. Chen et al. investigated the free vibration analysis of orthogonal-woven fabric composites[3]. Maher et al. introduced an improved dynamical model for vibration damping in composite structures to investigate the stacking sequence and the degree of anisotropy as a function of the vibration modes[4]. Xu et al. studied the effects of woven structures on the vibration properties of the composites[5]. Rath and Sahu studied the Vibration of woven fibre laminated composite plates in hydrothermal environment[6]. Nakanishi et al. investigated the vibration damping for woven fabric composites by Finite element analysis[7]. Namsone and Ermakov used an Inverse technique based on vibration tests for characterization of woven composite material properties. They modified a mixed numerical-experimental technique based on vibration tests and applied to determine the elastic material properties of woven composites.

2. Vibration in marine vehicles

When a ship is subjected to an impulsive load, such as when a descending anchor is suddenly arrested, it will execute elastic vibrations in addition to whatever rigid body motions are excited. Of these vibrations some are observed only locally and some are observed throughout the hull. There are a number of sources of vibration and noise present in a ship or marine vehicle [8].

Typically these may include:

- The prime movers-typically diesel engines.
- Shaft-line dynamics.
- Propeller radiated pressures and bearing forces.
- Air conditioning systems.
- Maneuvering devices such as transverse propulsion units.
- Cargo handling and mooring machinery.
- Vortex shedding mechanisms.
- Intakes and exhausts.
- Slamming phenomena.

3. Fundamental equations

Recently, in the study of transient elastic wave propagation in woven fabric composites, Chen and Chou proposed a one-dimensional (1D) analysis based upon the mosaic model and shear lag approach. Chen and Chou studied the free vibration analysis of orthogonal-woven fabric composites. Summarized governing equations by Chen and Chou are as follows:

$$E_1A_1\frac{\partial^2 u_1}{\partial x_1^2}+\frac{bG}{h}(u_2-u_1)=A_1\rho_1\frac{\partial^2 u_1}{\partial t^2} \tag{1}$$

$$E_2A_2\frac{\partial^2 u_2}{\partial x_1^2}+\frac{bG}{h}(u_2-u_1)=A_2\rho_2\frac{\partial^2 u_2}{\partial t^2} \tag{2}$$

$$E_1A_1\frac{\partial^2 u_3}{\partial x_2^2}+\frac{bG}{h}(u_4-u_3)=A_1\rho_1\frac{\partial^2 u_3}{\partial t^2} \tag{1}$$

$$E_2A_2\frac{\partial^2 u_4}{\partial x_2^2}+\frac{bG}{h}(u_4-u_3)=A_2\rho_2\frac{\partial^2 u_4}{\partial t^2} \tag{4}$$

4. Material properties

The material properties that used in modal vibration study for panels with two type of lamina determined by using the properties of carbon fibre and epoxy resin and different formulation for woven and biaxial non-woven lamina.

4.1 Woven fabrics

Woven-fibre composite materials represent a type of textile composite where strands are formed by the process of weaving[9]. Woven fabrics have many advantages such as ability to build structures with complex geometric shapes, Low manufacturing costs, ease of implementation, better out-of-plane properties and impact resistance. However, the geometry of this composite class is complex and there is a wide range of possible architectures and constituents because it is possible to act on microstructure geometry, weave type, hybridization or choice of constituents. The geometrical variables of the reinforcement (the yarn spacing, the yarn thickness and the weave type) or the fibre and resin types, the packing density of the yarns and the fibre volume fractions may be varied to obtain the specific mechanical properties. Carbon, glass or aramid fibres may be used as reinforcement[10].

generalized three-dimensional micro-mechanical model has been developed for predicting all elastic constants of woven fabric composites based on a three-dimensional geometric model and the variational principle by Sheng and Hoa [11].

A parametric study on the elastic properties of the layer made of woven fibres was carried out by Amirian and Kiasat [12]. The elastic properties estimated by an analytical method by equating the compliance matrix of one layer of woven fibre with two layers of unidirectional fibres. In this research, this method has been used to extract properties. Figure 1 showed the schematic of woven and non-woven biaxial fibres.

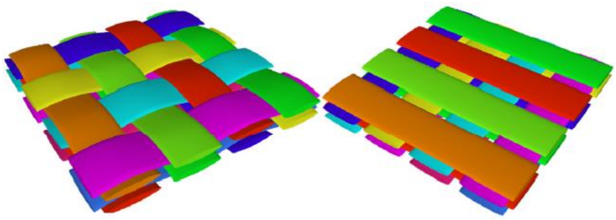


Figure 1. Woven and biaxial non-woven fibres.

In the table 1. Elastic properties of lamina consist of woven carbon and epoxy resin are given.

Table 1. Elastic properties of woven carbon with epoxy matrix.

properties	Carbon-epoxy
Young’s modulus x direction (GPa)	59
Young’s modulus y direction (GPa)	59
Young’s modulus z direction (GPa)	7.6
Poisson’s ratio xy	0.04
Poisson’s ratio yz	0.3
Poisson’s ratio xz	0.3
Shear modulus xy (GPa)	3.35
Shear modulus yz (GPa)	2.73
Shear modulus xz (GPa)	2.73

4.2 Unidirectional and biaxial non-woven fibres

Unidirectional composite lamina properties are calculated using the following formulation for a unidirectional ply with the same matrix and fibre properties as in reference [13]. Biaxial non-woven layers consist of two UD plies oriented in zero and 90 degrees.

$$E_{11} = \varphi . E_{fL} + (1 - \varphi) . E_m \tag{5}$$

$$E_{22} = \frac{E_m}{1-\vartheta_m^2} . \frac{1+0.85.\varphi^2}{(1-\varphi)^{1.25}+\varphi . \frac{E_m}{E_{fT}.(1-\vartheta_m^2)}} \tag{6}$$

$$\vartheta_{12} = \varphi . \vartheta_{f12} + (1 - \varphi) . \vartheta_m \tag{7}$$

$$G_{12} = G_m . \frac{1+0.8\varphi^{0.8}}{(1-\varphi)^{1.25}+\frac{G_m}{G_{f12}}.\varphi} \tag{8}$$

In Table 2, elastic properties for a lamina consisting of woven carbon fibre and epoxy resin are given.

Table 2. Elastic properties of UD carbon-epoxy lamina.

properties	value
Young’s modulus x direction (GPa)	123
Young’s modulus y direction (GPa)	7.8
Young’s modulus z direction (GPa)	7.8
Poisson’s ratio xy	0.27
Poisson’s ratio yz	0.42
Poisson’s ratio xz	0.27
Shear modulus xy (GPa)	5
Shear modulus yz (GPa)	3.06
Shear modulus xz (GPa)	5

5. Geometrical and FEM model

For investigation of vibration in marine composite panels, a panel including longitudinal and transverse frames used in bottom of a composite craft is selected. Fixed boundary conditions at the edges (position of webs and bulkheads) are applied in modal vibration analysis. Geometry of panels are shown in figure-2.

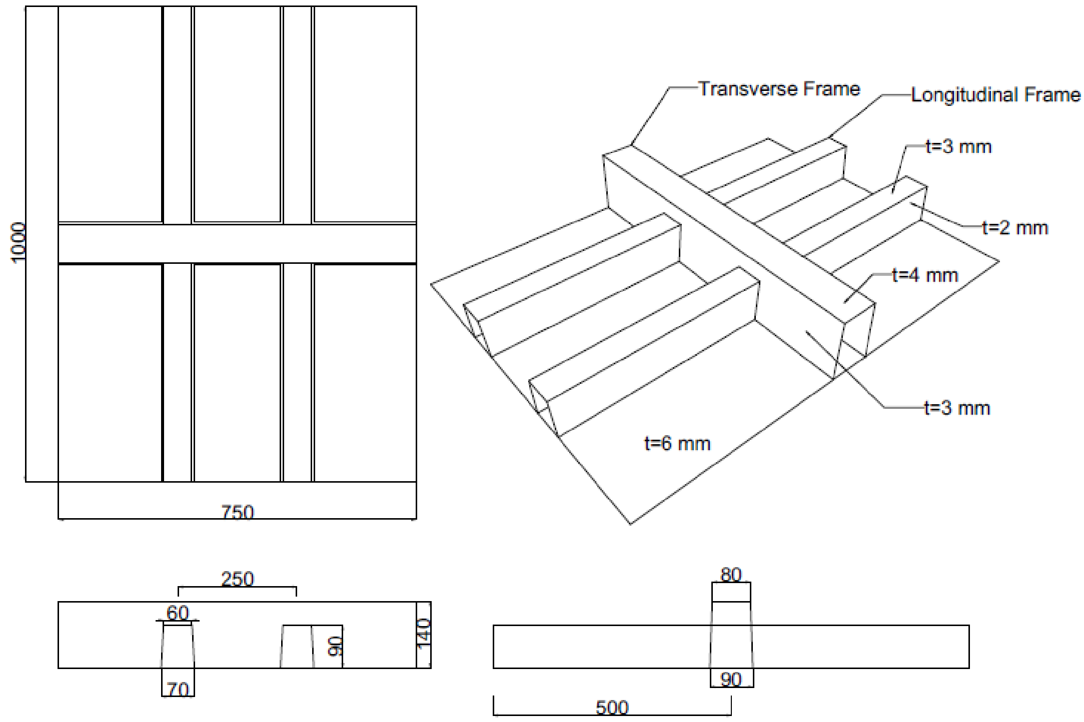


Figure 2. Geometry of selected panel.

FEM model prepared using ANSYS workbench with shell element include 4 node element. Figure-3. Showed the FEM model of selected panel. Panel laminated with two different lamina (woven and non-woven biaxial) and the thickness of each ply is 0.5 mm. biaxial ply consist of two UD ply with fibre orientation in zero and ninety degree to panel. Each UD ply have a 0.25 mm thickness.

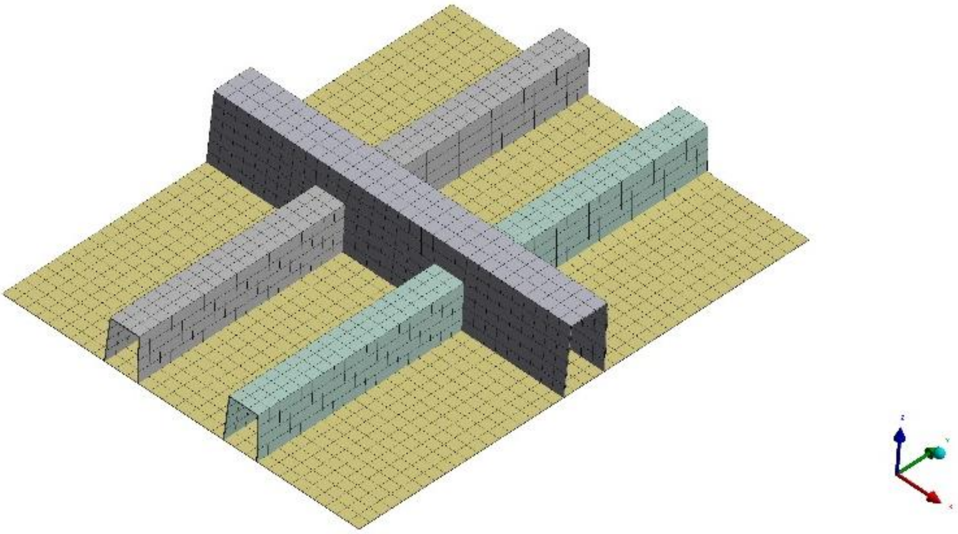


Figure 3. FEM model of selected panel.

6. Modal Vibration analysis and B.C.

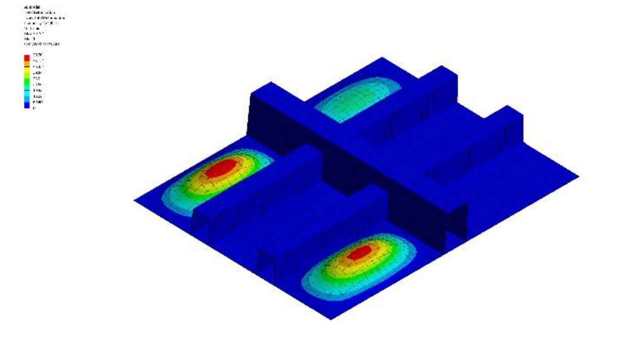
Modal Analysis is a powerful procedure to obtain dominant vibration modes in structures from measurements of the structural response only. Traditionally, modal analysis is applied using acceleration measurements to obtain the shapes, frequencies and structural damping of the flexural vibration Modes. With some modifications the procedures can also be applied to strain measurements and both types of data combined. Ships operating in waves are continuously subjected to varying loads from waves. As a result of these loads the ship undergoes rigid body motions and deformations. The latter can be subdivided into two types, a quasi-static and a dynamic response. The quasi static response depends only on the stiffness distribution of the structure. The dynamic response also depends on the mass distribution. The dynamic response of a ship may be characterised by its modal parameters[14].

Modal Analysis for comparison of vibrational characteristics of panels that laminated with two different type of lamina implemented.

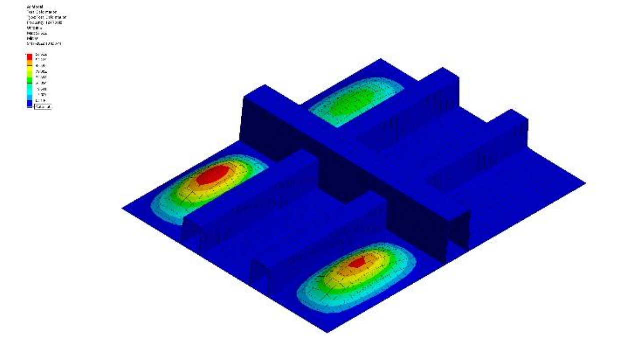
4 Edge of stiffened panel Fixed due to the position of transverse bulkheads and webs in the end of longitudinal stiffeners and the position of keel and side in the end of transverse frame.

7. Result and discussion

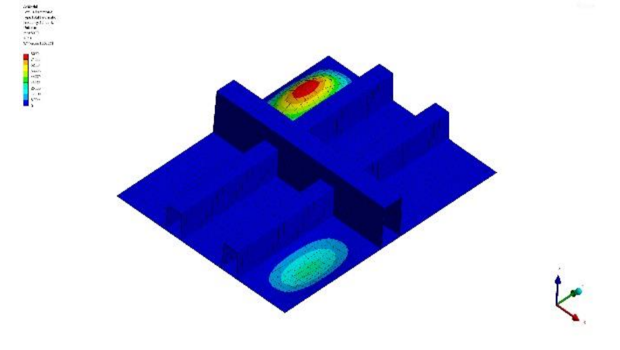
The first six vibrational mode shape for laminated panel with biaxial and woven ply illustrated in figure 4. Similar mode shapes observed for panels with different lamination consist of UD and woven fibres. Also primary mode shapes occurs in shell and does not happen in longitudinal stiffeners or transverse frame. Frequency of vibrational modes and total deformation in the first 12 modes also shown in table-3. It can be understood that despite the low in plane tensile and compressive modulus for woven fibers, due to its high shear modulus, the same results are obtained for its natural frequencies compared to unidirectional fibers. Also, there is no significant difference in the total deformation of laminated panels with different lamina (woven and non-woven).



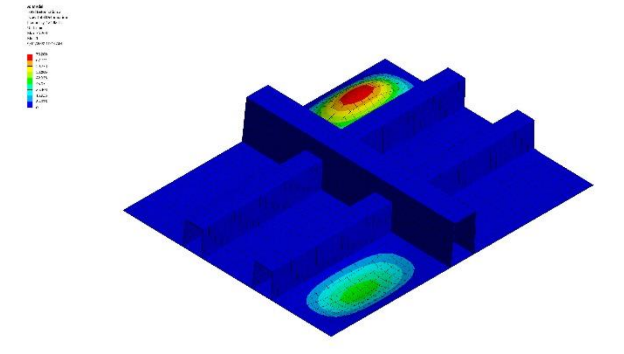
Mod shape-1-Laminated panel with Biaxial ply



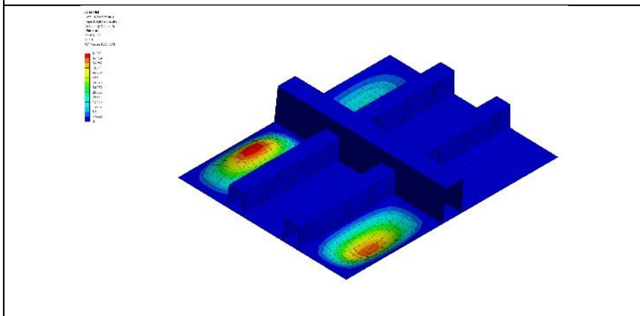
Mod shape-1- Laminated panel with woven ply



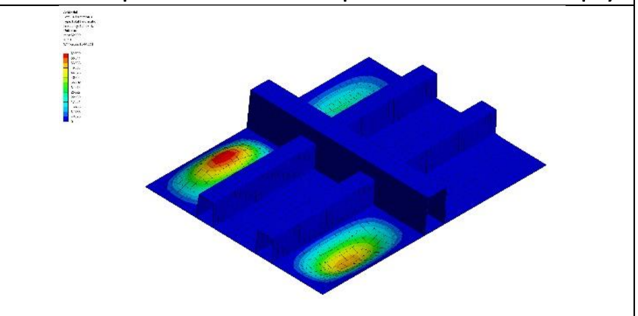
Mod shape-2- Laminated panel with Biaxial ply



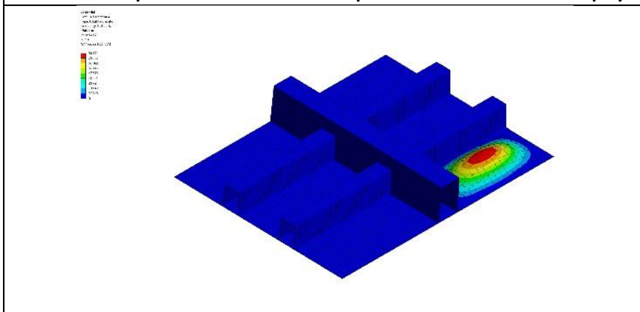
Mod shape-2- Laminated panel with woven ply



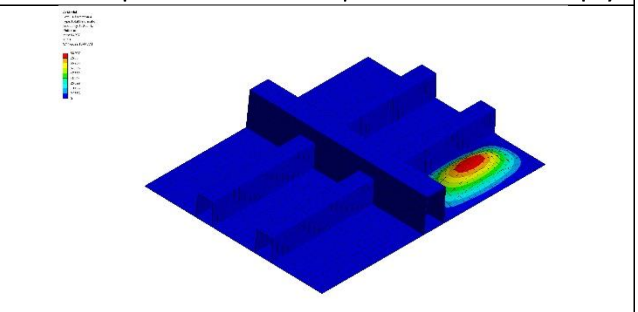
Mod shape-3- Laminated panel with Biaxial ply



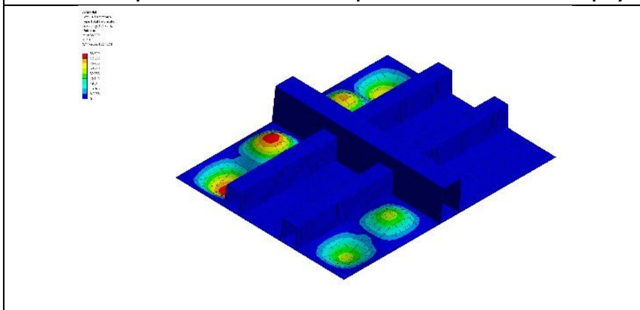
Mod shape-3- Laminated panel with woven ply



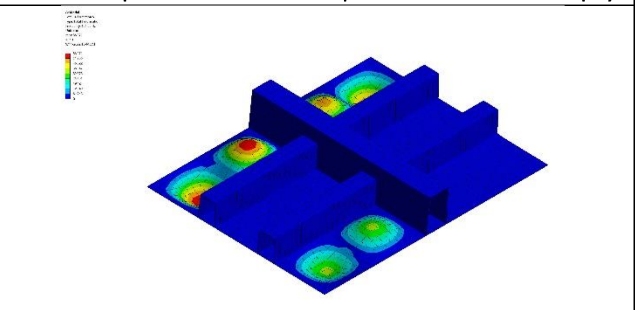
Mod shape-4- Laminated panel with Biaxial ply



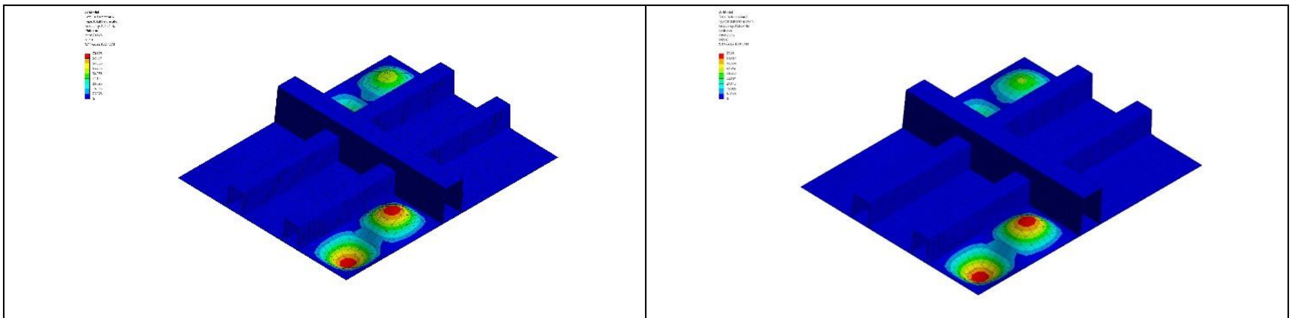
Mod shape-4- Laminated panel with woven ply



Mod shape-5- Laminated panel with Biaxial ply



Mod shape-5- Laminated panel with woven ply



Mod shape-6- Laminated panel with Biaxial ply | Mod shape-6- Laminated panel with woven ply

Figure 4. The first six vibrational modes for laminated panel with biaxial and woven ply.

Table 3. Frequency and total deformation of panels laminated using woven and non-woven ply.

	Panel Laminated by Non-woven ply		Panel Laminated by woven ply	
Mode Shape	Frequency	Total Deformation	Frequency	Total Deformation
1	124.85	59.761	124.73	58.622
2	124.93	80.59	124.82	76.209
3	124.98	61.911	124.87	62.829
4	130.66	86.171	130.26	86.097
5	158.75	58.829	158.66	58.271
6	158.84	70.178	158.77	72.43
7	158.92	59.66	158.85	59.963
8	163.82	89.173	163.23	89.185
9	164.1	83.762	163.88	84.003
10	172.64	91.92	171.51	91.439
11	196.63	88.777	196.42	88.804
12	205.23	91.012	204.76	90.991

8. Conclusion

Modal vibration analysis using FEM method is applied to calculate the frequency and total deformation in primary modes of free vibration for panels laminated by two different laminae, that is woven and non-woven biaxial lamina. The results showed that in spite of low axial elastic modulus for woven fabrics, the panel laminated by woven fibre lamina have the same vibration behaviour as the panel laminated by biaxial non-woven lamina. Also, the first six mode shapes of the two panels consisting of different lamina (woven and biaxial non-woven) are similar in addition to the same total deformation.

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