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Finite Element Analysis of Various Composite Honeycomb Cores Under Tensile Loading

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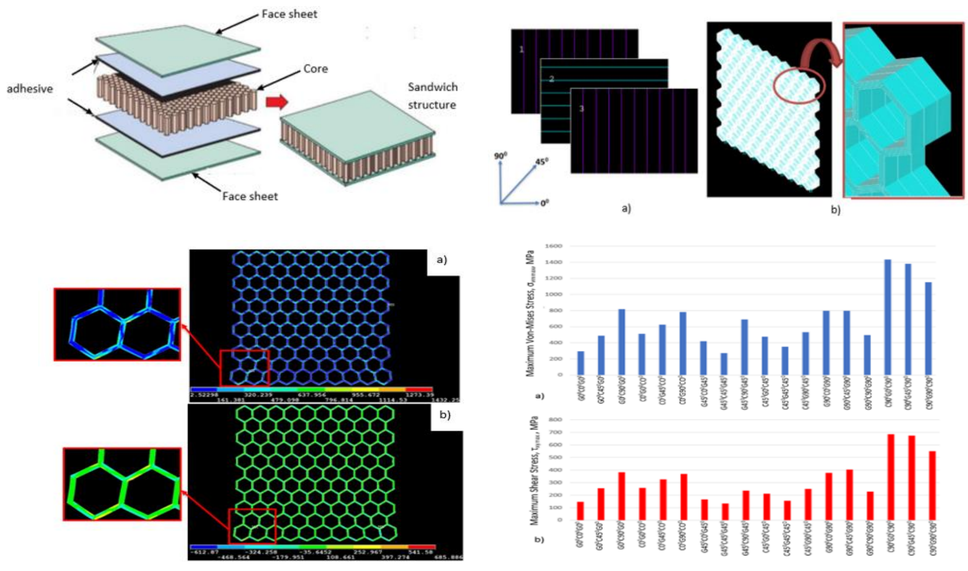
HIGHLIGHTS

- Manufacturing methods of Honeycomb core
- Finite element analysis of composite honeycomb core
- Effect of fiber directions on mechanical behavior of honeycomb core

GRAPHICAL ABSTRACT



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ABSTRACT

Sandwich composite structures are widely used in significant applications of many fields such as aerospace, automotive and defense. An increase in the usage of sandwich structures make the researchers focus on investigating the possible various face sheet and core materials which are the main parts of sandwich structures. In recent years, improvements in additive manufacturing methods enabled producing the structures with desired dimensions with less material waste and less production steps. In this study, manufacturing methods of honeycomb cores were examined firstly and then a group of finite element analysis (FEA) were conducted on various composite honeycomb cores with different layer sequences under tension in order to determine their mechanical behaviors. The results exhibited that layer sequence and materials have a great effect on Von-Mises (σ_{vm}) and shear stress (τ_{xy}) occurring in honeycomb core.

1. INTRODUCTION

Sandwich structures are three-layered laminates consisting of two thin but stiff face sheets (skins) and a lightweight but thick honeycomb or foam core [1,2] and adhesive parts as shown in Figure 1 [3]. Face sheets and core materials of

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sandwich structures are glued to each other by using adhesives. In sandwich structures, face sheets provide support for core and the main goal of the core structure is to increase flexural stiffness of the entire sandwich structure with very little weight gain. However, using a core material with significantly low density reduces stiffness and strength characteristics which increase the possibility of the complete failure of the composite sandwich structure [4].

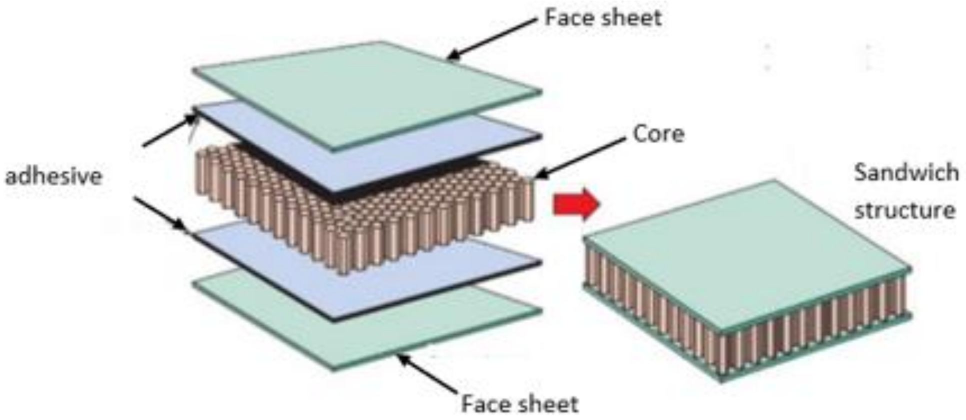

Fig. 1. *Basic schematic view of sandwich structure [3]*

Sandwich structures are extensively used in aerospace, defense, automotive, energy system fields [5]. Besides, sandwich core materials can be classified into two main categories as homogeneous support of skins and nonhomogeneous support of skins like shown in Figure 2 [6]. It is announced that honeycomb core materials market size was valued at USD 1.87 Billion in 2016 and is projected to reach USD 3.21 Billion by 2022. The increasing demand for lightweight, high strength, and environment-friendly packaging solutions is driving the growth of the honeycomb core materials market across the globe [7]. Besides, thermoplastic, aluminum, Nomex, stainless steel, titanium, aramid paper, ceramics, carbon or fiberglass can be used to manufacture honeycomb cores with various manufacturing methods [8,9].

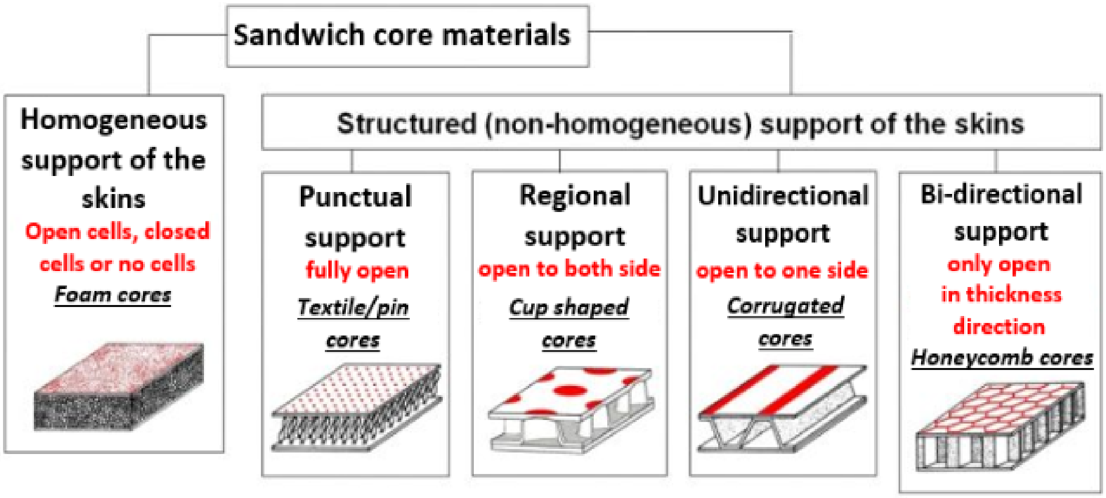

Fig. 2. *Classification of sandwich core materials [6]*

In last decade, new honeycomb core production methods like additive manufacturing of composite materials and laser cutting or milling process after hand lay-up of composite materials came up and their usage popularity went up to higher levels day by day with the help of improvements technology unlike traditional honeycomb core manufacturing methods like adhesive bonding, resistance welding, brazing, diffusion bonding and thermal fusion. Resistance welding, brazing and diffusion bonding processes are only suggested for cores to be used at very high temperatures. Hence, adhesive bonding is the most preferred method as traditional honeycomb core manufacturing and two different adhesive bonding methods were shown in Figure 3 below [10-12].

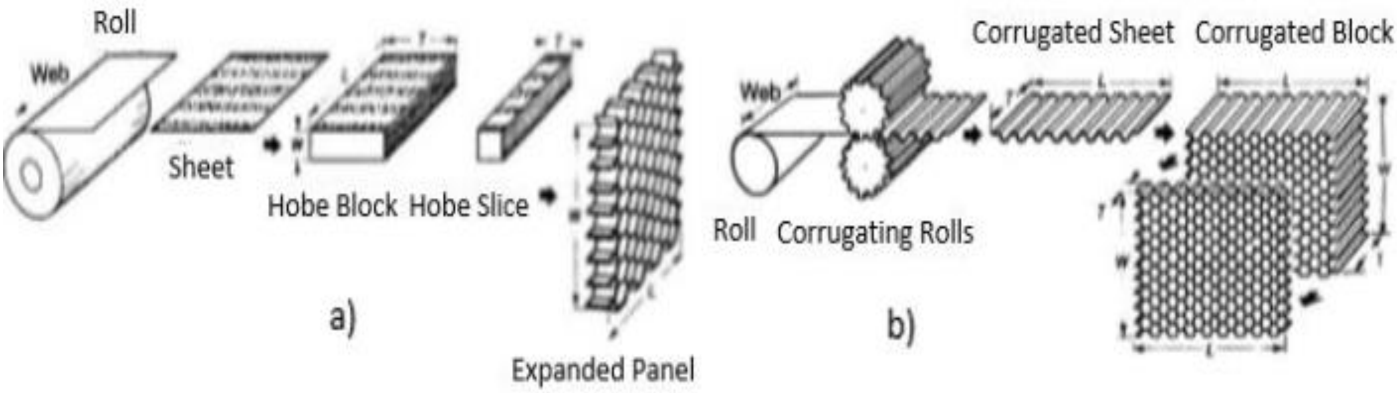

Fig. 3. *Traditional honeycomb core manufacturing methods a) Expansion method of core manufacturing, b) corrugation method of core manufacturing [12].*

In this study, unlike most of studies conducted in literature, finite element analysis of honeycomb core made of composite materials were examined in order to predict occurring Von-Mises stress (σ_{vm}) and shear stress (τ_{xy}) in honeycomb cores for various layer sequences related with fiber direction like 0^0, 45^0 and 90^0 and materials such as glass-epoxy or carbon-epoxy under tension.

2. FINITE ELEMENT ANALYSIS

Firstly, the cad model of composite honeycomb core was designed by using AutoCAD designing programme. After that, this model was transferred to Ansys Apdl finite element analyzing programme in order to prepare the model for finite element analysis. In Ansys Apdl programme, 3D 4node 181 element type was chosen and related information with finite element analysis such as material and mesh properties were tabulated in Table 1 with details. As can be seen from Table 1, glass-epoxy and carbon-epoxy materials were used in analysis and their material properties like elasticity modulus (E), shear modulus (G), Poisson's ratio (ν) and density (ρ) were obtained by using composite mixing rules equations (1-5) given below and both of these materials were mixed as %50 glass or carbon and %50 epoxy [13,14].

$$Ex = Ef\,Vf + Em\,Vm \qquad (1)$$

$$Ey = \frac{Em\,Ef}{Vf\,Em + Vm\,Ef} \qquad (2)$$

$$\nu xy = \nu m\,Vm + \nu f\,Vf \qquad (3)$$

$$Gxy = \frac{Gm\,Gf}{Vm\,Gf + Vf\,Gm} \qquad (4)$$

$$\nu xy/_{Ex} = \nu yx/_{Ey} \qquad (5)$$

Table 1. *Calculated laminate material properties by using composite mixing rules*

Material	Ex (GPa)	Ey (GPa)	Ez (GPa)	νxy	νxz	νyz	Gxy (GPa)	Gxz (GPa)	Gyz (GPa)	P (g/cm³)	Mesh size (mm)
Glass-epoxy	38,5	9,35	9,35	0,22	0,05	0,05	3,47	3,47	3,47	1,89	0,5
Carbon-epoxy	112,5	9,77	9,77	0,25	0,02	0,02	3,29	3,29	3,29	1,52	0,5

In Ansys programme, honeycomb core was designed again in order to create 3 layers by using. Fiber directions in layer sequence of $90^0 - 0^0 - 90^0$ and meshed view of model with 3 layers were presented in Figure 4a and Figure 4b.

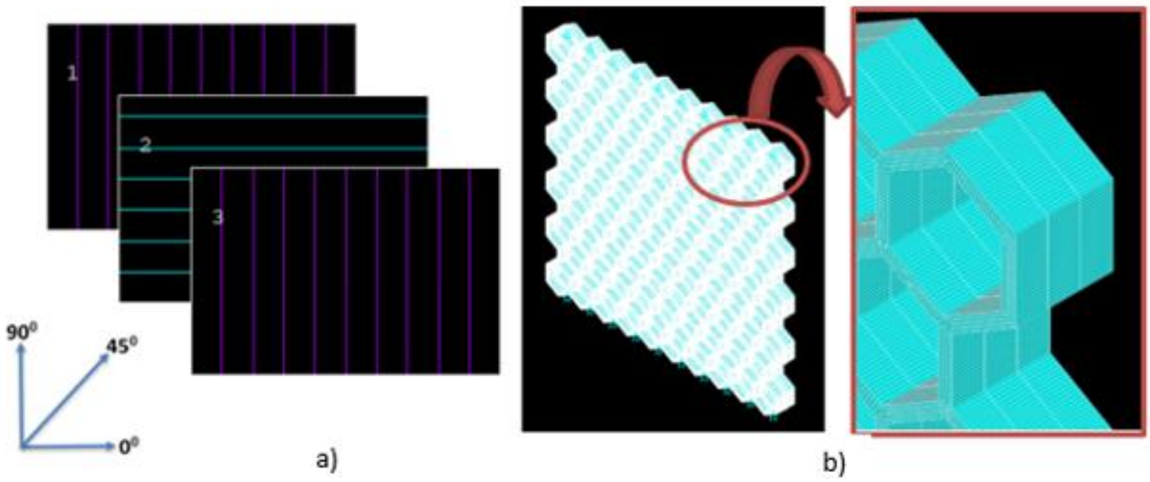

Fig. 4. *a) Schematic view of a layer sequence of 90^0 – 0^0 – 90^0, b) meshed model*

Furthermore, designed honeycomb core model were meshed with quad mesh type and element edge length of 0.5 mm. Moreover, 10 nodes from the bottom were fixed as ancastre and 10 nodes from the top were pulled 5 mm through y axis as boundary conditions (Figure 5).

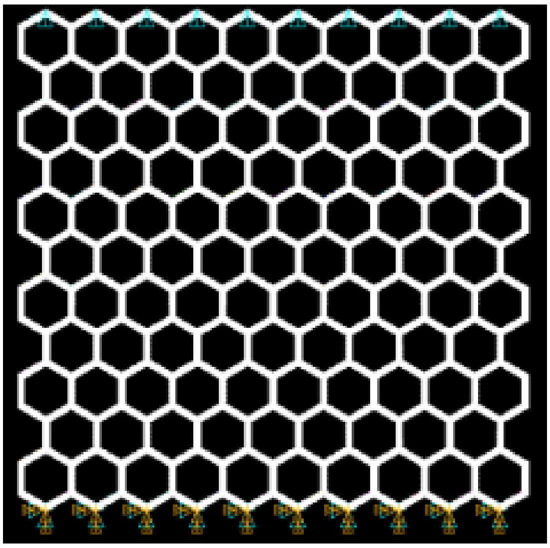

Fig. 5. *Boundary conditions of finite element model*

3. RESULTS AND DISCUSSION

Honeycomb core structures have a significant role to provide strength enough besides to be light in order to minimize the weight of sandwich structure which is widely used in many engineering fields. Hence, 18 finite element analysis of honeycomb core were examined to observe the differences with the change of direction of fibers. In Figure 6a and Figure 6b, σvm and τxy distributions were shown respectively for composite honeycomb core with Carbon 90^0 – Glass 0^0 – Carbon90^0 ($C90^0G0^0C90^0$) as an example. Maximum Von-Mises ($σvm_{max}$) and shear stresses ($τxy_{max}$) consisted of at the joints of ribs.

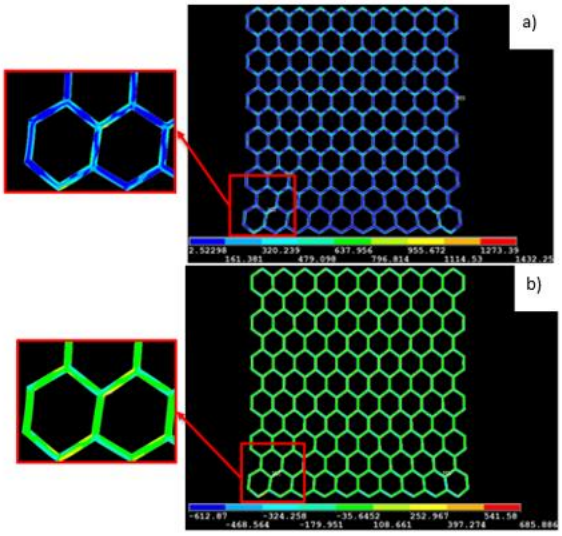

Fig. 6. *a) Von-Mises stress distribution on model, b) Shear stress distribution on model*

Maximum Von-Mises stress (σvm_{max}) and maximum shear stress (τxy_{max}) occurred in each finite element analysis were presented in Figure 7a and Figure 7b. The results show that σvm_{max} of 1432,25 MPa and τxy_{max} of 685,886 MPa occurred in honeycomb core with layer sequence of Carbon 90^0 – Glass 0^0 – Carbon90^0 and the lowest σvm_{max} of 271,32 MPa and the lowest τxy_{max} of 133,71 MPa have been observed in honeycomb core with layer sequence of Glass 45^0 – Carbon 45^0 – Glass 45^0. Furthermore, it's an interesting result that when top and bottom layers made of Carbon-epoxy instead of Glass-epoxy, honeycomb core includes more σvm in all combinations without layer sequence of 45^0 – 90^0- 45^0. Hence, it can be expressed that number of layers made of materials with high elasticity modulus like Carbon-epoxy have a significant role in formation of σvm. On the other hand, as mentioned above, in the layer sequence of Glass 45^0 – Carbon 90^0 – Glass 45^0 more σvm was obtained although the number of Carbon-epoxy layers less then Glass-epoxy and this situation presents how much the layer sequence is important while manufacturing a composite honeycomb core.

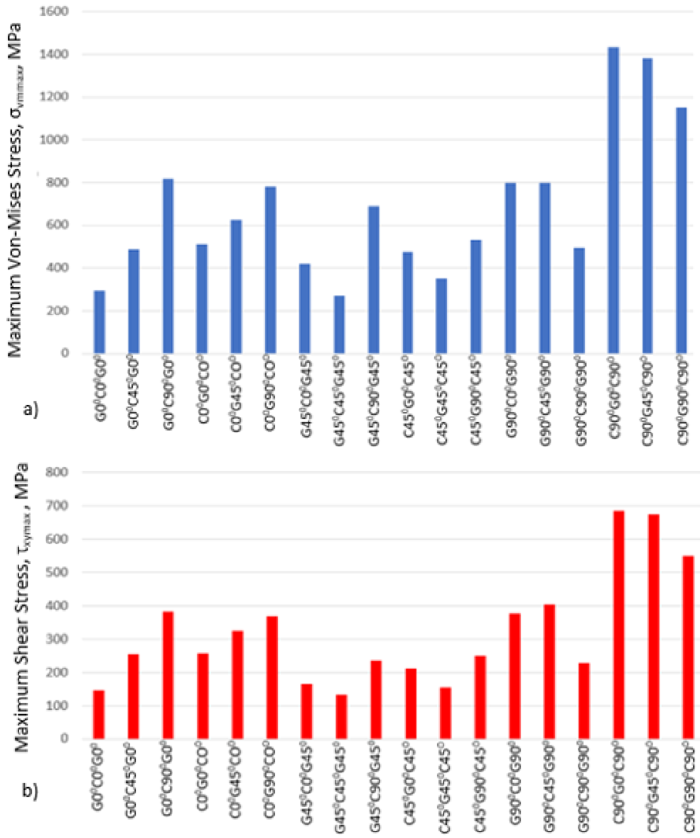

Fig. 7. *Change of stresses depend on layer sequence, a) Maximum Von-Mises stress vs layer sequence, b) Maximum shear stress vs layer sequence*

4. CONCLUSIONS

Key findings of this work are summarized as follows:

- ✓ Honeycomb cores can be manufactured in desired geometry by using additive manufacturing methods besides traditional honeycomb core manufacturing methods like expansion and corrugation.
- ✓ Maximum Von-Mises (σvm_{max}) and shear stresses (τxy_{max}) consisted of at the joints of ribs.
- ✓ The results show that σvm_{max} of 1432,25 MPa and τxy_{max} of 685,886 MPa occurred in honeycomb core with layer sequence of Carbon 90^0 – Glass 0^0 – Carbon90^0 and the lowest σvm_{max} of 271,32 MPa and the lowest τxy_{max} of 133,71 MPa have been observed in honeycomb core with layer sequence of Glass 45^0 – Carbon 45^0 – Glass 45^0.
- ✓ It can be expressed that number of layers made of materials with high elasticity modulus like Carbon-epoxy have a significant role in formation of σvm. On the other hand, as mentioned above, in the layer sequence of Glass 45^0 – Carbon 90^0 – Glass 45^0 more σvm was obtained although the number of Carbon-epoxy layers less then Glass-epoxy and this situation presents how much the layer sequence is important while manufacturing a composite honeycomb core.

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