The numerical study of the reinforcement layer orientation effect on the behaviour of laminated plates

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Abstract. The analysis of the simply supported square laminated plate was conducted employing two distinct Finite Element Method (FEM) models: one representing a quarter-section of a layered laminated composite plate, and the other representing the entire layered laminated composite plate. It was found that the plate's behavior and displacements are significantly influenced by the orientation of the fibers. Moreover, the quarter-section model of the layered laminated composite plate demonstrated limitations in its universal applicability.

1 Introduction

The utilization of composite materials—consisting of various constituents with differing properties—is witnessing a notable increase across multiple sectors. Particularly in structural engineering, these materials are indispensable for applications requiring the optimal balance between high strength and stiffness alongside minimal weight. Initially pioneered within the aerospace industry, composite materials have now expanded into manufacturing components characterized by complex geometries, exposure to considerable stresses, or serving as aesthetic elements.

Understanding a material's mechanical characteristics, behavior under load, and deformation patterns is essential for its integration into structural assemblies. Given the anisotropic nature of composite materials, meaning their mechanical properties vary by point and direction, analyzing their properties, behavior, and load response presents a more intricate challenge.

In the realm of materials engineering, a composite laminate is structured as a series of fibrous composite layers laminated together. These layers are typically comprised of fibers with high modulus and strength, embedded within a suitable matrix of polymer, metal, or ceramic. Fibers such as cellulose, graphite, glass, boron, and silicon carbide are preferred for their superior properties, while matrices commonly include epoxies, polyimides, aluminum, titanium, and alumina due to their compatibility and performance.

In contemporary engineering practices, structural components fashioned from modern composite materials often consist of multiple layers that are rigidly adhered to one another.

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These layers can be represented by a unidirectional, thin composite configuration, where parallel fibers are embedded within a matrix material (refer to Fig. 1.1) [1]. The thickness of each layer typically exceeds 0.1mm, with the fibers themselves having a diameter in the vicinity of 10µm. The mechanical attributes of the laminate are contingent upon both the properties of the constituent layers and their specific arrangement. Accordingly, understanding the behavior of each individual layer is essential for a comprehensive analysis of laminate structures.

Laminates stand as a prevalent form of composite material, constructed from multiple thin layers of fibers bonded together with an epoxy resin. The characteristic properties of a laminate are derived from the type of fibers employed in each layer, alongside the total number of layers and their respective thicknesses.

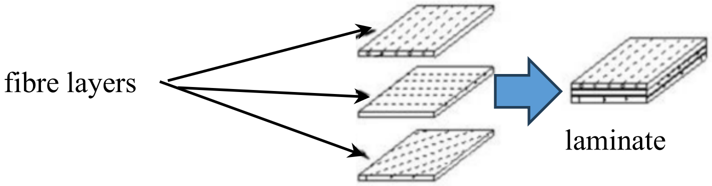


Fig. 1. Layered laminate composite.

2 Numerical experiments

The simply supported square laminated plate is considered, with the length and the width $L = 20$ cm, and thickness $h = 1$ cm. The uniform transverse pressure load $q = 1$ MPa is subjected on multilayered plate. The lay-up is made of three layers, all with the same orthotropic material properties. The material axes are different in each layer and are oriented at 0, 45 and 90 degrees from the axes x, respectively. The layers have the same thickness 3.33 mm. $E_a = 50 \cdot 10^4$ MPa, $E_b = 2 \cdot 10^4$ MPa, $E_c = 2 \cdot 10^4$ MPa, $G_{ab} = 1 \cdot 10^4$ MPa, $G_{ac} = 1 \cdot 10^4$ MPa, $G_{bc} = 0.4 \cdot 10^4$ MPa, $v_{ab} = 0.01$, $v_{ac} = 0.01$, $v_{bc} = 0.3$.

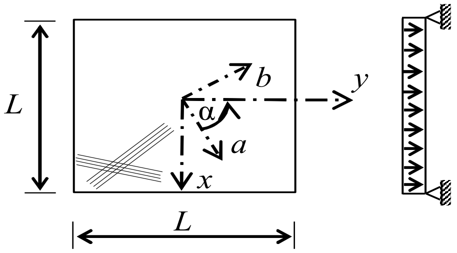


Fig. 1. Schema of the layered composite square plate.

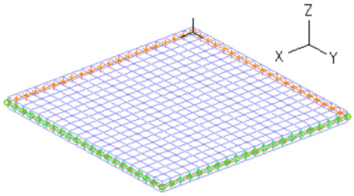
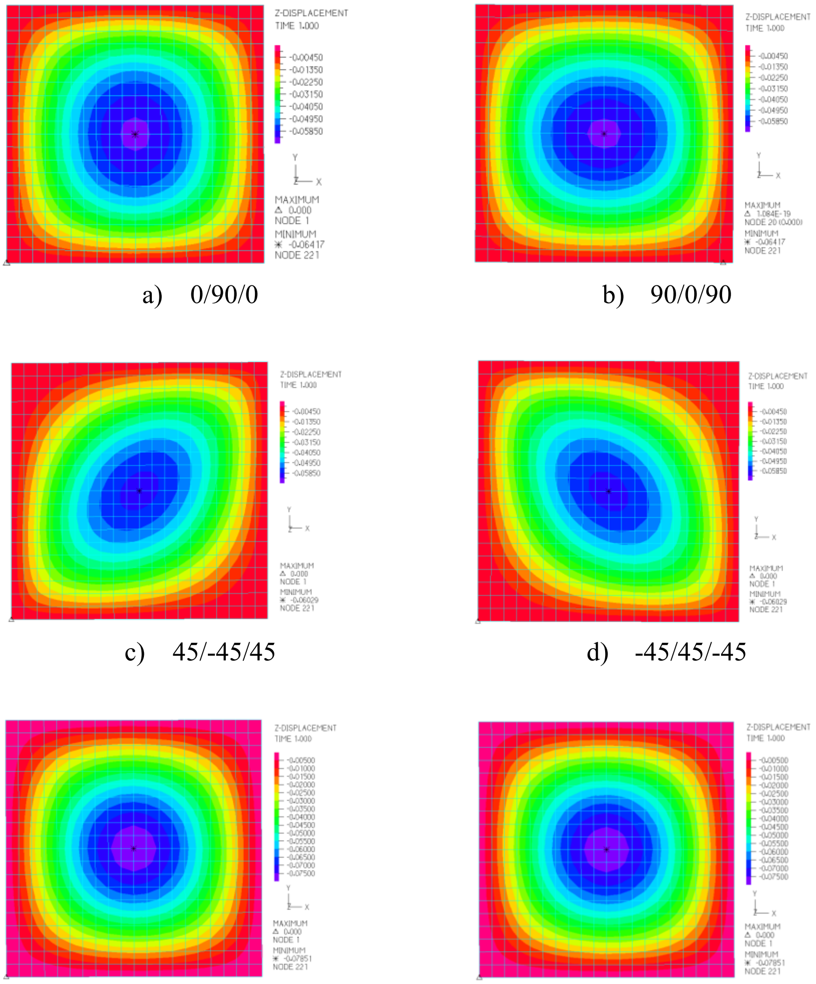


Fig. 2. Numerical model of the layered laminate composite in Figure 1.

Figure 1 documents the square laminate plate, its support and loading. The numerical model of the plate from Figure 1 is shown in Figure 2. The multilayered 4-node shell element with possibilities using the orthotropic material was used.



a) 0/90/0 b) 90/0/90

c) 45/-45/45 d) -45/45/-45

e) 0/45/90 f) 90/45/0

Fig. 3. The displacement of the layered laminate composite plate depend on the fibres orientation, a) 0/90/0, b) 90/0/90, c) 45/-45/45, d) -45/45/-45, e) 0/45/90, d) 90/45/0.

Figure 3 documents the normal displacements at the centre of the layered laminate composite plates depending on fibres orientation in the layers, namely

a) 0/90/0,
b) 90/0/90,
c) 45/-45/45,
d) -45/45/-45,
e) 0/45/90,
f) 90/45/0.

It is evident from the documentation of the deformation that the fibres orientation in the layers has an effect on the behaviour of the layered composite plates as well as on the normal displacement in its centre. The values of the maximum of the normal displacement at centre of the layered simply supported square composite plate are document in Figure 4.

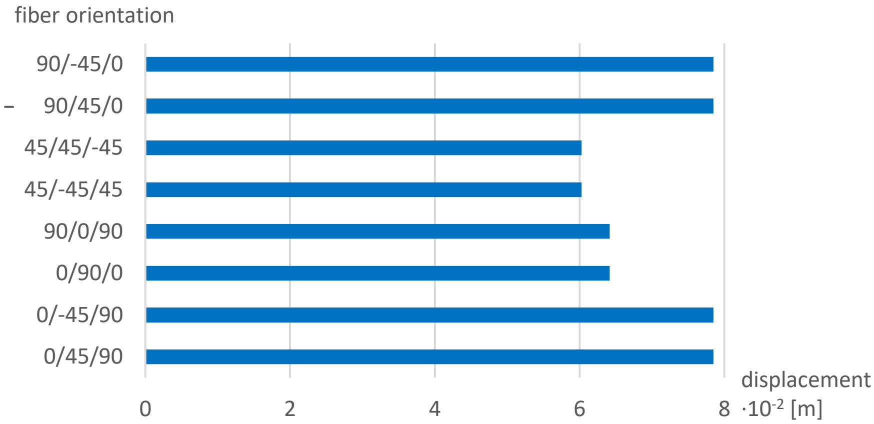
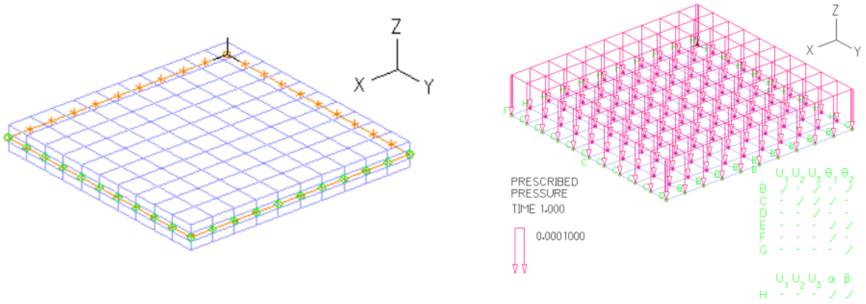


Fig. 4. The values of the normal displacement at the centre of the layered composite plate in depending on the fibre's orientation.

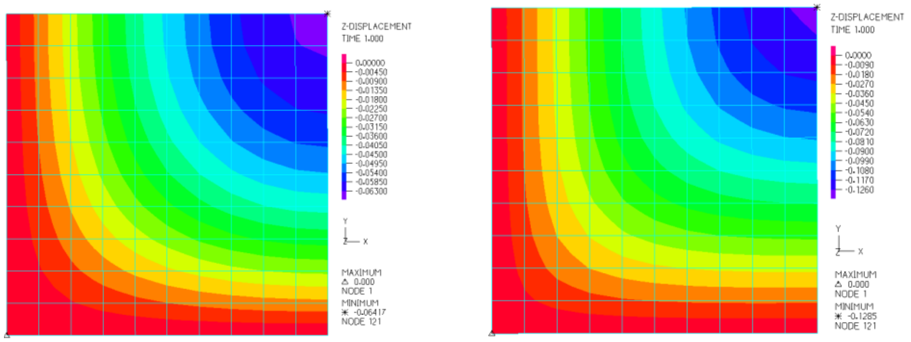
The layered laminate composite plate was also solved by the next numerical model of only of the plate quarter, with using the boundary conditions of symmetry. Figure 5 documents the numerical model of the square laminate plate quarter,

a) model and meshing of the numerical model of the square laminate plate quarter,
b) the loading and the boundary conditions of the numerical model.



a) b)

Fig. 5. Numerical model of the layered laminate composite quarter in Figure 1, by using symmetry, a) model and meshing, b) the loading and the boundary conditions.



a) b)

Fig. 6. Z-displacement of the layered laminate composite quarter depend on the fibres orientation, a) 0/90/0, b) 45/-45/45.

From the results obtained for the vertical deflections, it is evident that the symmetry of the numerical solution gives identical results only for the orientation of the stiffening 0/90/0 and 90/0/90. For the assumed 45 fibres orientation, the results are not identical, the numerical model of the layered composite plate quarter is not possible to use.

Table 1. Comparison of the normal displacements at the centre of the layered composite plate depend on the fibre's orientation.

Fibres orientation	**Maximum value of z-displacement**	
	Numerical model of the layered composite quarter [mm]	**Numerical model of the layered composite plate [mm]**
0/45/90	0.08051	0.07851
0/-45/90	0.07544	0.07851
0/90/0	**0.06417**	**0.06417**
90/0/90	**0.06417**	**0.06417**
45/-45/45	0.1285	0.06029
-45/45/-45	0.04269	0.06029
90/45/0	0.08051	0.07851
90/-45/0	0.07544	0.07851

3 Conclusion

The simply supported square laminate plate was considered, and solved by Finite Element Method by using two models, as:

- the numerical model of the layered laminate composite plate quarter and
- the numerical model of the layered laminate composite plate.

It is possible to conclude from the results obtained:

- the behaviour and displacements are depend on the fibre orientation,
- the maximum values of the normal displacements at the centre of the layered laminate composite plates are equal only for the fibre orientation 0/90/0 and 90/0/90 for used model,
- the models used do not give the same results for the normal displacements at the centre of the layered laminate composite plates for considered fibre orientation 45,
- the numerical model of the layered laminate composite plate quarter is not universally applicable.

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