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Numerical Study of the Mechanical Behavior of a Composite Material Plate

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Abstract: Composite materials are playing an increasingly significant role in the field of mechanics, such as aeronautics, aerospace, ships, and modern cars. The objective of this work was to investigate the mechanical properties and behavior of a composite plate (carbon/epoxy) through various tests, including tension, compression, and bending, using numerical analysis. Additionally, static analysis of mechanical behavior was performed, as well as the natural vibration of undamped structures. This analysis aimed to determine stresses, displacements, natural frequencies, and modes of free vibration. The obtained results illustrated that the composite material has a significant impact on improving the quality of mechanical properties and increasing the lifetime of materials, making it a valuable option for design and repair techniques. Furthermore, the results obtained in this work align well with previous literature studies. By examining these parameters, this study aimed to enhance our understanding of how composite materials perform under different mechanical loads and dynamic conditions, thus contributing valuable data to advance the field of composite mechanics.

Keywords: Composite material, Vibration, Stress, Fiber, Mechanical tests.

Introduction

In response to the consistently high demands in the industrial sector, particularly in the areas of safety and energy consumption control, major aircraft manufacturers have been driven to develop lightweight structures that exhibit enhanced mechanical strength and rigidity. Composite materials, with their remarkable mechanical properties, low weight, chemical resistance, superior fatigue resistance, and adaptability in shaping, emerge as the optimal solution in the industrial landscape. These composite materials find wide-ranging applications across various industrial sectors, prominently in the construction of both civil and military aircraft. They are engineered through the fusion of two or more materials characterized by distinct appearances and compositions. This harmonious amalgamation of diverse components yields a product distinguished by specific high-performance properties and unique characteristics.

Composites offer the advantage of creating lightweight components with attributes like corrosion resistance and effective thermal and electrical insulation. However, composite materials are susceptible to specific dynamic forces, notably impact forces encountered during both service and operation. Unlike metallic materials, defects

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resulting from these forces may remain partially hidden. Thus, the development of non-destructive methods for detecting these defects is of paramount importance.

One of the foremost challenges in the use of composite materials lies in the measurement of mechanical properties, including elastic moduli and ultimate strengths in all directions. These data serve as essential inputs for finite element calculations and failure criteria. In particular, determining mechanical properties in the fiber direction often governs the thickness of a component, as composite components are frequently designed with fibers aligned in the directions of maximum stress. Therefore, methods for precisely and reliably measuring these properties are imperative for efficient design. Understanding the phenomena associated with damage and the ability to identify the mechanisms governing the mechanical behavior of carbon fibers in conjunction with epoxy resin are crucial for the design and development of multifunctional composite structures exposed to various types of loading over their service life.

Laminates are composed of individual layers stacked together, each layer having a distinct orientation relative to a common reference frame for the entire laminate. This reference frame choice, particularly the layer stacking orientations, significantly influences the resulting mechanical properties. Laminates can be categorized into various types:

(i) Balanced: A laminate containing an equal number of layers oriented in the +θ and -θ directions.
(ii) Symmetric: A laminate with layers symmetrically arranged about a central plane.
(iii) Orthogonal: A laminate with an equal number of layers oriented at 0° and 90° angles.

In this work, the evaluation of stresses, displacements, and natural frequencies in a laminated composite material plate were numerically studied.

Numerical Simulation

The numerical simulation of a composite plate was specifically designed to investigate its mechanical behaviour. Simulation serves two primary purposes. Firstly, it aids in comprehending internal phenomena by providing access to the mechanisms governing them. Secondly, it enables us to apply structural knowledge to new configurations, reducing the cost of a study with an optimized number of tests. Simulation is a versatile tool that not only replaces experiments that could be slow and laborious on a physical test bench but also broadens the designer's capabilities by decoupling variables that are inherently interconnected in structures. Numerical simulations will be conducted on samples comprised of carbon fibre and an epoxy matrix. However, eight-ply laminated composite were conducted. Table 1 shows the different characteristics of composite material.

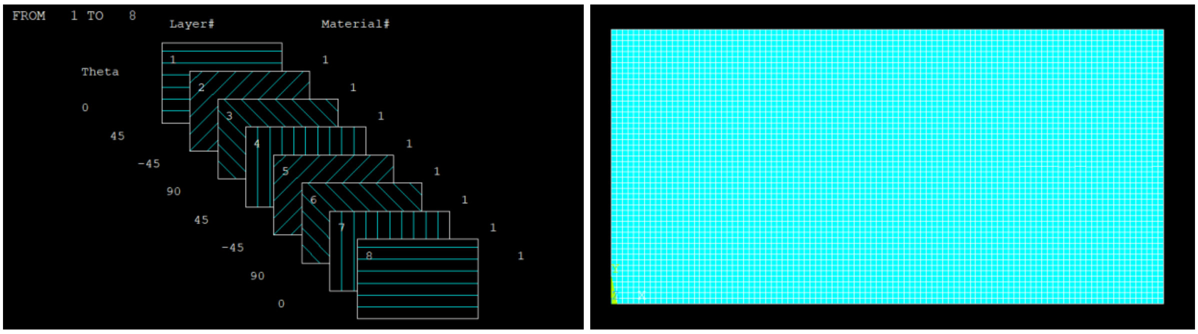
Table 1. Characteristics of composite material used in this work

Properties	Values	Properties	Values
Density	1632.9 kg/m^3	Poisson ratio YZ	0.4
Young's modulus X direction	$2.3\text{x}10^{11}$ Pa	Poisson ratio XZ	0.2
Young's modulus Y direction	$2.3\text{x}10^{10}$ Pa	Shear modulus XY	$9\text{x}10^{9}$ Pa
Young's modulus Z direction	$2.3\text{x}10^{10}$ Pa	Shear modulus YZ	$8.2143\text{x}10^{9}$ Pa
Poisson ratio XY	0.2	Shear modulus XZ	$9\text{x}10^{9}$ Pa

Results and Discussion

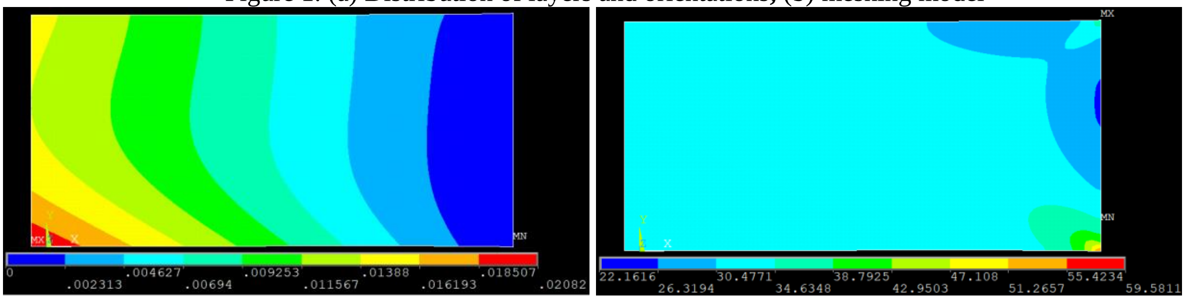
Numerical software was used to meticulously determine the natural frequencies (Table 2) and mechanical characteristics. The modal analysis within the analysis software necessitates several crucial material properties, including Young's modulus, geometric characteristics, density, and Poisson's ratio. These properties play an integral role in defining the structural behaviour of the composite plates under investigation (Figure 1).

Young's modulus and Poisson's ratio are derived from elastic parameters and are fundamental in quantifying the material's stiffness and deformation characteristics. These parameters, in combination with the geometric properties, are vital for creating an accurate representation of the composite plate's geometry within the simulation environment. The numerical results of tensile and bending tests are shown in Figures 2 and 3 respectively.



(a) (b)

Figure 1. (a) Distribution of layers and orientations**,** (b) meshing model



(a) (b)

Figure 2. Tensile test (a) displacement on axe X, and (b) stress on axe X

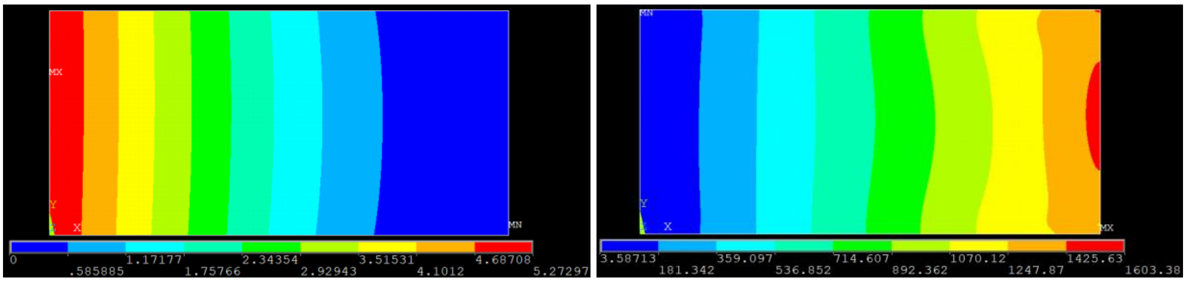


Figure 3. Bending test (a) displacement on axe Z, and (b) equivalent stress

Table 2. Natural frequency

Set	Frequency (Hz)
1	38.488
2	98.680
3	162.64
4	211.22
5	318.24
6	506.19
7	560.70
8	599.31
9	602.29
10	620.73

Conclusion

This study involved simulating the behavior of an aeronautical composite composed of carbon fiber and an epoxy matrix, with the goal of developing a strategy for replacing aging metallic structures with advanced materials, such as epoxy/carbon composites. These results served as the foundation for conducting numerical simulations using commercial software.

The obtained findings have highlighted variations in the mechanical behavior of composite materials, particularly laminates, which provide insights into the possibility of using different types of reinforcement. The strength of these materials relies on the careful selection of components and the precise arrangement of fibers. As a result, we can tailor the degree of material anisotropy based on the specific composite used, taking into account factors such as the type of reinforcement and the orientation of fibers.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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