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Mechanical Behavior Prediction of Carbon Fiber Reinforced Polymer Through ANSYS 21 Modeling

Ehasanul Islam Rafi[1], Chaitanya Roy Chowdhury[2], Md. Jafrul Hassan[2], Anik Molla[3], Hriday Kumar Gharamy[2], Md. Rokunuzzaman[2]
[1]Dept. of Industrial and Production Engineering,
Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh
[2]Dept. of Mechanical Engineering,
Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh
[3]Dept. of Glass and Ceramic Engineering,
Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh
E-mail: anikmolla241@gmail.com

Abstract

Composite materials have revolutionized material science by providing superior properties, including high strength-to-weight ratios and corrosion resistance, which are crucial for advancements in industries such as automobiles, aerospace, and construction. The incorporation of composite materials in constructing automobile structures is essential for passenger safety during accidents. The investigation's core aim is to augment the structural efficacy of automobile body parts while preserving their lightweight attributes. The study explores the composite configurations of carbon fiber-reinforced PVC composite. The proposed composite was designed optimizing strength, stiffness, and weight. Carbon fiber was selected for its superior tensile strength and stiffness, and the PVC foam for its lightness, thermal insulation, and structural integrity as the matrix material. The study conducted a comprehensive investigation to determine the tensile and compressive behaviors of the composite. The study further evaluated the natural frequency in different modes. In addition, harmonic analysis highlighted the response of the composite subjected to sinusoidal loads.

Keywords: Carbon fiber, PVC, Composite, Polymer, Automobile

1. Introduction

Composite materials, which are multiphase structures, have gained significant demand in the cutting-edge application of manufacturing sectors. Their unparalleled attributes often outstrip those of conventional single-phase materials. The advancement of technology increasingly requires materials that possess multifunctionality—single-phase materials usually fail to achieve the requirements; therefore, the development of composite materials has become inevitable. Composite materials have a phenomenal ability to be tailored to any specific application, which provides immense flexibility in the development of different equipment, machinery parts, and tools [1].

One of the fundamental objectives of the automobile and aerospace industries is to develop lightweight materials that possess exceptional mechanical and functional properties. So far, extensive exploration of materials, including manganese, aluminum, advanced steel, titanium, and so on, has been conducted; however, there are many challenges regarding such materials. The higher production cost, tendency to oxidation, limited flexibility, and complex manufacturing are some of them. Therefore, researchers are looking for sustainable solutions to address these issues [2].

Carbon fiber-reinforced polymer composites (CFRPs) are recognized as sustainable, lightweight materials that are extensively employed in manufacturing advanced equipment and components. These composites are composed of carbon fibers, which serve as the reinforcement, and a polymer matrix. Carbon fibers are particularly attractive due to their superior strength-to-weight ratio. Furthermore, CFRPs display remarkable thermal characteristics, including efficient heat conduction, thermal stability, and oxidation resistance. Their mechanical attributes, such as high strength, modulus, low density, and fatigue resistance, make them versatile for multifunctional applications. In CFRPs, carbon fibers primarily provide structural load-bearing capabilities, while the matrix plays a crucial role in maintaining the alignment and integrity of the fibers. It facilitates stress transfer and ensures the cohesion of the composite under load. The combination of reinforcement and matrix, which can

be metallic, ceramic, or polymeric, offers vast potential for diverse material properties. Polymers, known for their exceptional characteristics, are often favored as matrices, mainly due to their ability to enable the production of complex, lightweight structures and low-cost [1], [3], [4].

In the automobile industry, CFRPs have been extensively used to produce various components, such as car bumpers and wheels, car roofs, and door panels. Moreover, CFRPs are often considered suitable for developing different machinery, engine parts, tanks, brakes, and pressure vessels. Prior studies demonstrate that the application of CFRP results in a 40-50% weight reduction, which eventually renders higher fuel efficiency and better performance. CFRPs, in addition, are eco-friendly, further solidifying their immense demand in the automotive sectors [2], [5], [6], [7].

CFRPs used in automotive sectors must possess adequate mechanical properties to maintain rigidity in response to the wide range of impacts they encounter. The materials are often exposed to static and dynamic loads, which may bring about tension, compression, bending, and other challenging situations. One of the primary criteria for the selection of these materials is their ability to maintain stability and retain the proper structural inertness under such circumstances [8], [9].

This study numerically designs a CFRP composite with PVC as the matrix, intended for car roof applications. Mechanical performance is evaluated through compressive, tensile, modal, and harmonic analyses, assessing material behavior under various loading conditions.

2. Materials and Methodology

For sample preparation, PVC foam was used as the matrix material, and carbon fiber was used as reinforcement. The materials were chosen from the in-built materials library of ANSYS. Carbon fiber was used because of its high strength, which serves as a suitable matrix material. The specifications of carbon fiber and PVC foam were collected from the ANSYS material library shown below. The sample was designed and analyzed using ANSYS software. This software has mostly been used to analyze various types of results when subjected to necessary boundary conditions using the finite element analysis (FEA) approach. The essential contents were chosen from the built-in ANSYS library. The dimensions of the sample were determined to be a one-third ratio derived from the analysis's standard dimension [3].

Table 1. Sample Materials

Material	Density (kg/m^3)	Young's Modulus (GPa)	Poisson Ratio	Shear Modulus (GPa)
Carbon Fiber	1800	230	0.2	9
PVC Foam	60	0.07	0.3	0.026

Table 2. Values for each parameter

Parameter	Value (mm)
Length	480
Width	330
Thickness (per layer)	10

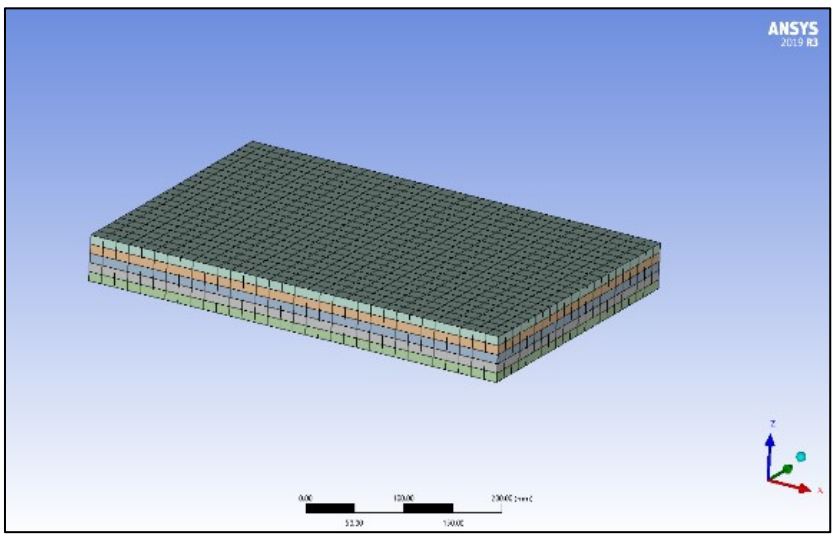


Fig. 1. Schematic Representation of the Meshed Sample

3. Performance analysis

Tensile and compressive characteristics of the CFRP were evaluated considering one face of the sample was fixed and a 1000 N tensile and compressive load was applied on the other face. ANSYS explicit dynamics was used to determine the stress profile when the sample is subjected to 1000 N tensile and compressive load for 0.01 seconds. Fig. 2. (a) and (b) show the stress profile with respect to time for tensile and compressive load, respectively. The blue curve shows the average stress and the green curve shows the maximum stress. For tensile load, the maximum stress is 0.286 MPa, and for compressive load, it is 0.174 MP.

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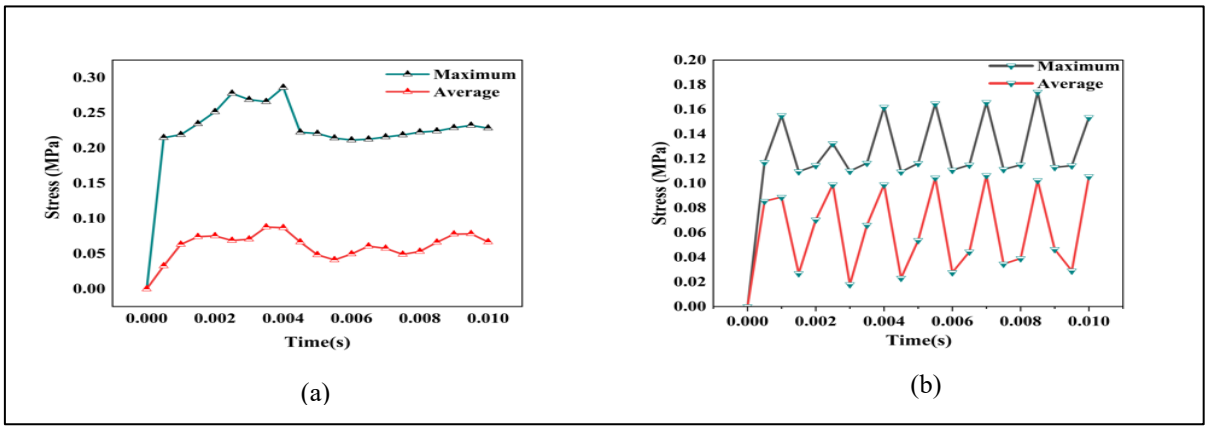
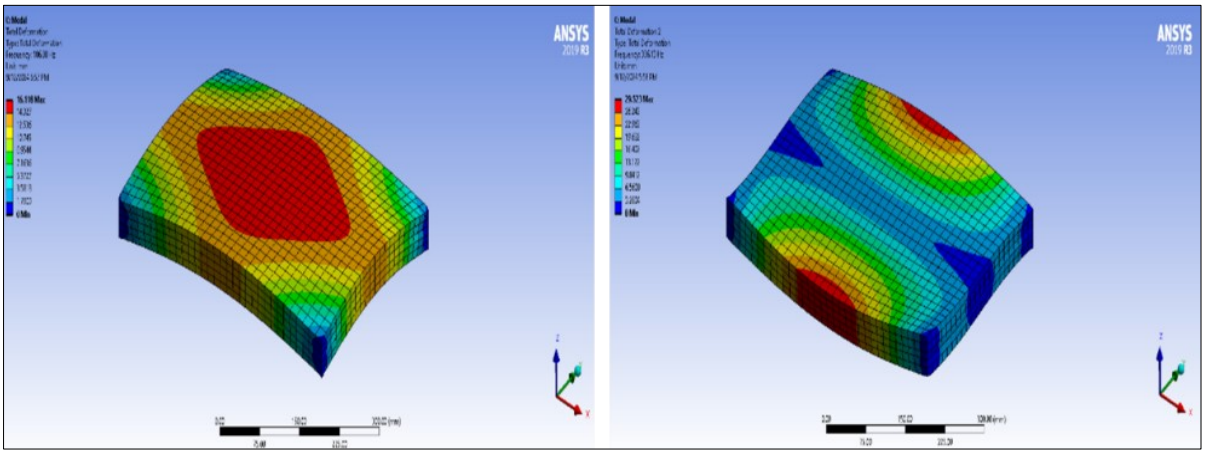
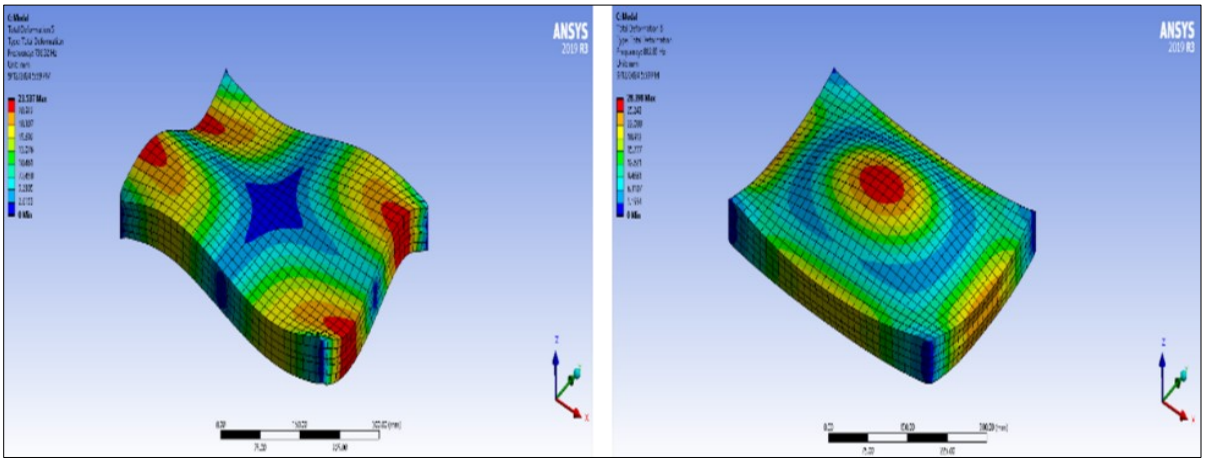
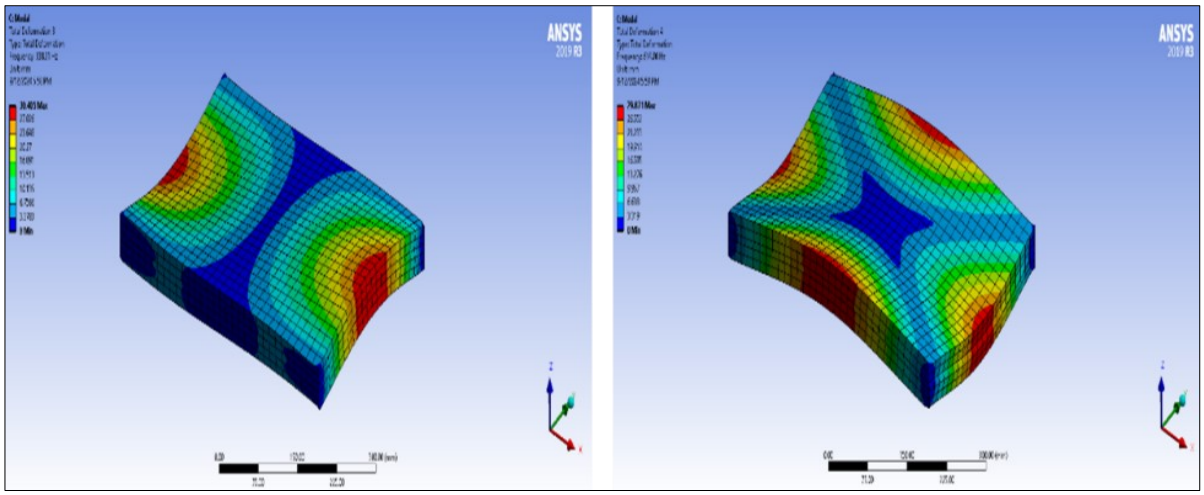


Fig. 2. (a) Variation of Tensile Stress with Time, (b)Variation of Compressive Stress with Time







(e) (f)

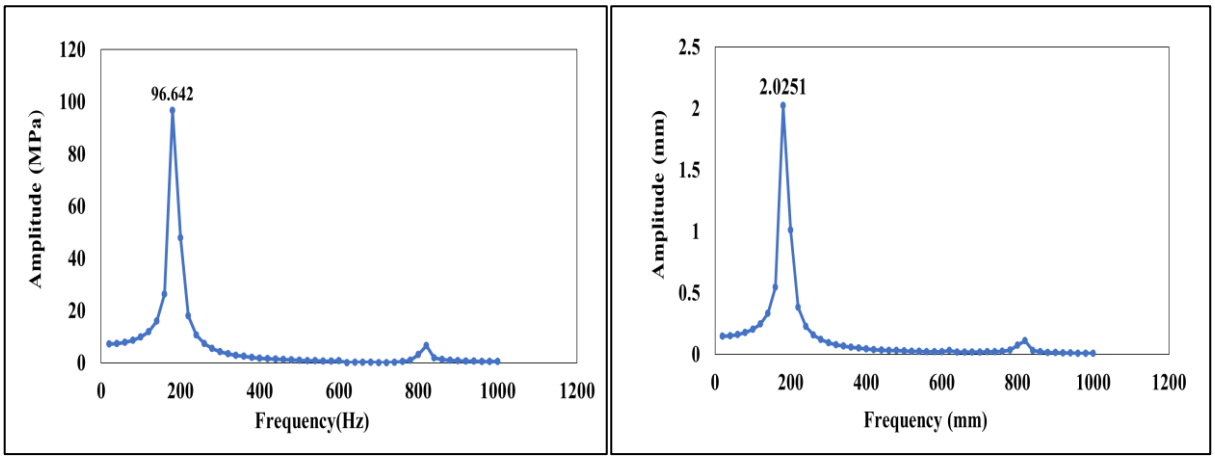
Fig. 3. Schematic Representation of Total Deformation in Mode Shape (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6

Table 3. Natural Frequency of the Corresponding Mode Shapes

Mode Shape	Frequency (Hz)
1	186.88
2	336.13
3	338.31
4	614.08
5	736.32
6	812.83

The modal analysis was carried out by fixing the four corner edges and a total of six mode shapes (eigen vectors) and their respective natural frequencies. Fig. 3 shows the determined mode shapes, and Table 3 shows their corresponding natural frequencies. The minimum natural frequency is for mode shape 1 (186.88 Hz) and maximum is for mode shape 6 (812.83 Hz).

The results from the modal analysis were given as input to the harmonic analysis setup in ANSYS. The mode superposition method was used to perform the harmonic analysis considering the mode shapes and natural frequency obtained from the modal analysis. An external sinusoidal load of 1000 N was applied. As the minimum and maximum natural frequencies are 186.88 and 812.83 Hz, the harmonic analysis frequency range is between 0 and 1000 Hz. At these resonance points, the stress shown in Fig.4 (a) and the displacement amplitudes in Fig. 5 (b) are considerably higher compared to adjacent conditions. However, the displacements observed are relatively small and unlikely to cause significant damage to the structure, which ensures its desired reliability and stability.



(a) (b)

Fig. 4. Variation of (a) Stress (b) Displacement Amplitude with Different Excitation Frequency

4. Conclusion

In brief, this study numerically demonstrated a CFRP composite's design and performance analysis, employing PVC as the matrix and carbon fiber as reinforcement. The study shed light on the tensile and compressive behavior of the introduced CFRP composite. Moreover, vibrational and harmonic responses were thoroughly evaluated. The findings show that under a 1000 N load, the maximum tensile and compressive stress were found to be 0.286 MPa and 0.174 MPa, respectively, indicating superior resistance to tensile over compressive forces under short-duration loading. Vibration analysis considered six modes and revealed natural frequencies between 186.88 Hz and 812.83 Hz. The harmonic analysis was performed under a sinusoidal load between 0–1000 Hz. The resonance frequencies were recorded where displacement and stress amplitudes peak. The study suggests the composite exhibited significant structural stability when subject to these sinusoidal loads. The study may be useful in optimizing CFRP risk in practical applications.

5. References

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