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Numerical Analysis of Multilayer Composite Under Free Vibration Conditions

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Abstract: Laminated composites consist of multiple layers that are fused together to improve their mechanical and physical characteristics. Typically manufactured using pressure and heat techniques, ensuring a strong bond between the layers. Laminated composite materials are ideal for applications that require high performance while reducing weight. type of layer arrangements symmetric have been used in composite panels. The behavior of separated panels has been studied using the symmetric model to verify the natural frequency results of the composite panels, through the analysis of finite element models using software that provides an integrated environment for designing and analyzing models. Different diameters of rubber particles (1.8 mm, and 3.3 mm) used effect size on mechanical properties. The results related to the natural frequency were utilized, where the maximum symmetry recorded was 1058.1 Hz and the minimum was 166.68 Hz at a diameter of 1.8 mm, while the maximum was 975.56 Hz and the minimum was 153.84 Hz at a diameter of 3.3 mm. The numerical analyses showed good results regarding the natural frequency. These materials are characterized by their hardness and flexibility, making them suitable as a waterproof coating and effective insulator, which enhances their use as a coating or adhesive.

Keywords: Modal assessment, Composite shell, Elastic particles, Balanced laminate, Primary frequency

Introduction

In recent years, a multitude of investigations have been carried out regarding rubber and its various compounds, given their importance and wide-ranging uses. The properties of rubber compounds make them suitable for many contemporary industrial purposes, as they possess remarkable mechanical characteristics and can endure stress without undergoing permanent changes (Almuramady, 2023). This material is also utilized to safeguard technical equipment, bridges, and buildings from vibrations due to its exceptional flexibility (Oñate, 2024). Additionally, rubber is often viewed as a budget-friendly option, rendering it suitable for roles in which fillers, connecting rods, and exhaust outlets are required to resist deformations resulting from heat produced by exhaust (Almuramady, 2023). Processed rubber has the potential to influence the transient response of composite structures, thereby affecting their dynamic performance when exposed to abrupt or fluctuating loads (Shangguan, 2025).

Among the primary impacts of ground rubber on the short-term response, we identify damping, in which the ground rubber particles spread throughout the composite material function as damping elements, taking in and dispersing vibrational energy (Rastogi, 2024). This helps reduce vibrations and improve the overall stability of the structure during transient events, while also enhancing its shock resistance (Gorgis, 2024). Shredded rubber is produced by cooling with liquid nitrogen to freeze used car tires, which are then broken down into small particles. Rubber granules offer several benefits, as they delay the occurrence of cracks and reduce the effects of temperature changes (Lee, 2021). They also enhance the material's resistance to aging, flaking, and damage caused by moisture, improving its performance in harsh weather conditions and under heavy traffic (Damil, 2023). Many previous studies have addressed the effect of different diameters of rubber particles on the crossover analysis, including the impact reinforcing material applications and traditional materials. The findings suggest that incorporating particular proportions of white cement could serve as a viable option in building projects, since its proportions closely correspond to those of the carbon black analyzed (Al-Mayali, 2025).

A novel reinforcement substance has been created, utilizing improved applications with carbon black and conventional materials. The findings suggest that incorporating specific amounts of white cement could serve as a viable substitute in construction uses, since these amounts resemble those of carbon black that have been analyzed (Abdul–Hdi, 2025). The creation of seven rubber formulations was examined by utilizing a mixture of natural rubber and synthetic rubber in various proportions (Almuramady, 2022). Tire rubber served as a substitute for materials that absorb oil because of its ability to resist water (Sales, 2024). The influence of various forms of the rubber base designed for vibration dampening was also examined (Abd Al-Nabi, 2025). Three distinct forms (cylindrical, hexagonal, and rhomboidal) of identical dimensions were created, and ANSYS version 11 software was employed to model the simulation. Potential methods for repurposing and recycling old tires at the tire manufacturing facility in Diwaniya were explored by Abd-Ali (2023) as well.

The research involved rheometric experiments to assess damping characteristics and processing conditions. Additionally, it examined how these factors influence mechanical traits like strength, rigidity, and elasticity, suggesting their possible applications in different industries (Al-obaidi, 2022). The investigation utilized the finite element analysis technique with ANSYS software to evaluate the effectiveness of the car roof design. It focused on examining the structural components of fiber-reinforced synthetic rubber SBR (Abd-Ali, 2022). Findings indicated that a higher fiber content improves tensile strength but leads to a decrease in elongation properties (Abd-Ali, 2024). Additionally, segments of rubber are utilized in numerous industrial and commercial settings (Al-Nesrawy, 2023). The actual characteristics of rubber when exposed to thermal oscillations have been illustrated, enabling it to take on random shapes when subjected to an outside force, aiding in the durability of its form (Hassan, 2021). The problem of exhaustible natural resources and contamination from non-biodegradable tires has also been tackled, emphasizing the significance of recycling these tires to lessen their adverse environmental effects and realize economic advantages (Abd-Ali, 2020).

The investigation into the rubber element of the cement filling system has been conducted, with rubber utilized in a defined quantity at a heat of 180 degrees Celsius and maximum pressure (Al-Nesrawy, 2024). Nano-sized zinc oxide particles, created through the sol-gel process, were employed as a substitute for traditional zinc oxide to examine their influence on the mechanical properties of rubber (Chen, 2020). The effect of the orientation of glass fibers in the polymer matrix reinforced with impact compounds used in automobiles was also investigated through tensile and bending tests (Ali, 2023).

The mechanical and physical properties of the process were reviewed using three types of carbon black (N326, N330, and N660) at a concentration of 51 parts per million of rubber, in three formulations containing natural rubber (Majeed, 2022). The current study addressed effect recycled particles rubber on modal analysis of composite structures based on numerical solutions. Several parameters were investigated, including the symmetrical and asymmetrical configurations of the rubber particles, and their impact on the natural frequency of multilayered structures was determined.

Natural Vibration

Mathematical for Natural Vibration of Model Analysis

In normal vibration, it is assumed that the response of the plate is periodic.

$$\{u\}=\{u^o\}e^{i\omega t},\quad \{v\}=\{v^o\}e^{i\omega t},\quad \{\Delta\}=\{\Delta^o\}e^{i\omega t},\ i=\sqrt{-1} \tag{1}$$

$\{\Delta^o\}$. The text discusses the time-invariant capacity vector and refers to the natural vibration frequency of the system represented by the symbol ω.

$$\begin{bmatrix} [k^{11}] & [K^{12}] & [K^{13}] \\ [k^{12}] & [K^{22}] & [K^{23}] \\ [k^{13}] & [K^{23}] & [K^{33}] \end{bmatrix} - \omega^2 \begin{bmatrix} [M^{11}] & [0] & [M^{13}] \\ [0] & [M^{22}] & [M^{23}] \\ [M^{13}]T & [M^{23}] & [M^{33}] \end{bmatrix} \begin{Bmatrix} \{u^e\} \\ \{v^e\} \\ (\Delta^e) \end{Bmatrix} = \begin{Bmatrix} \{F^1\} \\ \{F^2\} \\ \{F^3\} \end{Bmatrix} \quad (2)$$

For free vibration, the equation of motion becomes:

$$\begin{bmatrix} [k^{11}] & [K^{12}] & [K^{13}] \\ [k^{12}] & [K^{22}] & [K^{23}] \\ [k^{13}] & [K^{23}] & [K^{33}] \end{bmatrix} - \omega^2 \begin{bmatrix} [M^{11}] & [0] & [M^{13}] \\ [0] & [M^{22}] & [M^{23}] \\ [M^{13}]T & [M^{23}] & [M^{33}] \end{bmatrix} \begin{Bmatrix} \{u^e\} \\ \{v^e\} \\ (\Delta^e) \end{Bmatrix} = 0 \quad (3)$$

Results

The vibration response of the homogeneous layer was calculated using different diameters of rubber granules, and the results are graphically illustrated as shown in Figure 1. The illustrations include the mode shapes that display the deformation using the shell model in Abaqus software. A four layer with a mesh size 30cm of 25 cm × 25 cm, a thickness of 0.4 cm and a density of 2340 kg/m³ was used. Different diameters of rubber particles (1.8 mm, and 3.3 mm) used effect size mechanical properties as shown in Table 1.

Table1. Material properties of transient analysis.

Material properties	Reclaim Rubber	
	1.8mm	3.3mm
E_1 (Gpa)	15.39	13.082
E_2 (Gpa)	10.8	9.18
E_3 (Gpa)	4.7925	4.074
nu_{12}	0.3	0.3
nu_{13}	0.35	0.35
nu_{23}	0.3	0.3
G_{12} (Gpa)	1.96425	1.670
G_{13} (Gpa)	1.89	1.607
G_{23} (Gpa)	1.964	1.670

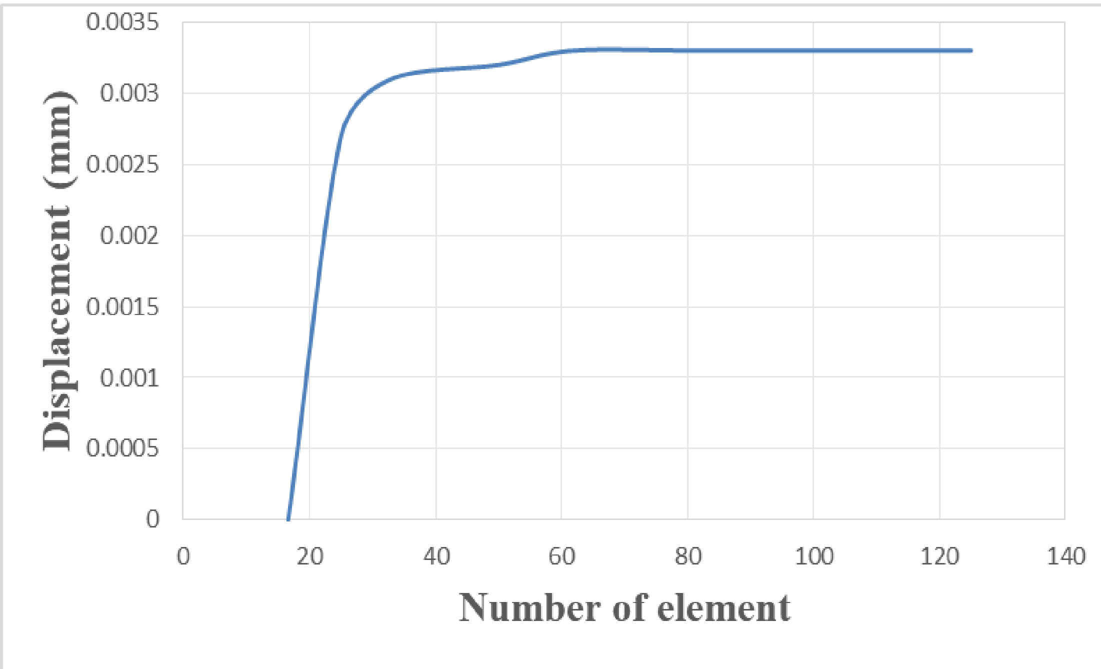


Figure 1. Element convergence

The highest frequency was obtained through the symmetric arrangement (0/90/90/0) at element convergence as shown in Figure 1. The clamped boundary conditions were applied at the shell edges in which fixed the translation and rotation degrees of freedom as shown in Figure 2.

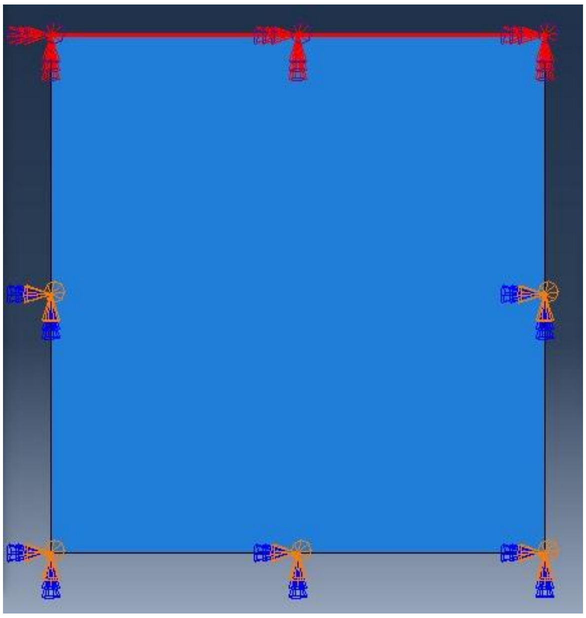
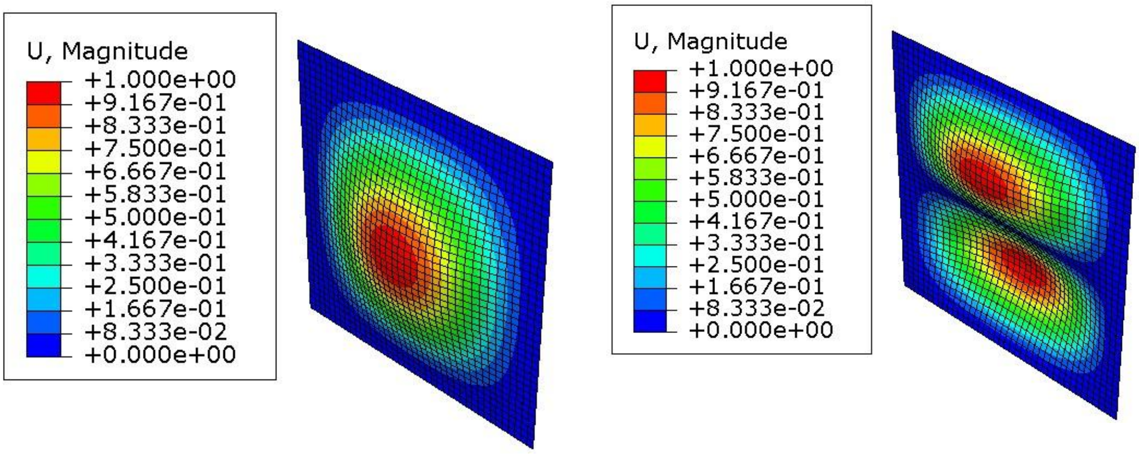


Figure 2. Boundary conditions

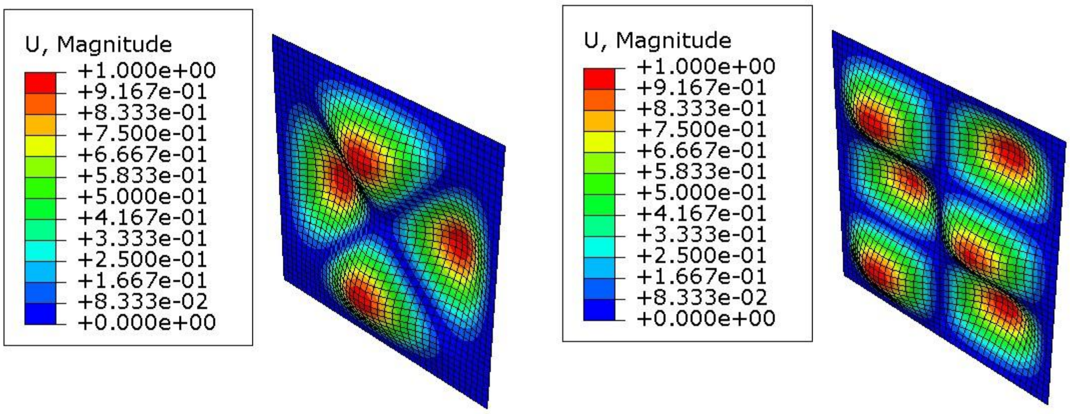
where the maximum symmetry recorded was 1058.1 Hz and the minimum was 166.68 Hz at a mesh size 1.8 mm as shown in figure 3 structure 12 modes vibration with different frequencies ranging from 166.86 Hz to 1058.1 Hz. Identical frequencies occur when the structure is symmetrical in shape and dynamic properties, resulting in a similar vibrational response across different modes. For example, mode shape 2 and mode shape 3 have the same frequency 338.82 Hz due to the symmetry of the structure and the similarity of the properties. The fundamentals frequency at laminated shell was illustrated in the figure 3a and 3b. the first two frequency represent. The bending and combined bending for the mode shape.



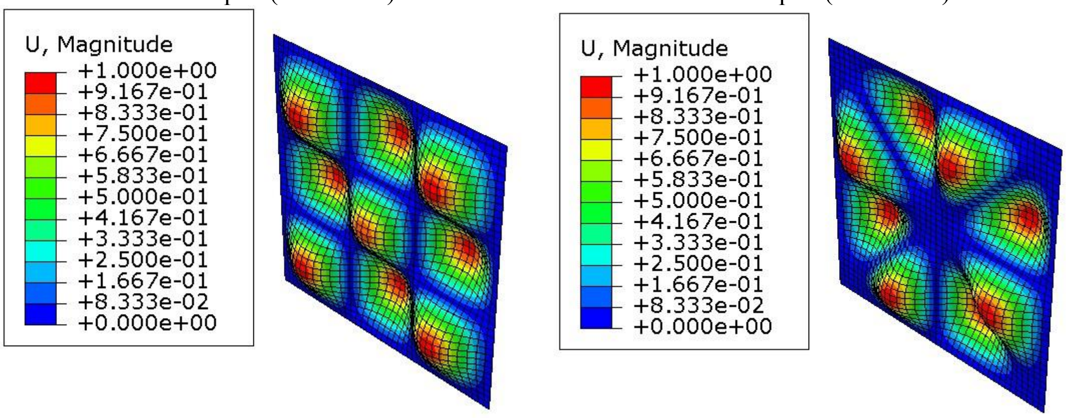
a- Mode shape1 (166.86HZ) b- Mode shape2 (338.82HZ)

Figure 3. The shapes of 1st and 2nd mode and frequency arrangements at diameters 1.8mm of rubber particles.

The third and fourth frequency represent the combined bending and complex bending as shown in the fig (4a - 4d). These frequencies are related to the dynamic properties of the structure, such as mass, stiffness, and damping. Low frequencies appear when the structure is more flexible and less stiff, resulting in a lower vibrational response. For example, mode shape 1 166.86 Hz exhibits a low frequency due to the simplicity of the shape and the low complexity of the vibration. High frequencies, on the other hand, appear when the structure is stiffer and less flexible, leading to a higher vibrational response. For instance, mode shape 12 1058.1 Hz shows a very high frequency due to the high complexity of the shape and vibration.



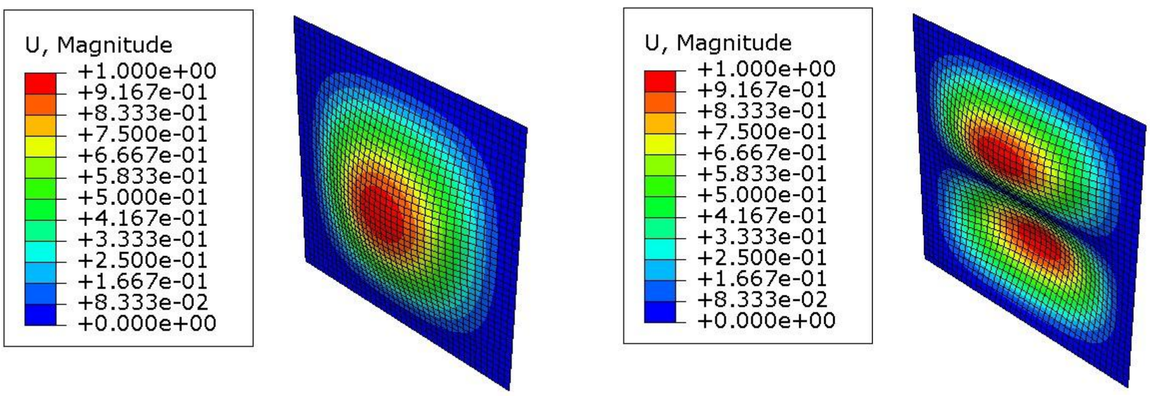
Mode shape3 (608.98HZ) Mode shape4 (720.84HZ)



Mode shape5 (930.31HZ) Mode shape6 (1058.1HZ)

Figure 4. The shapes of mode and frequency arrangements at diameters 1.8mm of rubber particles.

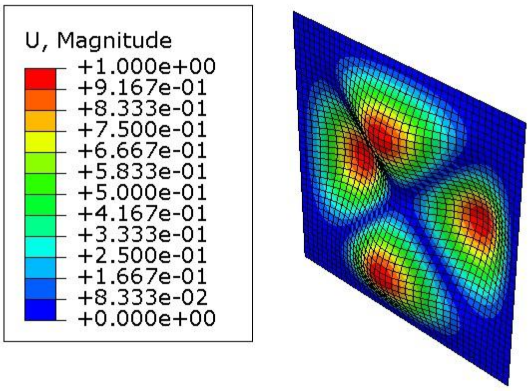
Various model's finite element used Abaqus CAE program to analyze the free vibration of cracked composite plates. The shell element model in the program allows for accurate prediction of the natural vibration frequency of plates containing rubber particles with a diameter of 3.3 mm, arranged in a (0-90-0-90) distribution and with a mesh size of 15 mm. The highest frequency recorded was 975.56 Hz, while the lowest fundamental frequency was 153.84 Hz as shown in Figure 5.



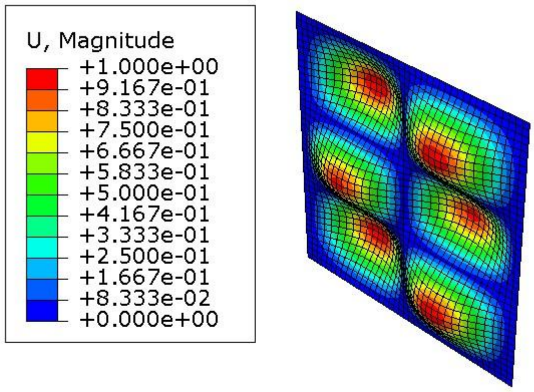
Mode shape1 (153.84HZ) Mode shape2 (312.38HZ)

Figure 5. The shapes of 1st and 2nd mode and frequency arrangements at diameters 3.3 of rubber particles.

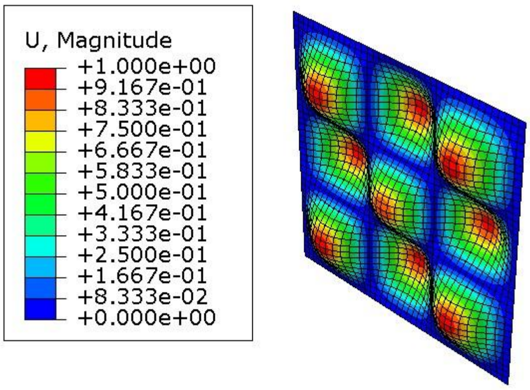
The third and fourth frequency represent the combined bending and complex bending as shown in the fig (6a - 6d). The results show that the structure has 12 modal shapes with frequencies ranging from 153.84 Hz to 975.56 Hz. These frequencies are related to the dynamic properties of the structure, such as mass, stiffness, and vibration. The low frequencies are a result of the simple shape of the structure and the low complexity of the vibrations, while the high frequencies arise from the significant complexity in the shape and vibrations. Additionally, the matching frequencies are a result of the symmetry of the structure and the similarity of its dynamic properties. Understanding these relationships is vital for designing and optimizing structures to withstand various loads and vibrations.



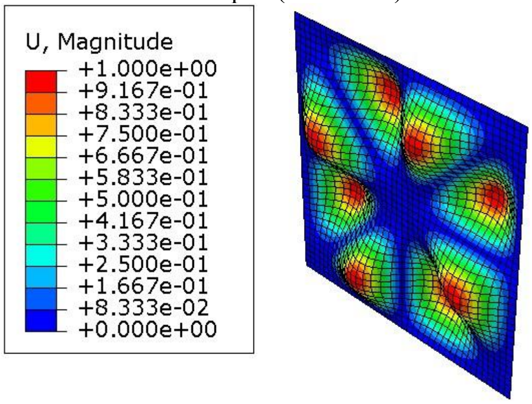
Mode shape3 (561.47HZ)



Mode shape4 (664.60HZ)



Mode shape5 (857.74HZ)



Mode shape6 (975.56HZ)

Figure 6. The shapes of mode and frequency arrangements symmetric (0/90/90/0) shell model, at diameters3.3 mm of rubber particles.

Conclusion

1. A good agreement was reached between the results of the GLPT model and the solid shell model in the Abaqus CAE program, as both reflect the behavior of the composite plate.
2. The natural frequency arrangements symmetric natural frequency (0-90-90-0), where the maximum symmetry recorded was 1058.1 Hz and the minimum was 166.68 Hz at a diameter of 1.8 mm is ideal in ensuring the natural frequency composite shell.
3. while the maximum was 975.56 Hz and the minimum was 153.84 Hz at a diameter of 3.3 mm. The numerical analyses showed good results regarding the natural frequency.
4. These materials are characterized by their hardness and flexibility, making them suitable as a waterproof coating and effective insulator, which enhances their use as a coating or adhesive.
5. In the Abaqus program, four elements are used through the thickness of the shell to represent each layer in the laminated composite plate. The modal response of the shell is analyzed, where the finite element model depends on the number of modes, including simple, double, and complex bending.
6. The relationship between frequency and shape becomes more complex, as frequency increases with the complexity of the shape. Grasping this connection is crucial for creating constructions that can endure stress and oscillations.
7. The simple design of the structure and the minimal intricacy of the vibrations lead to low frequencies, whereas the high frequencies originate from the considerable complexity found in both the shape and vibrations.

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest

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