J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011
Vol. 21(S2), (2026) 180-185
DOI: https://doi.org/10.51220/jmr.v21-S2.22

Simulation Based Transverse Vibration Study of Hybrid Composite Laminated Beam

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Received: 24.02.2025; Revised: 19.10.2025; Accepted: 22.11.2025

Abstract: The use of composite materials, particularly laminated composites, has increased in structural components due to their excellent strength-to-weight ratio. Every structure and its components have a specific natural or fundamental frequency at which they vibrate without external excitation, making it vital for designers to be aware of all the natural frequencies across different modes to avoid or eliminate resonance. This study on the vibration analysis of hybrid composite laminated beams is inspired by previous studies on simple laminated materials, focusing on the effects of critical factors such as load constraints, fiber orientation angle, and fiber volume fraction in the structure. This study examines the free-transverse-vibration behavior of a hybrid composite-laminated beam composed of S-glass-epoxy, aramid-epoxy & boron-epoxy. A simulation based analysis is conducted using the F.E.M., with ANSYS APDL as the solver. Various parametric investigations are performed to evaluate the effects of laminate properties on the three least fundamental frequencies. The investigated variables include fiber volume fraction, fiber orientation angle, and support-conditions (C-F and C-C arrangements). Additionally, other laminate factors are analyzed, emphasizing the potential applications of this hybrid composite in bridges, aircraft wings, and machine components.

Keywords: Resonance • Hybrid composite laminated • fiber orientation angle • transverse vibration • Fibre volume fraction • C-F • C-C arrangements.

Introduction

Composites are generally biphasic that are insoluble in each other and have distinct chemical properties, making them independent according to the Hume-Rothery law of solid solutions. In contemporary applications, traditional materials such as stone, wood, metals and alloys are progressively being substituted with advanced alternatives, including composite, F.G.M.(functionally-graded materials), and F.M.L. (fiber-metal-laminates). The importance of composite materials has grown due to their high-fatigue resistance and favorable weight-to-strength ratio, which are essential for addressing both static and variable challenges. Historical studies (Bao et al 1992) have shown that the primary origins of collapse in composite structures is interfacial de-bonding (Saini et al 2019), particularly when exposed to geometric discontinuities like cracks or notches, which lead to stress concentration and a reduction in natural frequency (Ali et el 2009). This reduction in natural frequency is particularly concerning, as it raises the risk of resonance at least frequencies, impacting the structure's dynamic response across various modes and altering key parameters such as the damping-coefficient, mode shapes, and fundamental frequencies (Barbero 2013). To prevent resonance, it's crucial to understand the damping-factors, fundamental frequencies, and mode shapes of the system, enabling the strengthening of the structure when necessary (Chondros et al 1998)

Methods of Vibration Study

There are two primary methods of study: the experimental approach & analytical approach (Danu et al 2019). The analytical method offers benefits such as shorter time requirements (Singh et al 2019), no concerns about machine setup, and being more costeffective compared to the experimental approach. On the other hand, experimental method (Ganesan et al 2007) provides precise solutions with several advantages, including comprehensive exposure, precise control, and well-defined results for the researcher (Hamada et al 1997). However, obtaining exact solutions for all complex engineering problems is often challenging. To address this, approximate methods (Danu et al 2020) like Finite Element Method (F.E.M.) (Danu et al 2021) are used, with several software packages available, including ANSYS, ABAQUS, SolidWorks, Fluent, and FORTRAN (Krawczuk et al 1994).

Validation with Krawczuk *et al.*

In this study, the results are first verified using the model introduced by Krawczuk et al. (1995) for composite made of graphite fiber & polyamide matrix, as depicted in Fig 1. The analysis is further extended to hybrid composites, considering multiple laminate variables such as fiber volume fraction (V), fiber orientation angle (Φ), and other structural parameters that influence the mechanical behavior and vibration characteristics of the composite material.

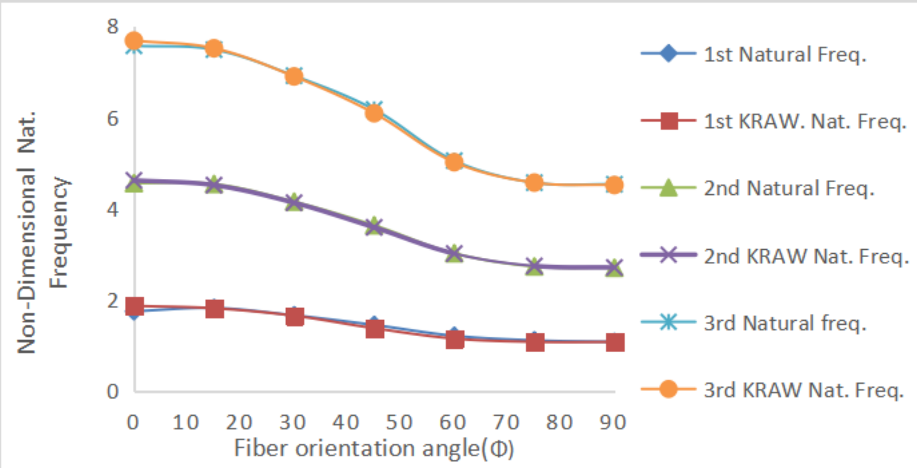

Fig.1 A comparative assessment of the present analysis and the study conducted by Krawczuk et al. [10] for a fiber-volume-fraction (V) of 0.1.

Material and Investigation Approach

Fundamental Equation

The Fundamental equation for the beam under free-vibration is given by Krawczuk et al., 1994, Li et al, 2014.

$$[K]-\omega^2[M]\{q\}=0 \quad (1)$$

In above equation,

K = Stiffness-matrix, **M** = Mass-matrix, **q** = Degree of freedom

Table.1 Mechanical Properties of Fiber & Matrix (Saini 2019)

Mechanical Properties		Modulus of Elasticity (GPa)		Modulus of Rigidity (GPa)		Poisson's Ratio		Mass-Density (kg/m^3)	
Fiber (f)	**Matrix (m)**	**Em**	**Ef**	**Gm**	**Gf**	**νm**	**νf**	**ρm**	**ρf**
Boron	*Epoxy*	3.25	393.00	1.25	163.75	0.3	0.20	1250	2700
Aramid	*Epoxy*	3.25	131.00	1.25	48.51	0.3	0.35	1250	1450
S-Glass	*Epoxy*	3.25	86.90	1.25	35.61	0.3	0.22	1250	2490

Beam Model

In the current beam model, geometric variables of the composite-laminated-beam (Pandey et al., 2019) are taken as height (H), width (B), and length (L) with values of 0.025

m, 0.05 m, and 1.00 m, respectively, as shown in Fig. 2. It is assumed that all the fibers are aligned at an angle Φ .

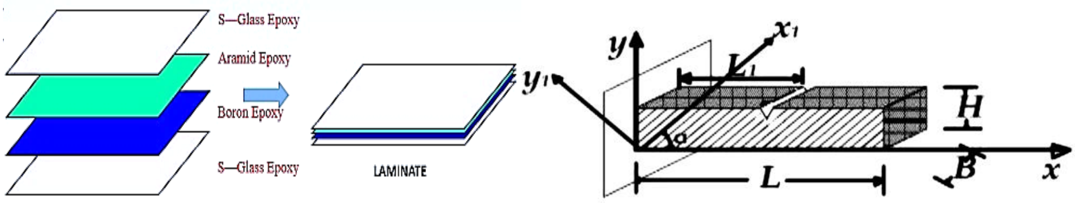

Fig 2. A diagram illustrating the laminate and laminated composite beam in C-F arrangement.

A brief explanation of the utilised element for meshing in Ansys APDL

In the current investigation, the SOLSH-190 (Solid Shell 190) element, as illustrated in Fig.3, is utilized. The Solid Shell 190 element combines the properties of both shell & solid elements (Saini et al 2017). It can model structures that combine thickness and solid properties, making it ideal for simulating thin-walled structures such as composite beams, plates, and shells. The SOLSH 190 element typically consists of four nodes, with each node having three degrees of freedom (translations in the X, Y, and Z directions), enabling it to capture both membrane and bending behaviors in a single element.

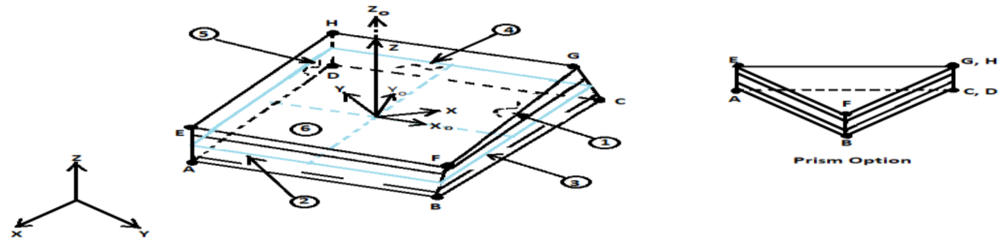

Fig.3 Geometry description of solid shell (SOLSH 190) element

Outcomes and Discussion

The impact of various variables, such as fiber volume fraction (V), support-conditions, and fiber fiber orientation angle(Φ), on the transverse-fundamental-frequency has been examined and discussed for crack-free unidirectional hybrid composite beam.

Impact of Fiber orientation angle(Φ) on three least Transvers-Fundamental Frequencies for crack-free hybrid-composite-laminated beam

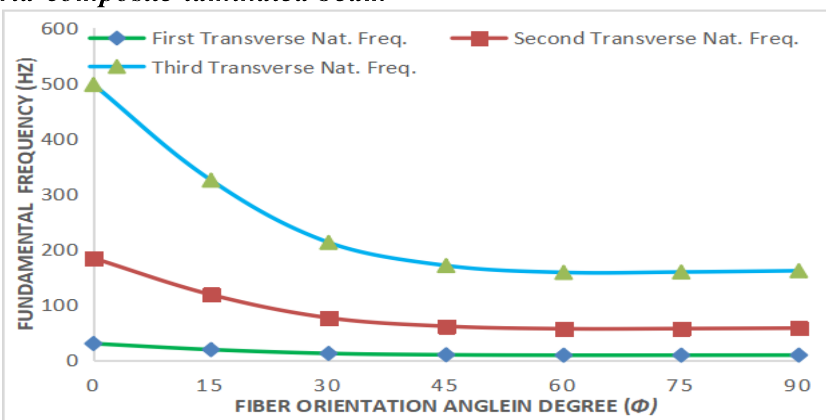

Fig. 4.1 Fiber orientation angle (Φ) in relation to the three lowest transverse natural frequencies of a crack-free hybrid composite beam.

 DOI: https://doi.org/10.51220/jmr.v21-S2.22

Fiber orientation angle (Φ) as a variable influencing the three lowest transverse-fundamental frequencies of a crack-free hybrid composite beam.

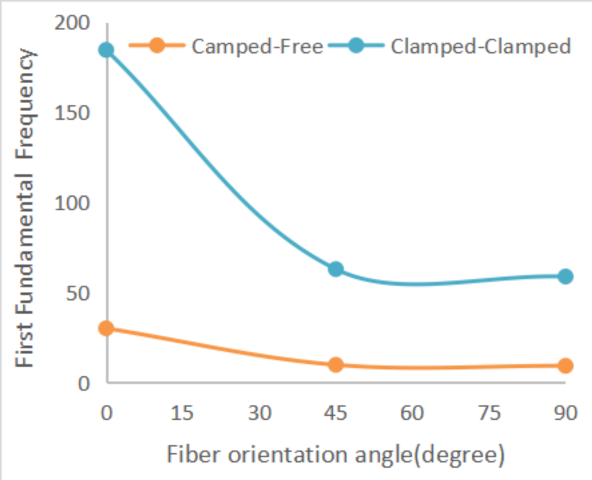

Fig. 4.2 Influence of Boundary condition and Fiber orientation angle(Φ) as a function of First Fundamental Frequency

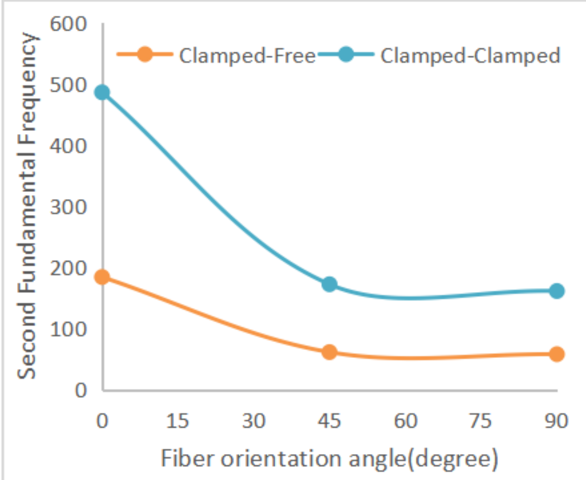

Fig. 4.3 Influence of Boundary condition and Fiber orientation angle(Φ) as a function of Fundamental Natural Frequency

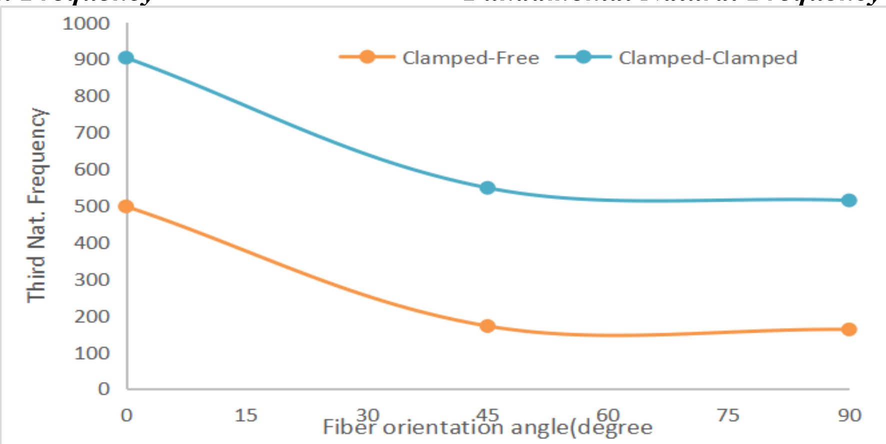

Fig. 4.4 Influence of Boundary condition and Fiber orientation angle (Φ) as a function of Third Natural Frequency

Fiber volume fraction as a function of the three lowest transverse natural frequencies in a crack-free hybrid composite beam

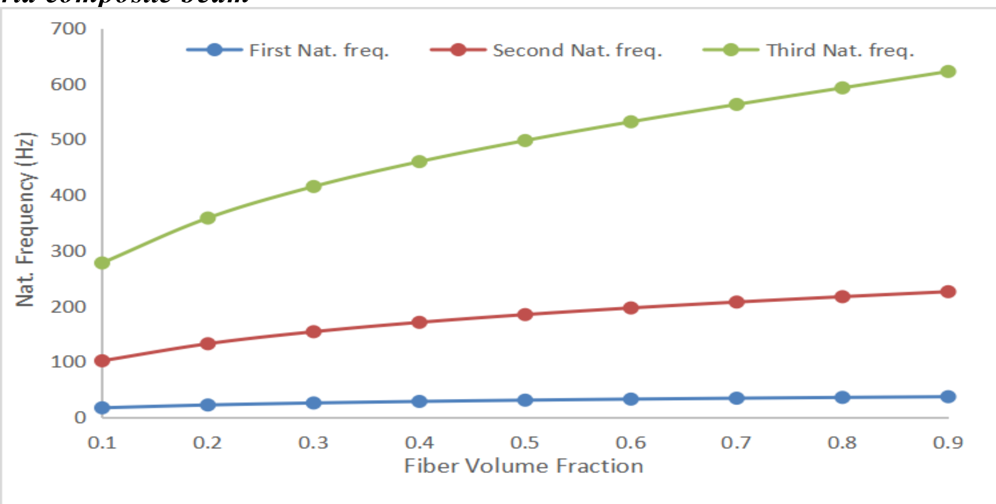

Fig. 4.5 Fiber Volume Fraction as a function of the Natural frequencies

Summary and Conclusion

1. In the unidirectional clamped-free configuration, the natural frequency decreases as the fiber orientation angle increases.
2. A crack-free unidirectional composite beam with a clamped-clamped configuration exhibits higher natural frequencies compared to a clamped-free configuration as it is more rigid.
3. In the unidirectional clamped-free configuration, the natural frequency increases as the fiber volume fraction increases.

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