

# Impact Of Number Of Layers And Plate Aspect Ratio On Variation Of Frequency With Temperature And Moisture Concentration For Simply Supported Composite Laminates

Thimmegowda M B <sup>1</sup>, Sreedharamurthy T <sup>2</sup>, Raviprakash T N <sup>3</sup>

<sup>1</sup> Department of Mechanical Engineering, Government polytechnic Turuvekere, Karnataka, India

<sup>2</sup> Department of Mechanical Engineering, Government polytechnic Turuvekere, Karnataka, India.

<sup>3</sup> Department of Mechanical Engineering, Government School of Mines, KGF, Karnataka, India.

## ABSTRACT

A certain combination of in-plane load parameter values and the natural frequency of transverse vibration can cause unstable transverse vibrations in structural materials subjected to in-plane periodic stresses, which can result in parametric resonance. This instability may arise under compressive loads throughout a range of excitation frequencies, below the structure's critical load. Many strategies for preventing parametric resonance, such vibration isolation and dampening, may not be sufficient or safe at times, leading to unfavorable outcomes. Unlike the primary resonance, the parametric instability can occur even for modest excitation amplitudes and combinations of frequencies, not just at a single excitation frequency. When a structure is subjected to in-plane periodic stress, it is possible to discriminate between good and undesirable vibration regimes by analyzing its dynamic instability region (DIR) spectrum. These spectra are frequently calculated and given in terms of natural frequencies. Therefore, a crucial component of the dynamic instability study of composite plates and shells in a hygrothermal environment is the very precise estimation of these values.

**Keywords:** Temperature concentration, Moisture concentration, Plate aspect ratio, Composite laminates, Number of layers.

## 1. Introduction

Since composite materials are lightweight, have high specific strength, high specific stiffness, and low specific density—all of which lower total operating costs—they are finding increased usage in high-performance engineering applications such as aerospace, civil, naval, and others. Recent developments in composites in the commercial aircraft industry, such as the Boeing 787 and Airbus 350/380, all-composite empennages on the Boeing 7J7 and McDonnell Douglas MD-91X, and military aircraft like the B-2 bomber and Nighthawk F117-A fighter, are intended to limit sonic fatigue caused by the new fuel-efficient propfan or unducted fan (UDF) engines. The structures utilized in the aforementioned fields are frequently subjected to high temperatures and dampness.

The temperature fluctuations and moisture absorption appear to have a negative impact on the strength and stiffness of the structural composites. A basic understanding of their vibrations and static and dynamic stability properties under hygrothermal conditions is necessary for this vast variety of practical applications.

Without taking into account hygrothermal effects, a thorough examination of the vibration and buckling effects of plates and shells has been conducted. The buckling and vibration characteristics of laminated composite panels in a hygrothermal environment—an environment that has seen a rise in use in recent years. Researchers are interested in the topic of dynamic instability of laminated curved panels in hygrothermal environments because it hasn't been thoroughly researched before.

The aforementioned discussion makes it evident that a current area of interest is the investigation of many elements of vibration and stability research on woven fiber laminated composite plate structures in hygrothermal environments. A thorough grasp of the response properties of these structural elements is crucial given all these developments and design specifications. Prior research in this field must be thoroughly reviewed in order to determine the purpose and extent of the current study. Industry analysts claim that due of laminated composite materials' enhanced fatigue life, greater stiffness-to-weight ratio, and superior corrosion resistance, their application has expanded considerably in recent years.

Experimenting with various fiber orientations and stacking orders may improve a panel's stiffness-to-weight ratio and result in a more energy-efficient design. But by including the appropriate patterns into the design, a panel's specific strength and stiffness may be boosted even further without appreciably reducing the panel's overall weight. These benefits have been utilized in the current work, which examines structures of trapezoidal laminated composite panels. Composites are often used in laminate form in a variety of technical and non-engineering areas, including aerospace, mechanical, marine, and civil engineering. The aerospace and aviation sectors have made substantial use of these composite laminated panels ever since they were created. More recently, they have also been used in civil engineering structures, such as bridge decks and girders, as well as for reinforcing and retrofitting structural members, among other uses.

## 2. Literature Review

Because laminated composite plates have a higher stiffness and strength to weight ratio, a higher resistance to impact damage, and a longer lifespan than some other structures, they are being used in a variety of light weight and load carrying structural parts of various aerospace, automotive, and civil engineering structures. Furthermore, these structural elements need to be cut for a number of purposes, including access, quality assurance, weight loss, ventilation, and inspection. Cutouts are frequently used in aeronautical structures as access ports for several systems, including mass reduction, electrical and mechanical, and fuel lines. Throughout their service lives, the majority of these structures encounter dynamic loads.

Resonance causes the greatest amount of harm. Composite plate cutouts may influence the dynamic properties in a way that multiplies the number of resonance possibilities. Therefore, vibration analysis plays a critical role in the design of buildings to predict their reaction. By taking the appropriate precautions to avoid resonance, structural vibrations may be regulated. In mechanical, aeronautical, and

civil applications, the free vibration characterization of composite plates with cutout has shown to be an extremely valuable problem.

For many years, researchers have focused on the numerous applications of ordinary metals and their alloys as well as the growing need for composite materials in plates and shells. The primary focus of the investigation is the dynamic instability analysis of flat and curved panels in a hygrothermal environment; however, for the sake of relevance to this investigation, some pertinent research works on free vibration, buckling, and dynamic instability analysis of flat and curved panels subjected to hygrothermal loadings are also taken into consideration. To find the gaps in the current literature, a thorough and critical assessment of a few recent relevant research is conducted.

Many researchers have employed analytical and computational techniques to conduct in-depth studies on the free vibration behavior of laminated composite plates. Here are a few notable recent studies, distilled for clarity. Thai et al. [1] examined the vibration behavior of composite plates using enhanced plate theory. Cong et al. investigated the free vibration of composite plates using one-dimensional integrated radial basic function networks. [2]. Xiang et al. [3] created an  $n$ th order shear deformation theory to study the vibration of composite square plates. Motley et al. [4] investigated the effects of boundaries on the vibration responses of cantilevered composite plates using FEM. Using FEM, Ahmed et al. [5] investigated the static and dynamic properties of graphite-epoxy composite plates.

Sharma and Mittal [6] used FEM to investigate the vibration of cross-ply and angle-ply plates by elastically restricting the edges. Malekzadeh and Zarei [7] examined the vibration behavior of composite plates made of carbon nanotube-reinforced composite layers using a differential quadrature technique. Thinh et al. [8] and Boscolo & Banerjee [9] looked into the vibration properties of composite plates using the dynamic stiffness approach. Sayyad and Ghugal [10] examined sandwich and composite plate vibration. By using higher order FEM models, the sandwich plate vibration problem was analytically addressed by Belarbi et al. [12] and Mantari and Ore [11].

Young-Wann [13] used the Rayleigh Ritz approach to construct the frequency equation and then evaluated the vibration characteristics of initially strained functionally graded rectangular metal and ceramic plates in a thermal environment. Matsunaga [14] used the power series expansion method to investigate the stability and free vibration issues of sandwich plates and angle-ply laminated composites under heat stress. An overview of the impact response of composite plates made of woven fabric was provided by Atas and Samna in 2008. Several experiments were conducted to investigate the damage process in detail, from the point of damage beginning until the point of ultimate perforation.

By utilizing the finite element approach and taking into account the intrinsic material damping property of the composite material, Jeyaraj et al. [15] reported the vibration and acoustic response characteristics of a fiber-reinforced composite plate in a temperature environment. Using the finite element approach, Lal and Singh [16] examined the stochastic free vibration of laminated composite plates subjected to thermal loading under general boundary conditions, accounting for the random characteristics of the materials and thermal expansion coefficients. In their study, Gupta et al. [17] employed the Rayleigh Ritz technique to

assess the fundamental frequencies and examined the impact of a temperature gradient on the vibration of a non-homogeneous rectangular plate with bi-direction thickness variation.

Using the finite element approach, Fakhari and Ohadi [18] investigated the large amplitude vibration of functional graded material (FGM) plates under transverse mechanical loads and temperature gradients. Using the Raleigh Ritz Technique, Gupta and Sharma [19] examined the impact of a linear temperature gradient on the vibrations of trapezoidal plates whose thickness changes parabolically.

### 3. Governing Equation and Solution

The governing equilibrium system equations of free vibration of laminated composite shell panels are produced by extracting the pertinent variables from the equation. The following might be used to express these equations:

$$\{K_s - \omega^2[M]\}\{\delta\} = 0$$

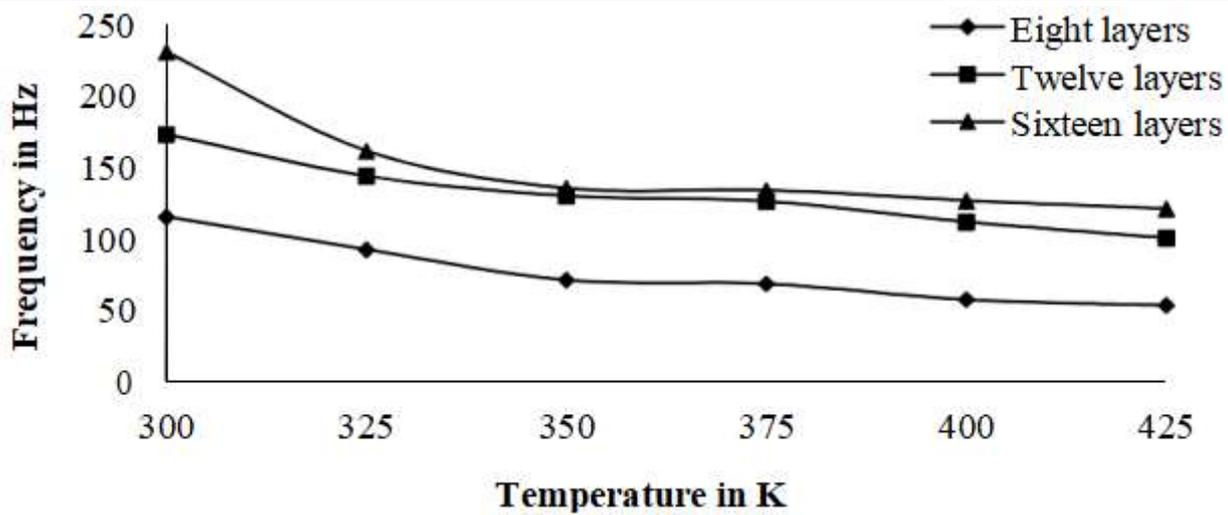
where,  $K_s$  is the stiffness matrix,  $\omega$  is the critical frequency parameter,  $M$  is the mass matrix and  $\delta$  is the displacement vector.

### 4. Results and Discussions

ANSYS creates a finite element code based on the mathematical shell panel model that was previously produced. The free vibration analysis of laminated composite shell panels has been produced for a model with 10 degrees of freedom (DOFs). The validity and accuracy of the current procedure are examined by comparing the results to those documented in the literature. An additional ANSYS code simulation model is made in order to confirm the results of the present mathematical model. To validate the developed model, the output from the ANSYS (using the Block-Langczos technique) and the MATLAB code is compared with previous research. The examination into validation and convergence shows that the current results are in good agreement with the corpus of previous literature. Examined is the effect of various parameter combinations on the composite shell panels' vibration responses. These combinations include the support condition, lay-up method, aspect ratio (a/b), and number of layers. The non-dimensionalized fundamental frequency is thought to be

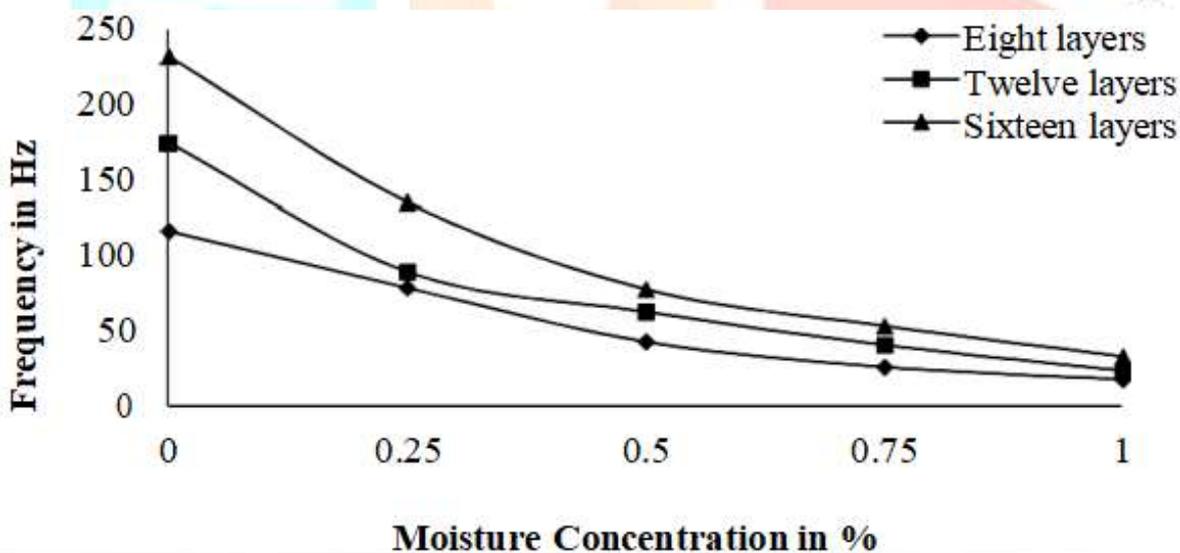
$$(\varpi) = \omega b^2 / \sqrt{\rho / (E_2 h^2)}$$

Figures 1 and 2 illustrate the fluctuation of frequencies in Hz of woven fiber composite plates subjected to increases in temperature and moisture content with varying numbers of layers. For varying numbers of layers, the vibration frequencies drop as temperature and moisture rise. The vibration frequencies of laminates with symmetric lay-up grow progressively as the number of layers increases. The extreme humidity will cause the composite plates to become less rigid.



**Figure 1: Variation of frequency in Hz with temperature for simply supported of 16 layers, 12 layers, 8 layers fiber composite plates**

The current study presents the findings for laminates that were exposed to a consistent distribution of temperature and moisture content. Experimental analysis has been conducted on sixteen layered glass fiber/epoxy laminates with simply supported boundary conditions. FEM was used in all calculations, which were performed in MATLAB code.



**Figure 2: Variation of frequency in Hz with moisture concentration for simply supported of 16 layers, 12 layers, 8 layers fiber composite plates**

There is a documented vibration frequency in Hz. The aspect ratios depicted in figures 3 and 4 are 0.5, 1.0, and 2. Because the plate becomes less rigid as aspect ratios increase, vibration frequencies fall as temperature and moisture content rise. Beyond 400K and 0.75% moisture concentration, it is noticed that aspect ratios 1 and 2 see a drop in vibration frequency that approaches zero as temperature and moisture concentration rise. This is because hygrothermal buckling begins beyond those points.

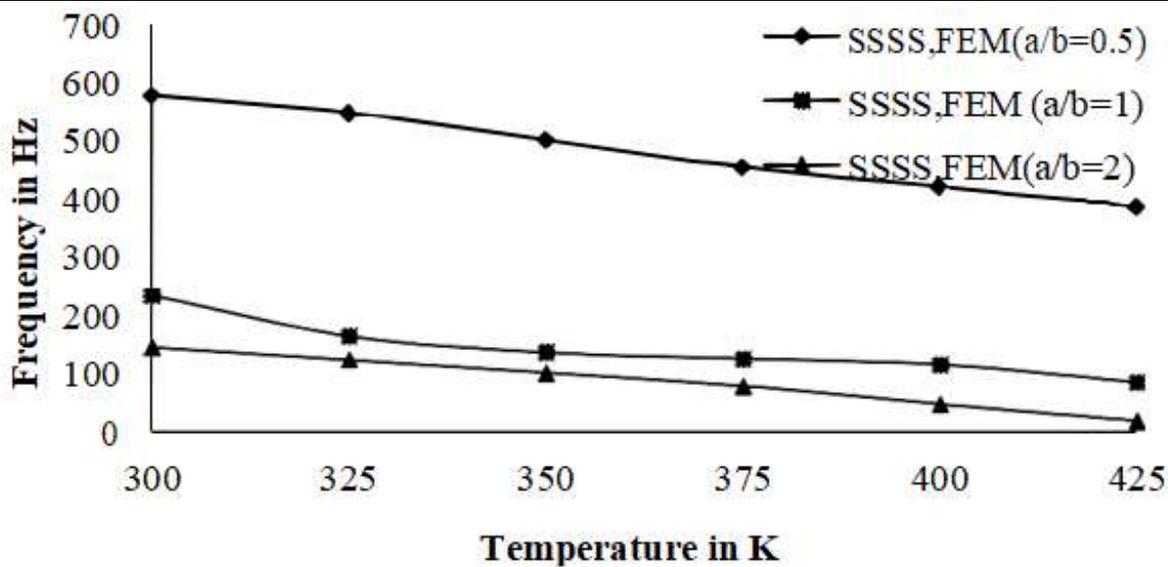


Figure 3: Variation of frequency in Hz with temperature for simply supported of 16 layers fiber composite plates

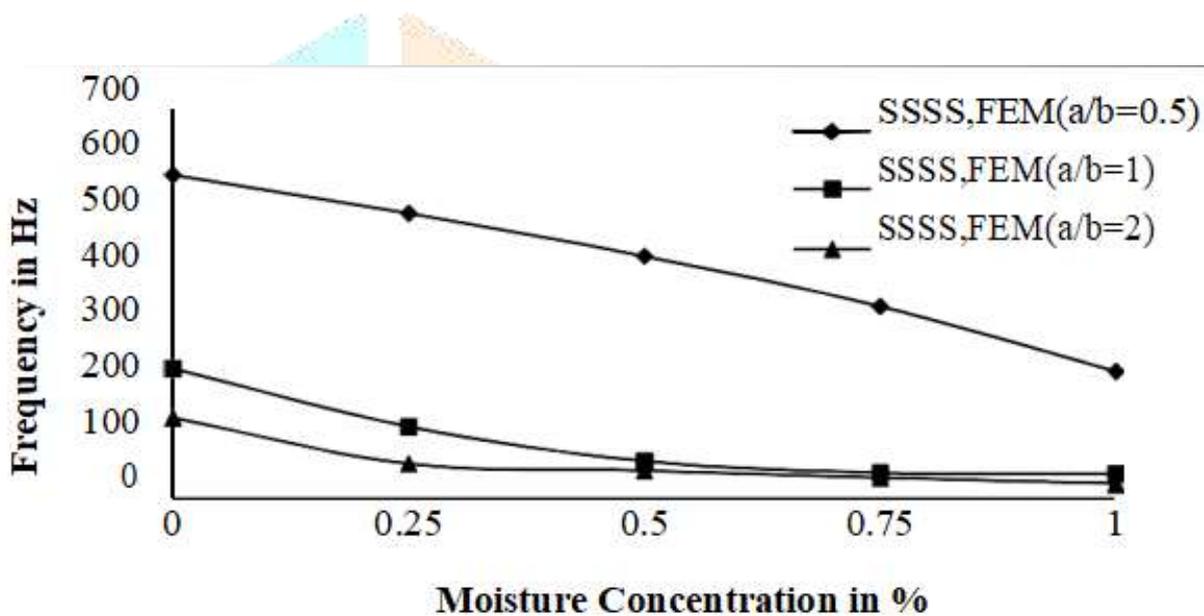


Figure 4: Variation of frequency in Hz with moisture concentration for simply supported of fiber 16 layers composite plates

## 5. Conclusion

Higher order mid-plane kinematics is used to calculate the laminated composite single panel's free vibration behavior. In order to assess the excess mechanical deformation of the laminated panel, the geometry matrix associated with frequency is analyzed using Green-Lagrange strain displacement relations. Using an eight noded isoparametric Lagrangian element with ten degrees of freedom per node, a linear finite element is developed, implemented, and solved numerically to produce the necessary results. By addressing the linear eigenvalue problem, the nondimensional fundamental frequency and critical buckling load parameters are found. The following are the more particular findings drawn from the current investigation:

The inherent frequencies of laminated composite plates in a hygrothermal environment correspond rather well. Because all laminates become less rigid as temperature rises, the inherent frequencies of vibration of fiber composite plates also rise. For all laminates, the vibration frequencies of the laminated plates likewise significantly drop as the moisture content rises. Compared to symmetric laminates, anti-symmetric laminates vibrate at greater frequencies. However, when hygrothermal conditions rise, the frequency falls. As the number of layers increases, so do the vibration frequencies of composite plates under hygrothermal stresses. However, when hygrothermal conditions rise, the frequency falls. In a hygrothermal setting, the fundamental frequencies of vibration drop as plate aspect ratios rise. In a hygrothermal environment, the vibration frequencies rise as the thickness of the composite plates increases.

## References

1. Thai H-T, Kim S-E. Free vibration of laminated composite plates using two variable refined plate theory. *Int J Mech Sci* 2010; 52:626–33.
2. Ngo-Cong D, Mai-Duy N, Karunasena W, Tran-Cong T. Free vibration analysis of laminated composite plates based on FSDT using one-dimensional IRBFN method. *Comput Struct* 2011; 89:1–13.
3. Xiang S, Jiang S, Bi Z, Jin Y, Yang M. A nth-order mesh less generalization of Reddy's third-order shear deformation theory for the free vibration on laminated composite plates. *Compos Struct* 2011; 93:299–307.
4. Motley MR, Kramer MR, Young YL. Free surface and solid boundary effects on the free vibration of cantilevered composite plates. *Compos Struct* 2013; 96:365–75.
5. Ahmed JK, Agarwal VC, Pal P, Srivastav V. Static and dynamic analysis of composite laminated plate. *Int J Innov Technol Explor Eng* 2013; 3:56–60.
6. Sharma AK, Mittal ND. Free vibration analysis of laminated composite plates with elastically restrained edges using FEM. *Cent Eur J Eng* 2013; 3:306–15.
7. Malekzadeh P, Zarei AR. Free vibration of quadrilateral laminated plates with carbon nanotube reinforced composite layers. *Thin-Walled Struct* 2014; 82:221–32.
8. Thinh TI, Nguyen MC, Ninh DG. Dynamic stiffness formulation for vibration analysis of thick composite plates resting on non-homogenous foundations. *Compos Struct* 2014; 108:684–95.
9. Boscolo M, Banerjee JR. Layer-wise dynamic stiffness solution for free vibration analysis of laminated composite plates. *J Sound Vib* 2014; 333:200–27.
10. Sayyad AS, Ghugal YM. On the free vibration analysis of laminated composite and sandwich plates: A review of recent literature with some numerical results. *Compos Struct* 2015; 129:177–201.
11. Mantari JL, Ore M. Free vibration of single and sandwich laminated composite plates by using a simplified FSDT. *Compos Struct* 2015; 132:952–9.
12. Belarbi M-O, Tati A, Ounis H, Khechai A. On the Free Vibration Analysis of Laminated Composite and Sandwich Plates: A Layerwise Finite Element Formulation. *Lat Am J Solids Struct* 2017; 14:2265–90.

13. Young-Wann, K. (2005): Temperature dependent vibration analysis of functionally graded rectangular plates, *Journal of Sound and Vibration*, Vol. 284(3-5), pp.531-549.
14. Mutsunaga, H. (2007): Free vibration and stability of angle-ply laminated composite and Sandwich plates under thermal loading, *Journal Composite Structures*, Vol. 77(2), pp. 249-262.
15. Jeyaraj, P., Ganesan, N and Padmanabhan, C. (2009): Vibration and acoustics response of a composite plate with inherent material damping in a thermal environment, *Journal of Sound and Vibration*, Vol.320, pp. 322-338.
16. Lal, A. and Singh, B. N. (2010): Stochastic free vibration of laminated composite plates in thermal environments, *Journal of Thermoplastic Composite Materials*, Vol.23, pp. 57-77.
17. Gupta A.K, Panwar V and Vats RP. (2010): Vibrations of non- homogeneous rectangular plate of variable thickness in both directions with thermal gradient effect, *Journal of Applied Mathematics*, Vol.1, pp. 456- 463.
18. Gupta, A.K and Sharma, P. (2011): Effect of linear thermal gradient on vibrations of trapezoidal plates whose thickness varies parabolically, *Journal of Vibration and Control*, Vol.17 (8).
19. Fakhari, V and Ohadi, A. (2011): Nonlinear vibration control of functionally graded plate with piezoelectric layers in thermal environment, *Journal of Vibration and Control*, Vol.17 (3), pp. 449- 469.

