Impact of Plate Thickness ratio and Boundary Conditions on Variation of frequency with temperature and moisture concentration of Laminated Composite Panel

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ABSTRACT

A certain combination of in-plane load parameter values and the natural frequency of transverse vibration can induce unstable transverse vibrations in structural materials subjected to in-plane periodic loads, resulting in parametric resonance. This instability can occur under compressive loads at a variety of excitation frequencies below the structure's critical load. Many solutions for reducing parametric resonance, such as vibration isolation and dampening, may not always be effective or safe, resulting in negative effects. Unlike the main resonance, the parametric instability can occur at low excitation amplitudes and combinations of frequencies, rather than simply at a single frequency. When a structure is exposed to periodic in-plane stress, the dynamic instability region (DIR) spectrum can be used to distinguish between favorable and undesirable vibration regimes. These spectra are routinely computed and expressed in terms of natural frequencies. As a result, extremely exact measurement of these values is an important component of the dynamic instability investigation of composite plates and shells in a hygrothermal setting.

Keywords: Temperature concentration, Moisture concentration, Plate thickness ratio, Laminated composite, Boundary conditions.

1. Introduction

Composite materials are increasingly being used in high-performance engineering applications such as aerospace, civil, naval, and others due to its lightweight nature, high specific strength, high specific stiffness, and low specific density, all of which reduce total operating costs. 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, such as 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 constructions used in the aforementioned fields are regularly exposed to high temperatures and humidity.

Temperature changes and moisture absorption appear to reduce the strength and stiffness of structural composites. A fundamental understanding of their vibrations, as well as static and dynamic stability qualities under hygrothermal conditions, is required for this wide range of practical applications.A detailed evaluation of the vibration and buckling effects of plates and shells was carried out without regard to hygrothermal effects. The buckling and vibration properties of laminated composite panels in a hygrothermal environment, which has seen an increase in utilization in recent years. Researchers are interested in the issue of dynamic instability of laminated curved panels in hygrothermal conditions since it has not been adequately investigated previously.

The preceding discussion demonstrates that a current topic of interest is the exploration of many aspects of vibration and stability research on woven fiber laminated composite plate structures in hygrothermal conditions. Given all of these advances and design specifications, understanding the reaction characteristics of these structural parts is critical. Prior research in this topic must be thoroughly studied before determining the objective and scope of the current study. According to industry observers, the use of laminated composite materials has increased significantly in recent years due to their longer fatigue life, higher stiffness-to-weight ratio, and superior corrosion resistance.

Experimenting with different fiber orientations and stacking patterns can increase a panel's stiffness-to-weight ratio, resulting in a more energy-efficient design. However, by including the necessary patterns into the design, a panel's particular strength and stiffness can be increased even more without significantly reducing the panel's overall weight. These advantages have been used in the current study, which investigates the architectures of trapezoidal laminated composite panels. Composites are commonly utilized in laminate form in a wide range of technical and non-engineering applications, including aeronautical, mechanical, marine, and civil engineering. Since its inception, composite laminated panels have been widely used in the aerospace and aviation industries. They have recently been employed in civil engineering structures such as bridge decks and girders, as well as for reinforcing and retrofitting structural elements, among other applications.

2. Literature Review

Laminated composite plates are used in a variety of light weight and load bearing structural parts of various aerospace, automotive, and civil engineering structures because they have a higher stiffness and strength to weight ratio, a higher resistance to impact damage, and a longer lifespan than some other structures. Furthermore, these structural sections must be cut for a variety of reasons, including access, quality control, weight decrease, ventilation, and inspection. Cutouts are commonly utilized in aeronautical constructions as access points for a variety of systems, including mass reduction, electrical and mechanical, and fuel lines. The bulk of these structures will be subjected to dynamic loads during their service life.

Resonance causes the most harm. Composite plate cuts may alter the dynamic characteristics in a way that increases the number of resonance possibilities. As a result, vibration analysis is crucial in building design since it predicts their reaction. Structural vibrations can be controlled by taking proper precautions to prevent resonance. In mechanical, aeronautical, and civil applications, free vibration characterisation of composite plates with cutouts has shown to be an exceedingly valuable problem. For many years, researchers have concentrated on the diverse applications of regular metals and alloys, as well as the increasing demand for composite materials in plates and shells. The investigation's primary focus is the dynamic instability analysis of flat and curved panels in a hygrothermal environment; however, for the sake of relevance, some relevant research works on free vibration, buckling, and dynamic instability analysis of flat and curved panels subjected to hygrothermal loadings are also considered. To identify gaps in the current literature, a detailed and critical review of a few recent relevant studies is done.

Many researchers have used analytical and computational tools to perform detailed investigations into the free vibration behavior of laminated composite plates. Here are a few noteworthy recent research, summarized for clarity. Thai et al. [1] investigated the vibrational behavior of composite plates using enhanced plate theory. Cong et al. studied the free vibration of composite plates with one-dimensional integrated radial basic function networks. [2]. Xiang et al. [3] developed an nth-order shear deformation theory to investigate the vibration of composite square plates. Motley et al. [4] studied the impact of boundaries on the vibration responses of cantilevered composite plates using FEM. Ahmed et al. [5] used FEM to explore the static and dynamic characteristics of graphite-epoxy composite plates. Sharma and Mittal [6] employed FEM to study the vibration of cross-ply and angle-ply plates with elastically restricted edges. Malekzadeh and Zarei [7] investigated the vibration behavior of composite plates comprised of carbon nanotube-reinforced composite layers using a differential quadrature method. Thinh et al. [8] and Boscolo & Banerjee [9] investigated the vibration properties of composite plates using a dynamic stiffness technique. Sayyad and Ghugal [10] investigated sandwich and composite plate vibrations. Belarbi et al. [12] and Mantari and Ore [11] used higher order FEM models to analyze the sandwich plate vibration problem. Young-Wann [13] used the Rayleigh Ritz technique to develop the frequency equation and then tested the vibration properties of functionally graded rectangular metal and ceramic plates in a heat environment. Matsunaga [14] employed the power series expansion method to study the stability and free vibration of sandwich plates and angle-ply laminated composites under heat stress. Atas and Samna published an outline of the impact response of composite plates comprised of woven cloth back in 2008. Several studies were undertaken to thoroughly analyze the damage process, from the point of first damage to the point of ultimate perforation.

Jeyaraj et al. [15] investigated the vibration and acoustic response characteristics of a fiber-reinforced composite plate in a temperature environment using the finite element method and accounting for the composite material's inherent material damping property. Lal and Singh [16] used the finite element approach to investigate the stochastic free vibration of laminated composite plates subjected to thermal loading under generic boundary conditions, accounting for the materials' random properties and thermal expansion coefficients. In their study, Gupta et al. [17] used the Rayleigh Ritz technique to determine the fundamental frequencies and investigated the effect of a temperature gradient on the vibration of a non-homogeneous rectangular plate with bidirectional thickness change. Fakhari and Ohadi [18] used a finite element approach to analyze the large amplitude vibration of functional graded material (FGM) plates under transverse mechanical stresses and temperature gradient. Gupta and Sharma [19] used the Raleigh Ritz Technique to investigate the effects of a linear temperature gradient on the vibrations of trapezoidal plates with parabolically changing thicknesses.

3. Governing Equation and Solution

Extracting the relevant variables from the equation yields the governing equilibrium system equations for free vibration of laminated composite shell panels. The following could be used to express these equations:

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

where, • $K s$ • is the stiffness matrix, • is the critical frequency parameter, • M • is the mass matrix and • • • is the displacement vector.

4. Results and Discussions

ANSYS generates finite element code based on the previously created mathematical shell panel model. A model with ten degrees of freedom (DOFs) was used to conduct free vibration analysis on laminated composite shell panels. The current procedure's validity and accuracy are assessed by comparing the results to those documented in the literature. An extra ANSYS code simulation model is created to validate the results of the current mathematical model. To validate the created model, the ANSYS output (using the Block-Langczos approach) and MATLAB code are compared to earlier studies. The assessment of validation and convergence reveals that the current findings are in good agreement with the body of previous literature. The effects of different parameter combinations on the vibration responses of composite shell panels are investigated. These combinations include support criteria, lay-up methods, thickness ratios (b/t), and various boundary conditions. The non-dimensionalized fundamental frequency is considered to be

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

Figures 1 and 2 indicate that the side-to-thickness ratios are 25, 40, and 50, respectively, as the temperature and moisture levels increase. The hygrothermal environment changes solely as a function of thickness. It has been shown that high temperatures and moisture concentrations weaken composite plates. The thicker the plate, the stronger the stiffness, and the higher the vibration frequency, as seen in figures 1 and 2 in a hygrothermal atmosphere. The variance in vibration frequencies has increased the plate's susceptibility to localized shear deformation.

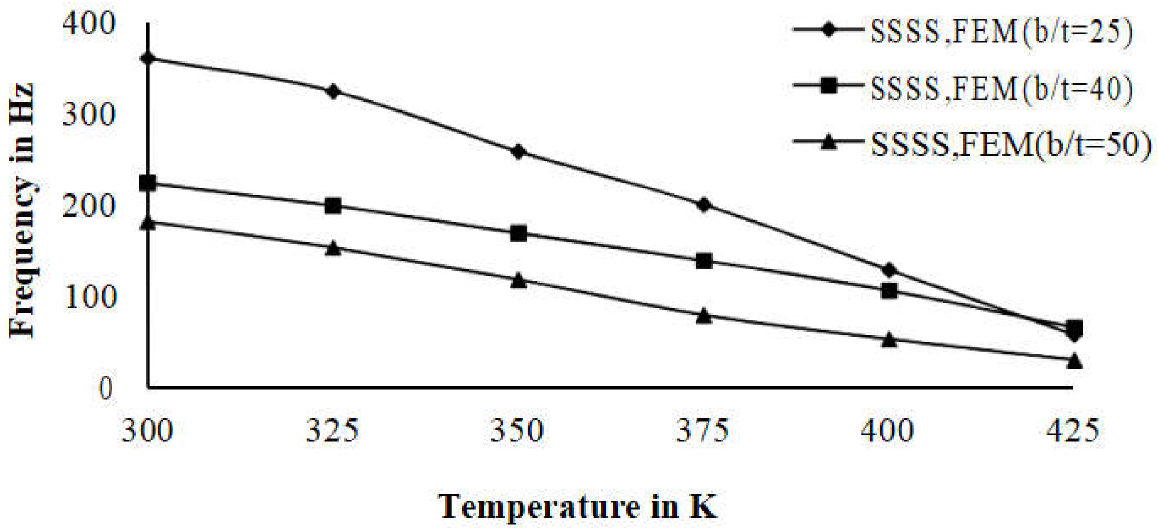

Figure 1: Variation of frequency in Hz with temperature for simply supported of 16 layers laminated composite plates

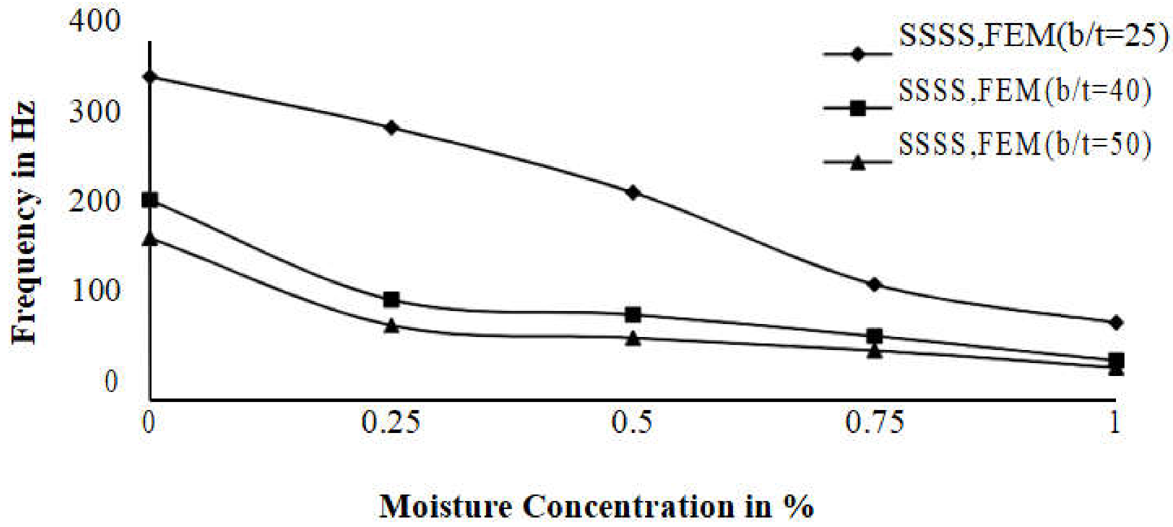

Figure 2: Variation of frequency in Hz with moisture concentration for simply supported of 16 layers laminated **composite plates**

The numerical results for sixteen layered Glass fiber/epoxy with simply supported boundary conditions and side-to-thickness ratios of 40 and 50 are compared to four edges clamped plates, as illustrated in figure 3 with increasing temperature and figure 4 with increasing moisture. For simply supported and clamped boundary conditions, the first mode analytical vibration frequency decreases as the side-to-thickness ratio increases. Elastic rigidities cause the analytical vibration frequency to be higher than its numerical counterparts.

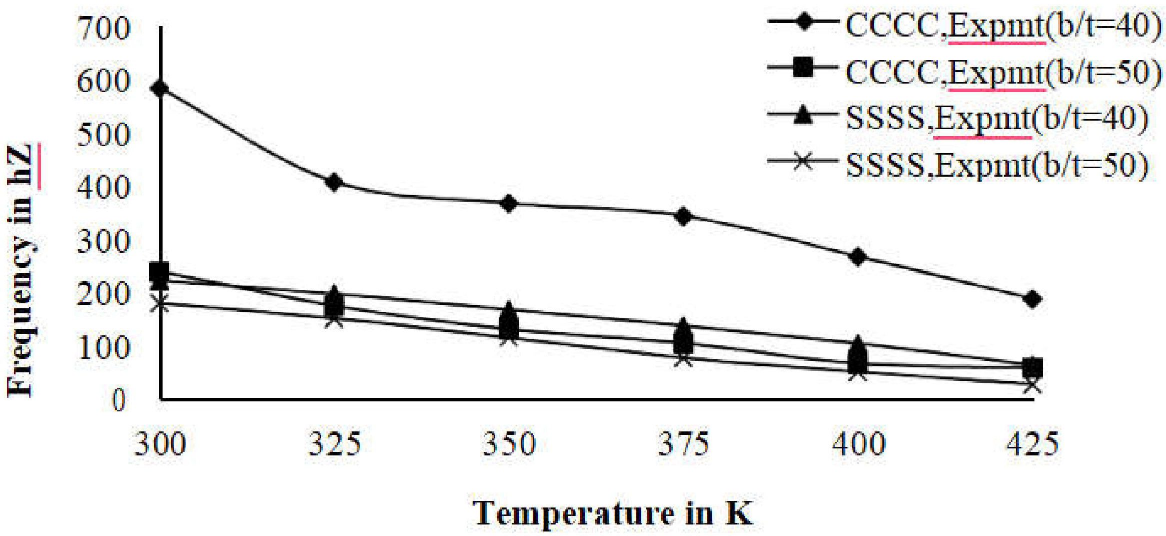

Figure 3: Variation of frequency in Hz with temperature for clamped of 16 layers laminated composite plates

Because of their stiff borders, clamped plates experience more severe hygrothermal changes than merely supported plates. The hygrothermal environment will diminish the stiffness of the composite plates under both clamped and simply supported boundary conditions. The zero frequency point indicates that hygrothermal buckling will occur at that location. Because of improved elastic rigidities and clamping effects at the edges, the vibration frequencies for the four-sided clamped boundary condition are higher than those for the simply supported condition.

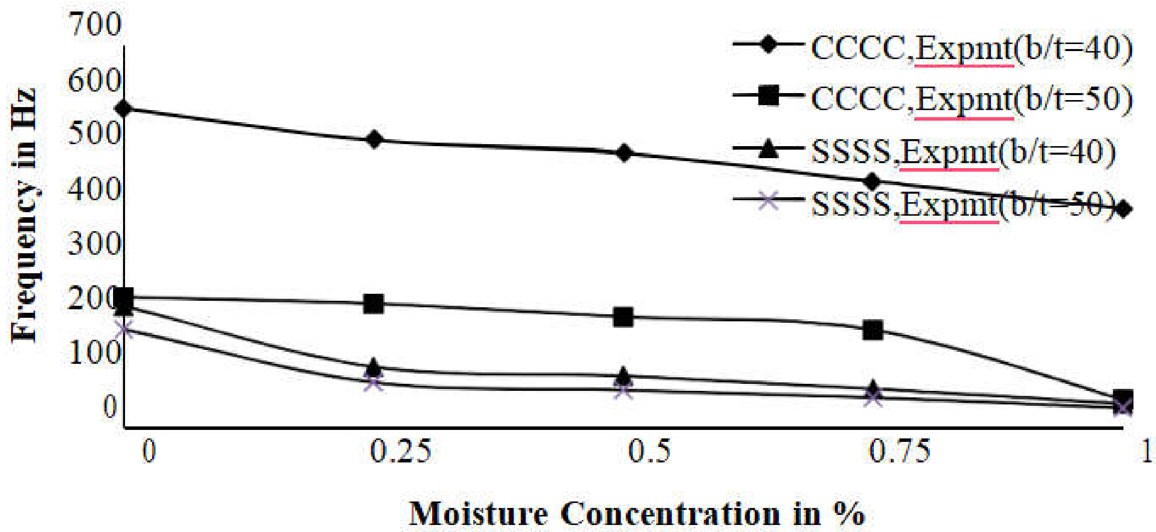

Figure 4: Variation of frequency in Hz with moisture concentration for clamped of 16 layers laminated composite plates

5. Conclusion

Higher order mid-plane kinematics is used to calculate the free vibration behavior of a laminated composite single panel. To determine the excess mechanical deformation of the laminated panel, the geometry matrix associated with frequency is evaluated using Green-Lagrange strain displacement relations. To achieve the desired results, a linear finite element is devised, implemented, and numerically solved using an eight-noded isoparametric Lagrangian element with 10 degrees of freedom each. By addressing the linear eigenvalue problem, the nondimensional fundamental frequency and critical buckling load parameters are determined. The following are the more specific conclusions from the current investigation:

The intrinsic frequencies of laminated composite plates in a hygrothermal environment match quite well. Because all laminates grow less stiff as temperatures rise, so do the intrinsic frequencies of vibration in fiber composite plates. The vibration frequencies of all laminated plates decrease dramatically as moisture content increases. Anti-symmetric laminates vibrate faster than symmetric laminates. However, when hygrothermal conditions improve, the frequency decreases. The vibration frequencies of composite plates under hygrothermal strains rise in proportion to the number of layers.However, when hygrothermal conditions improve, the frequency decreases. In a hygrothermal environment, the fundamental frequencies of vibration decrease as plate aspect ratios increase. In a hygrothermal environment, vibration frequencies increase as the thickness of the composite plates increases.

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