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Resonance Characteristics of Woven Fiber Composite Flat Panels in Hygrothermal Environment

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ABSTRACT

The present study deals with the parametric resonance characteristics of woven fiber laminated composite plates with uniform rise in temperature and moisture concentration. The effects of various parameters like increase in number of layers, ply-orientations of composite plates at elevated temperatures and moisture concentrations on the principal instability regions are studied using finite element method. The first-order shear deformation theory is used to model the composite plates under hygrothermal environment, considering the effects of transverse shear deformation and rotary inertia. The results on the dynamic stability studies of the woven fiber laminated composite plates with different parameters suggest that the onset of instability occurs earlier and the width of dynamic instability regions increase with rise in temperature and moisture. The instability occurs earlier with increase in temperature and moisture for different parameters.

Introduction

There is a tremendous increase in utilization of composite materials in thin walled structural components of aircrafts, submarines, automobiles and other high- performance civil engineering application areas. When exposed to high temperature and moisture, the changes in vibration, static and dynamic stability characteristics have necessitated a strong need to understand their dynamic behavior under different loading conditions. Everest Industries Limited is one of India's fastest growing building solutions companies for composite plate structures. Following a solutions approach where various products and services are integrated to meet customers' needs, Everest offers a complete range like Roofing, Ceilings, Walls, Floors, Cladding, Doors, and Pre-Engineered Steel Buildings for the Industrial, Commercial and Residential Sectors. Today, Everest is one of the most respected and renowned business entities in India and has gained a strong foothold in the market. The company has a pan India presence with a large distribution network and state-of-art manufacturing facilities at Kymore, Nashik, Coimbatore, Kolkata and Roorkee. Banking on its state-of-the art manufacturing facilities and an employee strength of over 1285 highly qualified and experienced designers, technicians and fabricators, Everest assures that all its products live up to its age old promise of Strength, Speed and Safety. The dynamic behavior of laminated plates changed significantly under various hygrothermal loading. Naik*et al* (2000) investigated the behavior of industry driven woven fabric laminated composite plates under transverse central low-velocity point impact by using a modified Hertz law and a 3D transient finite-element analysis. Botelho*et al* (2005) investigated with experiments the hygrothermal effects on damping behavior of metal/glass fiber/epoxy hybrid composites. Chen and Chen (1989) studied the free vibration of the laminated rectangular composite plate exposed to steady state hygrothermal environment. Sai Ram and Sinha (1992) investigated the effects of moisture and temperature on the free vibration of laminated composite plates using finite element method. Shen*et al* (2005) discussed in detail the effects of hygrothermal conditions on the dynamic response of shear deformable laminated plates resting on elastic foundations using a micro-to-micromechanical analytical model. However, the stability studies are less in literature. Thagaratnam*et al* (1989) studied the buckling analysis of composite laminates for critical temperature. The mathematical formulation is based on linear theory and the finite element method using semiloof elements. Sai Ram and Sinha (1992) investigated the effects of moisture and temperature on the static stability of laminated composite plates. The mathematical model based on finite element method which takes transverse shear deformation into account. Patel *et al* (2000) studied the hygrothermal buckling effects on the structural behavior of thick composite laminates using higher-order theory. The analysis is carried out employing a C^o QUAD-8 isoperimetric higher-order finite element. Babu and Kant (2000) proposed with

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a refined higher order finite element models for thermal buckling of laminated composite plates. Singh and Verma (2008) investigated the hygrothermal effects on the buckling of laminated composite plates with random geometric and material properties. A C^0 finite element model based on higher order shear deformation theory is used for deriving the eigenvalue problem. Srinivasan and Chelapandi (1986) studied the dynamic stability of rectangular plates due to periodic in-plane load by using finite strip method. Chen and Yang (1990) investigated on the dynamic stability of laminated composite plates by Galerkin finite element method. Kwon (1991) examined the dynamic instability of layered composite plates by finite element method by using higher-order bending theory. Balmurugan*et al* (1996) studied nonlinear dynamic instability of laminated composite plates using finite element model. Patel *et al* (1999) investigated on the dynamic instability of laminated composite plates supported on elastic foundations, subjected to periodic in-plane loads, using C^1 eight-nodded shear-flexible plate element. Sahu and Datta (2003) presented the dynamic stability behavior of laminated composite curved panels subjected to in-plane static and periodic compressive loads using finite element method. The boundaries of instability region were obtained using Bolotin's method and were represented in amplitude-excitation frequency plane.

Mathematical Formulation

Element stiffness matrix is given by:

$$[K_e] = \int_{-1}^{+1}\int_{-1}^{+1} [B]^T [D][B] |J| d\xi d\eta$$

The geometric stiffness matrix due to residual stresses is given by:

$$[K^r{}_{Ge}] = \int_{-1}^{+1}\int_{-1}^{+1} [G]^T [S][G] |J| d\xi d\eta$$

The geometric stiffness matrix due to applied in-plane loads is given by:

$$[K^a{}_{Ge}] = \int_{-1}^{+1}\int_{-1}^{+1} [H]^T [P][H] |J| d\xi d\eta$$

The element load vector due to the hygrothermal forces and moments is given by:

$$\{P_e^N\} = \int_{-1}^{+1}\int_{-1}^{+1} [B]^T \{F^N\} |J| d\xi d\eta$$

Results and Discussion

The effect of different increase in number of layers on the dynamic stability regions is illustrated in fig. 1-2 for eight layers, and sixteen layers as shown in fig. 3-4 with uniform rise in temperature and moisture respectively. It is observed from the figure that the structure is more stable under periodic loads with increase in number of layers. The excitation frequencies are increased with eight layers but the width of instability region is narrower showing instability region at higher frequencies. But for sixteen layers the frequencies are less and remain same with increase in width of instability region. As increase in number of layers from eight to sixteen layers the instability region is wider due to bending-stretching coupling, it means that the woven fiber laminated composite plates become stiffer with more number of layers. The excitation frequencies are decreased with rise in temperature and moisture for increase in number of layers. All further parametric studies are done with an eight layer laminate combination. It is observed from the figure 1-4, with increase in number of layers from 8 to 16. The origin of primary instability region is located at higher temperature and moisture beyond 375K and 0.75% respectively. As a result the laminated composite plate affected severely and loses its strength and becomes unstable at higher hygrothermal environment.

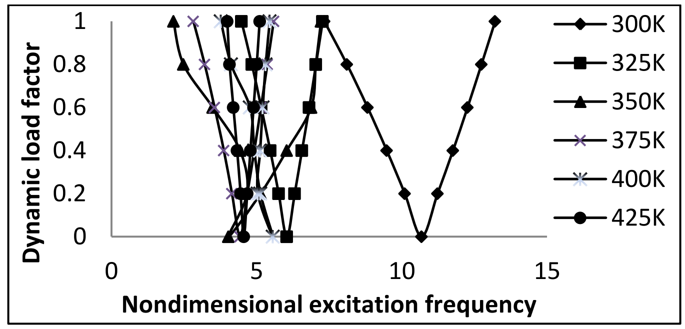

Figure1. Variation of instability regions with temperature for simply supported (s-s-s-s) of $[45/-45]_4$, a/b=1, α= 0.2, woven fiber composite plates.

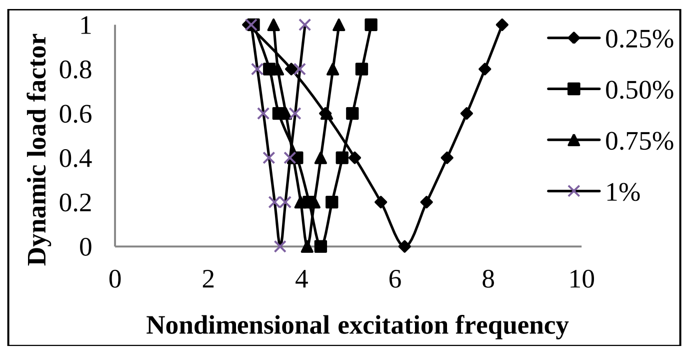

Figure 2. Variation of instability regions with moisture concentration for simply supported (s-s-s-s) of $[45/-45]_4$, a/b=1, α= 0.2, woven fiber composite plates.

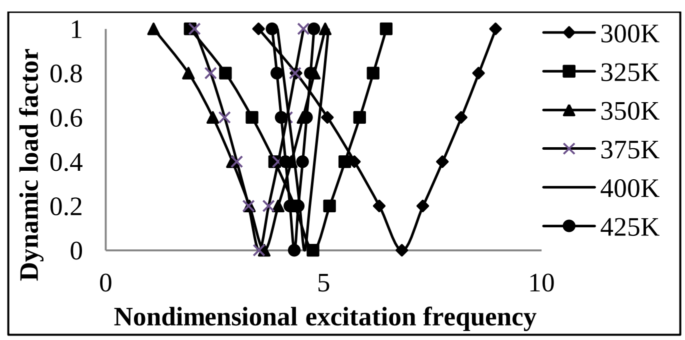

Figure 3. Variation of instability regions with temperature for simply supported (s-s-s-s) of $[45/-45]_8$, a/b=1, α= 0.2, woven fiber composite plates.

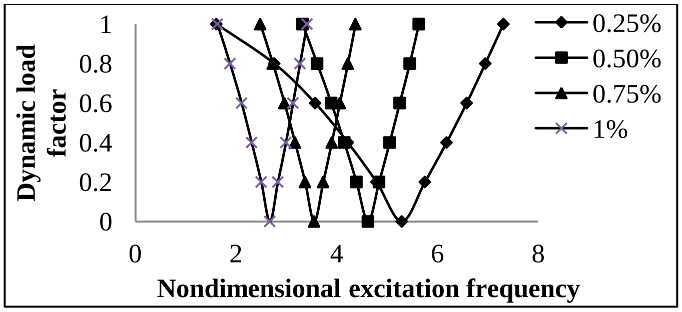

Figure 4. Variation of instability regions with moisture concentration for simply supported (s-s-s-s) of $[45/-45]_8$ a/b=1, α= 0.2, woven fiber composite plates.

The variation of instability regions is also studied for different lamination angles, 0° and 30° as shown in figure 5-8 respectively. As observed in figure 5-8, the instability region is smaller for 0° lamination angle with uniform rise in temperature and moisture, as compared to lamination angle for 30°. The instability width is increased with increase in lamination angle from 0° to 30° in hygothermal environment. The instability region for lamination angle 30° having lower excitation frequency as compared to 0°. The greater the lamination angle, the smaller is the instability region. The ply orientation for 0° seems to be the preferential ply orientation for the lamination sequence which is due to dominance effect of bending-stretching coupling.

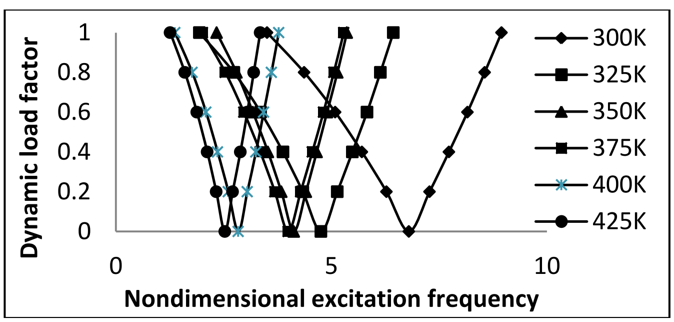

Figure 5. Variation of instability regions with temperature for simply supported (s-s-s-s) of $[0/-0]_4$, a/b=1, α= 0.2, woven fiber composite plates

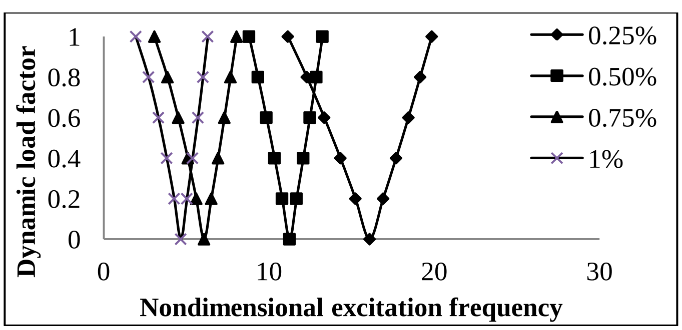

Figure 6. Variation of instability regions with moisture concentration for simply supported (s-s-s-s) of $[0/-0]_4$, a/b=1, α= 2, woven fiber composite plates

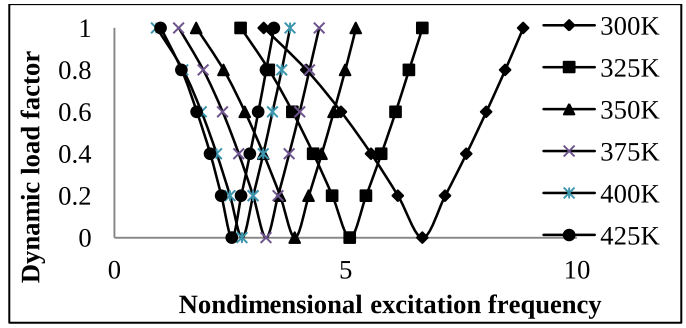

Figure 7.Variation of instability regions with temperature for simply supported (s-s-s-s) of $[30/-30]_4$, a/b=1, α= 0.2, woven fiber composite plates

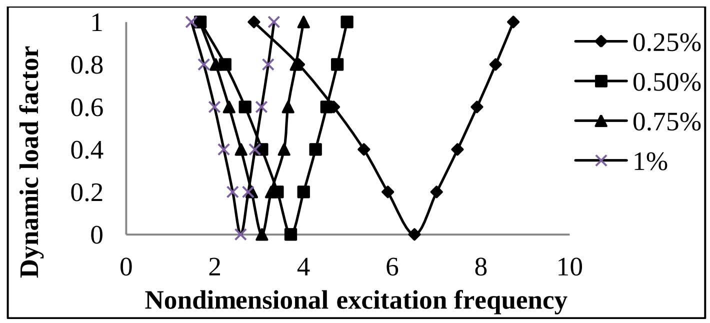

Figure 8. Variation of instability regions with moisture concentration for simply supported (s-s-s-s) of $[30/-30]_4$, a/b=1, α= 0.2, woven fiber composite plates

Conclusion

- A parametric stability study of woven fiber laminated composite plates in hygrothermal environment subjected to periodic in-plane loads is examined by considering an eight-noded plate element based on shear flexible theory. Numerical results are obtained for eight layered laminated plates using finite element method.
- From the present studies, it is concluded that the instability behavior of woven fiber laminated composite plates is greatly influenced by the geometry and lamination parameter. Such a property can be utilized to tailor the design of woven fiber laminated composite flat plates in hygrothermal environment.

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