International Journal of Research in Applied Science
Vol.3 Issue.1 (November–December) 2016

THERMAL EFFECTS ON NATURAL FREQUENCIES OF DELAMINATED COMPOSITE PLATES

H. S.Panda, S K Panda
Department of CIVIL Engineering,
Gandhi Institute for Technological Advancement (GITA), Bhubaneswar-752054 Odisha, India

Received on 11th June 2016 and Accepted on 24th July 2016

Abstract

Current research deals with numericalandexperimental studies on free vibration behavior of delaminated composite plates at varying temperature.A composite plate model with provision of central delamination is chosen for vibration subjected to thermal loading and numerical results of free vibration are obtained using Finite Element Method (FEM).Number of experiments is conducted to obtainnatural frequencies of free vibration for composite plates using B&K FFTAnalyzer with PULSE Lab Shop software, which matchwell with their predicted counterparts. Teflon film is embedded in the laminate, simulating the presence of delamination.

***Keywords*— Vibration, thermal environment, delamination**

I. INTRODUCTION

Laminated composites are prone to damage during their operational life .Their increased use in a variety of industrial applications has underlined the need for understanding their principal mode of failure that is delamination. In a broad sense, delamination is the separation of two adjacent plies in a laminated composite. The delamination problem is generally very complex in nature involving geometrical and material discontinuities. After it develops, the delaminated areas may extend gradually and reduce the effective stiffness of the laminate. Also, the varying environmental conditions due to rise in temperatures seem to have an adverse effect on the strength and stiffness of the structural composites and thus the life of the structure.

Studies on hygroscopic and dynamic behavior of laminated composite plates, considering delamination and thermal effects separately, are available in open literature. Ju*et al.* [1]presented numerical results on the variation of natural frequencies of composite plates with multiple delaminations by FEM considering the effect of transverse shear deformations. Sairam and Sinha[2] investigated the hygrothermal effects on the natural frequencies of free vibration of laminated composite plates by finite element method taking transverse shear deformation into account. Abot*etal.* [3] studied the moisture absorption process of woven fabric carbon-epoxy composites experimentally and its effect on the viscoelastic properties. Alnefaie [4] established numerical results on the variations in natural frequencies of carbon-epoxy composite plates with internal delamination . However, experimental studies on free vibration of composite plates, considering delamination and hygrothermal effects combinedly, are not available in literature. The present study takes into account both numericaland experimental investigation on free vibration behavior of delaminated composite plates under elevated temperature conditions.

II. FINITE ELEMENT FORMULATION:

Based on first order shear deformation theory, a quadratic isoparametric finite element formulation with five degrees of freedom per node is developed to perform all necessary computations using FEM for a composite plate model with central mid plane square delamination.

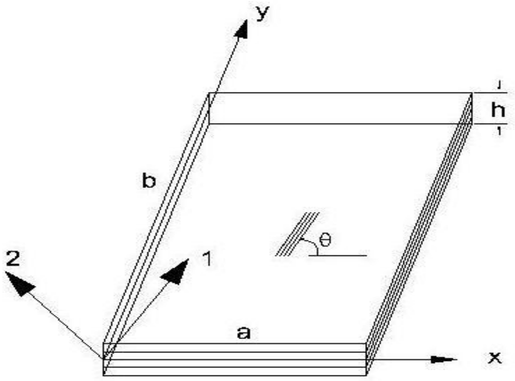

Fig1: Composite plate axes system

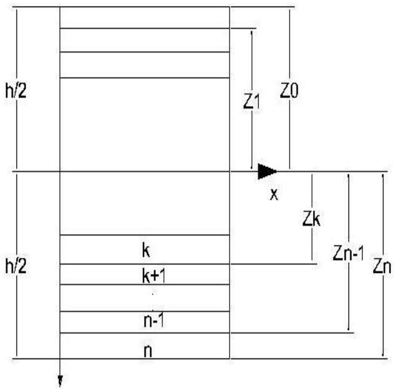

Fig 2: n layered laminate configuration.

The constitutive equations for the plate, when it is subjected to moisture and temperature, are given by

$$\{F\} = [D]\{\varepsilon\} - \{F^N\}, \qquad (1)$$

Where,

$$\{F\} = \{N_x, N_y, N_{xy}, M_x, M_y, M_{xy}, Q_x, Q_y\}^T.$$

$$\{F^N\} = \{N_x^N, N_y^N, N_{xy}^N, M_x^N, M_y^N, M_{xy}^N, 0, 0\}^T,$$

$$\{\varepsilon\} = \{\varepsilon_x^0, \varepsilon_y^0, \gamma_{xy}^0, K_x, K_y, K_{xy}, \varphi_x, \varphi_y\}^T,$$

The (^{0})corresponds tomid-plane values. N_x, N_y, N_{xy} are in-plane stress resultants, M_x, M_y, M_{xy} are moment resultants and Q_x, Q_y are transverse shear stress resultants. The terms with superscript (^{N}) represent the corresponding non-mechanical in-plane stress and moment resultants due to moisture and temperature. φ_x, φ_y are shear rotations in x-z and y-z planes respectively. 'ε , γ' stands for strains and 'K' stands for curvature of the plate.

The extensional, bending-stretching and bending stiffness of the laminate are expressed in the usual form as

$$(A_{ij}, B_{ij}, D_{ij}) = \sum_{k=1}^{n} \int_{z_{k-1}}^{z_k} (\bar{Q}_{ij})_k (1, z, z^2)\, dz, \quad i,j = 1,2,6 \qquad (2)$$

Similarly the shear stiffness is expressed as

$$(A_{ij}) = \sum_{k=1}^{n} \int_{z_{k-1}}^{z_k} \alpha (\bar{Q}_{ij})_k\, dz, \quad i,j = 4,5 \qquad (3)$$

'α' the shear correction factor which is assumed as 5/6 in line with many previous studies. It accounts for the non-uniform distribution of transverse shear strain across the thickness of the laminate.

The non-mechanical in-plane stress and moment resultants are given by,

$$\{N_x^N, N_y^N, N_{xy}^N\}^T = \sum_{k=1}^{n} \int_{z_{k-1}}^{z_k} (\bar{Q}_{ij})_k \{e\}_k\, dz,$$

$$\{M_x^N, M_y^N, M_{xy}^N\}^T = \sum_{k=1}^{n} \int_{z_{k-1}}^{z_k} (\bar{Q}_{ij})_k \{e\}_k\, z\, dz, \quad i,j = 1,2,6 \qquad (4)$$

Here,

$$\{e\}_k = \{e_x, e_y, e_{xy}\}_k^T = [T]\{\alpha_1, \alpha_2\}_k^T (T - T_0) \qquad (5)$$

are the non-mechanical strains of kth lamina, oriented at an arbitrary angle θ, in which

$$[T] = \begin{bmatrix} \cos^2\theta & \sin^2\theta \\ \sin^2\theta & \cos^2\theta \\ -\sin 2\theta & \sin 2\theta \end{bmatrix}$$

α_1 , α_2 are the thermal coefficients and their values are as $\alpha_1 = -0.3 \times 10^{-6}$/K and $\alpha_2 = 28.1 \times 10^{-6}$/K. C_0 and T_0 are the reference moisture content in % and temperature in Kelvin respectively and here their values assumed are 0 and 300K respectively.

For delamination, the stress and moment resultants of the sublaminate that lead to the elasticity matrix of the tth sub-laminate in the form

$$[D]_t = \begin{bmatrix} A_{ij} & z_t^0 A_{ij} + B_{ij} & 0 \\ B_{ij} & z_t^0 B_{ij} + D_{ij} & 0 \\ 0 & o & S_{ij} \end{bmatrix} \qquad (6)$$

For, $[A_{ij}]$, $[B_{ij}]$, and $[D_{ij}]$ i.j = 1,2,6 and for $[S_{ij}]$ i,j=4,5

III. EXPERIMENTAL WORK:

The Glass/Epoxy composite plateswere prepared using hand layup method. Teflon film was used to mark the centrally located delamination area on the mid plane of the specimens during preparation. Single mid plane delamination of three different sizes like 6.25%, 25% and 56.25% of the total area of the plate were considered.The plates were treated thermally with temperatures ranging between 300K-375K. Then the specimens were tested with the B&K FFTAnalyser with PULSE Lab Shop software for frequency measurement and compared with the present FEM formulation. 16 layered cross ply laminates were used throughout with simply supported boundary condition.

IV. RESULTS AND DISCUSSIONS

The accuracy of the present finite element formulation is verified by comparing it with the non-dimensional frequency results of Sairam and Sinha [2] as shown in Table-1. The present finite element results showed good agreement with previous studies.Table-1: Non-dimensional frequency λ= [ωna2(ρ/E2h2)1/2] of simply supported (0/90/90/0) plateE1=172.5 GPa, E2 = E3 = 6.9 GPa, G12 = G13 = 3.45GPa, G23 = 1.38GPa, ρ = 1600 Kg/m3, υ12= 0.25, a=b=0.5m, h=5mm, a/h=100

Mode Number	**Temp=325K**	
	Sairam and Sinha[2]	**Present FEM**
1	8.088	8.041
2	19.196	18.357
3	39.324	38.598

The variation of natural frequencies of free vibration for fundamental mode found from FEM and experimental (EXPT) results with different delamination areas under different temperature conditions are presented in figure 3.As shown, the fundamental frequencies of vibration based on present FEM results match well with the experimental ones. The frequencies of vibration of composite plates for 6.25%,25% and 56.25% delaminations under a constant temperature reduce from no delamination specimen in the range 12.73%, 29.29% and 41.97% respectively. With increase in temperature, the frequencies of vibration of composite plates having 0%,6.25%,25% and 56.25% delaminations reduce from the reference temperature in the range 9.8%, 14.5%, 24.32% and 34.2% respectively.

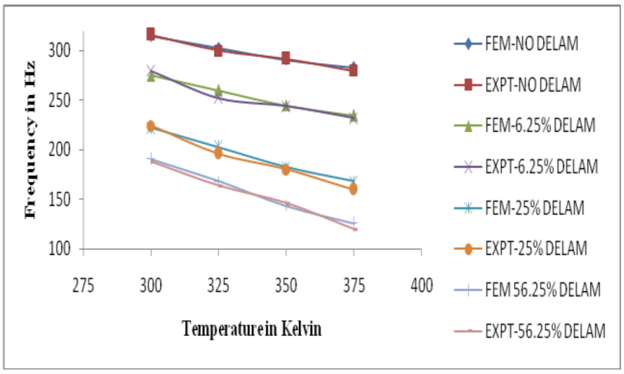

Fig 3: Variation of first mode frequencies of woven fiber simply supported composite plates subjected to variation in temperature for different delamination areas.

For the second and third mode, as shown in figures 4 and 5, the frequencies of vibration for composite plates having 6.25% delamination reduce only 3.9% from no delaminated plate, where as the plates having 25% and 56.25% delamination reduce in the range 28% and 44% respectively from no delaminated plate under constant temperature condition. Increment in temperature results in the reduction of frequencies in the range 1.3% to 4.5% for plates upto 6.25% delamination, where as the reduction of frequencies is in a wider range i.e. up to 10% and 16% respectively for the plates having 25% and 56.25% delamination, compared with the frequencies under reference temperature.

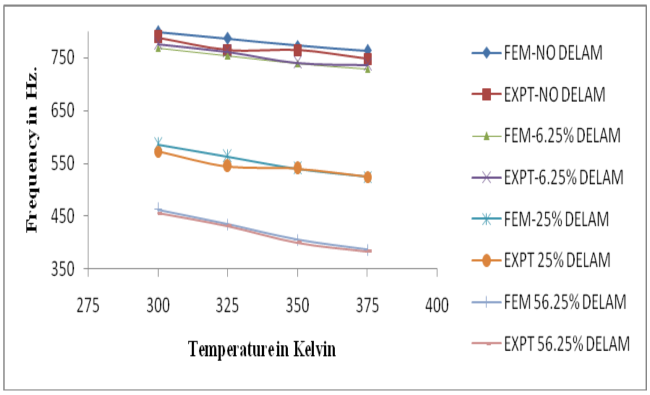

Fig 4: Variation of second mode frequencies of woven fiber simply supported composite plates subjected to variation in temperature for different delamination areas.

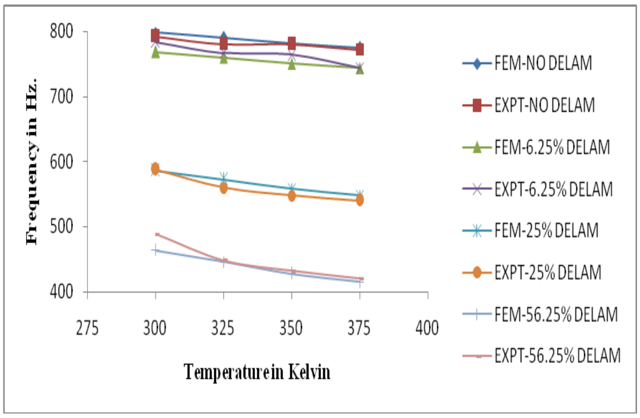

Fig 5: Variation of third mode frequencies of woven fiber simply supported composite plates subjected to variation in temperature for different delamination areas.

V. CONCLUSIONS

From the present study, it is concluded that

1. The frequency of vibration decreases with increase in delamination area.
2. The temperature increment shows also a reduction in frequencies.

VI. REFERENCES

[1] Ju F, et al.,'Finite element analysis of free vibration of delaminated composite plates', Int J of Composites Engg,1995, 5(2), 195-209.
[2] Sairam K S, Sinha P K,'Hygrothermal effects on the free vibration of laminated composite plates', Int J of Sound and Vibration,1992, 158(1), 133-148.
[3] Abot J Let al,' Hygroscopic behavior of woven fabric carbon epoxy composites', IntJ of Reinf Plastic Compo. 2005, 24(2), 195-207.
[4] AlnefaieK,'Finite Element modeling of composite plates with internal delamination Int J of Comp Structures, 2009, 90, 21-27.