International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Finite Element Analysis of Plate using Composite Material without and with Damping

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Abstract:

Composite materials have an extensive use compared to all other materials due to their excellent mechanical material properties as high stiffness to weight ratio and strength to weight ratio. Damping is very important factor in any mechanism and machine for diminishing unusual vibration force and sound as they affect their performances. Visco-elastic structures add passive damping by dissipative vibration energy in the term heat. The incorporation of damped material in composite offers the possibility of highly damped, light weight structure, which are vibration resistant. This paper presents the Finite Element Analysis (FEA) of laminated composite plate. For Finite element analysis ANSYS-13.0 software has been used. For the analysis both damped free and damped conditions have been considered. In damped condition passive damping material like rubber has been taken. The vibration reduction in both cases is compared and satisfactory results are obtained.

Key Word:Composite material, dynamic analysis, Modelling, FEA, Damping.

1. INTRODUCTION

The composite materials are used in mainly sector like aerospace, automobile and railroad sectors. Often these composite structures are subjected to severe vibrations which are undesirable in many industries. These vibrations must be minimized by appropriate designfeatures through active and/or passive damping treatments in order to improve damping property performance and reliability levels of structure and system.Passive damping treatments in composites as a result of the application of embeddedvisco-elastic materials which have greater advantages in terms of energy efficiency and reliability of machines& structures compared to active systems. Presently, there are a fewresearch works concerning noise and vibration control related to aircraft &plate and many researchers around the globe are focusing their research in the area of the dynamic analysis of the composite plate. Few of them are being focused here.

The 3-dimensional solutions for layered structures are described by Pagano (1969), however, the solutions are very difficult to obtain and cannot be given in strong form for most generalized geometry, boundary conditions and layout. Srikanth et al. (2013) have performed a static and modal analysis of composite, in which they performed analysis on 3 different materials like steel, carbon Epoxy & Glass Epoxy without & with viscoelastic material like rubber. The model of a shaft is taken and analysis using ANSYS. The structural analysis is done to verify the strength of the shaft and to compare the results for the three materials. Modal analysis is also done on the shaft to determine mode shape & find the frequency.Ravinder and Prashanti (2014) have performed an analysis on the heavy vehicle chassis without damping material and with damping material, damping material is hard rubber. The materials for heavy vehicle chassis are steel, carbon Epoxy and E – Glass Epoxy. The Static structural analysis is done to verify the strength of the heavy vehicle chassis and compare the results for three materials. We are conducting analysis with the different number of layers 3, 5,11with in the limit of same thickness. Modal analysis is also done on the heavy vehicle chassis to determine mode shapes. Design And Dynamic Analysis of Viscoelastic Structures for Propeller Shaft has been performed by Gollapudi and Raju (2013). The effect of damping on the performance of isotropic (like Steel) and orthotropic (like Carbon Epoxy & E-Glass Epoxy) structures are analyzed by using Finite Element Analysis. Damping factors, fundamental natural frequencies are increased for Steel Shaft, Carbon Epoxy Shaft and E- Glass Epoxy Shaft respectively, while embedding the rubber into the structure. The deflection value is decreased for same Shaft respectively, when rubber is embedded into the structure. The effect of damping on the performance of isotropic (steel) and orthotropic (Carbon Epoxy & E-Glass Epoxy) structures is analysed by finite element method.

In the current research, efforts have been made to analyse the plate without damping material and with damping material, with hard rubber as the damping material. The material for plate is carbon Epoxy. The free vibration structural analysis is done to verify the strength of the plate and compare the results for the material.

2.FINITE ELEMENT FORMULATION FOR THE PLATE AND SHELL ELEMENT:

2.1 Finite Element Formulation for the Plate:

The global coordinate system for the plate is as shown in the Figure 1.

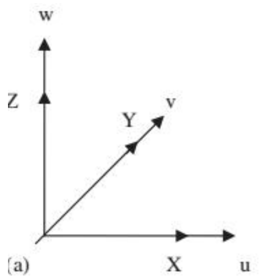

Figure 1: Global Coordinate system of plate

The displacement function (u,v,w) at appoint (x,y,z), First order shear deformation theory

$U(x, y, z, t) = u_0(x, y, t) + z\,\Theta_x(x, y, t)$

$v(x, y, z, t) = v_0(x, y, t) + z\,\Theta_y(x, y, t)$

$w(x, y, z, t) = w_0(x, y, t)$……………………..(1)

For higher order shear deformation theory having 6 degree of freedom per node is

$u(x, y, z, t) = z\Theta_x(x, y,) + z^3\overline{\Theta_x}(x, y, t)$

$v(x, y, z, t) = z\Theta_y(x, y, t) + z^3\overline{\Theta_y}(x, y, t)$

$w(x,y,z,t) = w_0(x,y,t) + z^2 w_0(x,y,t)$……….(2)

where, u_0, v_0, w_0, Θ_x, Θ_y are the mid plane displacement, whereas $\overline{\Theta_x}$ $\overline{\Theta_y}$ corresponding higher term in Taylor Expansion series Eight node iso parametric elements are used to develop the finite element analysis procedure. The degrees of freedom per node depend on the type of shear deformation theory used.The nodal coordinate system for the plate/shell element is shown in Figure 2. There are 6 degree of freedom (u_0, v_0, w_0, Θ_x, $\Theta_y \Theta z$) used when used first order shear deformation theory. The shape function of 8 nodded quadrilateral isoperimetric element, according to Cook et al. (1989). The curvilinear and local coordinate systems are described in Figure 3.

The shape functions can be expressed as

$N_i = 1/4(1+\zeta\zeta_i)(1+\eta\eta_i)$, i=1,2,3,4

$N_i = 1/2(1-\zeta^2)(1+\eta\eta_i)$, i=5,7

$N_i = 1/2(1+\zeta\zeta_i)(1-\eta^2)$, i=6,8………………………………………… (3)

So, above displacement are

$$U_0 = \sum_{i=1}^{8} (N_i u_{0i}), V_0 = \sum_{i=1}^{8} N_i v_{oi}, W_o = \sum_{i=1}^{8} N_i w_{oi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

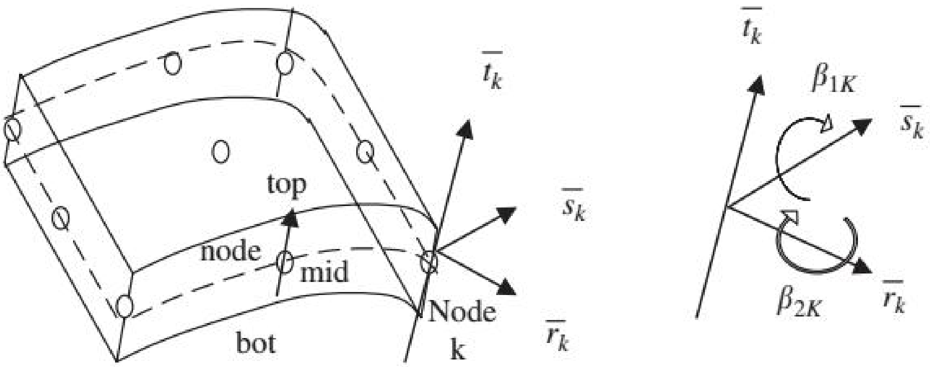

Figure 2: Nodal Coordinate system of Plate/shell Element

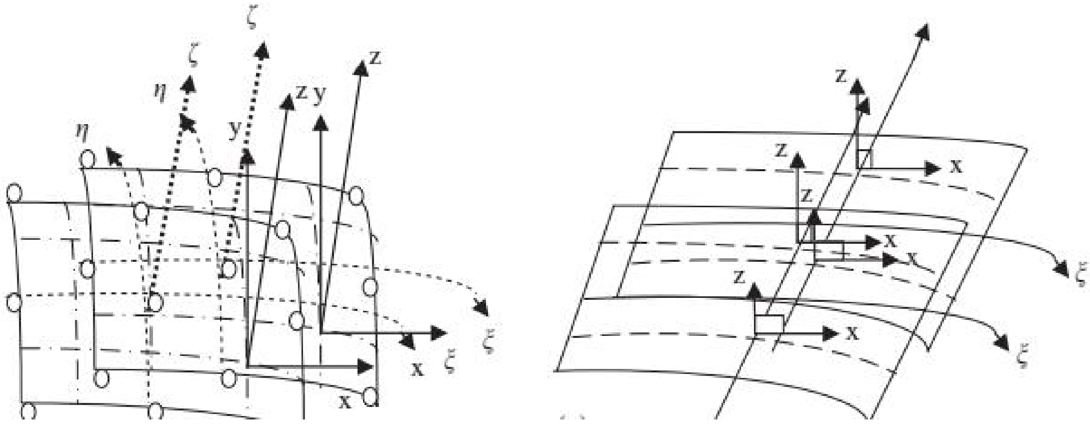

Figure 3: Curvilinear coordinate system & Local Coordinate system having η & ζ constant.

From equation (1) & (2) ,Started finite element from $\{u\} = [u, v]^T = [N]\{x\}$…(5)

Where [N]= [N1,N_2,N_3, N_4, N_5,N_6,N_7,N_8]

$[x] = [x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8]$…………………………………………………………………….(8)

In the absence of external and damping force,(undamped natural vibration) total energy of within element in lamina, $L_e = T_e - U_e$, L_e represent total energy, T_e is kinetic energy & U_e represent internal strain energy.

The dynamics equation of finite element equation become

$[M_e]\{\ddot{x}_e\} + [K_e]\{x_e\} = \{F_e\}$…………… …… (5)

Element mass matrix $[M_e] = \iint_{-\frac{h}{2}}^{\frac{h}{2}} [N]^T [\rho][N]\,(d\ \ )(d\ \ )$

$[N]^T$shape function matrix &$[\rho]$ inertia matrix.

Element stiffness matrix,$[K_e] = \int_{A_c} B^T [D][B] d$

[B]=strain displacement matrix,[D]=stress displacement matrix.

By assembling all the element mass and stiffness

Matrices with respect to the global coordinates the resulting equation is

$$[M_e]\{\ddot{x}_e\} + [K_e]\{x_e\} = \{F_e\}$$

Free vibration equation $[M_e]\{\ddot{x}_e\} + [K_e]\{x_e\} = 0$……………………..(6)

Therefore $\{\ddot{x}\}=\frac{d^2\{x\}}{dt^2}$.General solution of harmonics motion $\{x\} = \{\overset{\frown}{x}\}e^{i\iota}$ … (7)

From Equation (6) &(7),$[K] - \omega^2[M]\{\overset{\frown}{x}\}$=0………………..(8)

Solution of equation (8) yields the natural frequency ω &corresponding Eigen Vector$\{x\}$.

2.2 . Finite Element Formulation for Rectangular Element using ANSYS

For the finite element analysis of plate, using ANSYS shell 281 has been used. The element details are as shown in Figure 4.Shell 281 is suitable for analyzing thin to moderately thick shell structures. The element has eight nodes with six degrees of freedom at each node. It is well suited for linear, large rotation and large strain nonlinear application. It can also used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governd by the first order shear deformation**.**

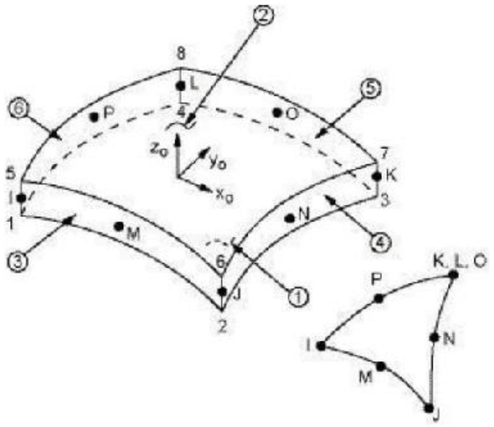

Figure 4: Shell Element 281 of ANSYS

3. FINITE ELEMENT ANALYSIS

3.1 Geometry property

The thickness of the plate has been kept smaller than1/5 of the largest dimension of plate and the thickness of test plate (embedded plate) even more reduced up to 1/10th the largest dimension of plate. The above dimensions are set keeping in view of the assumption of classical theory of bending of thin plates with small deflections. The dimensions of different viscoelastic materials are as shown in Table 1, and different material properties are as shown in Table 2.

Table 1: Dimensions of different viscoelastic materials

Materials/Dimension	**Length (m)**	**Breadth (m)**	**Thickness (m)**
Carbon Epoxy	0.01	0.01	0.001
Rubber	-	-	0.0001

Tabel 2: Properties of Carbon Epoxy &Viscoelastic Rubber

Material	**Young Modulus(N/m^2)**	**Density (kg/m^3)**	**Poisson Ratio(Y$_{12}$)**	**Shear modulus(G$_{12}$)**
Carbon Epoxy	1.31×10^{11} (longitudinal) 7×10^{9} (lateral)	1600	0.3	5.8×10^{9}
Rubber	3.1027×10^{6}	2.466	0.49	1.38×10^{11}

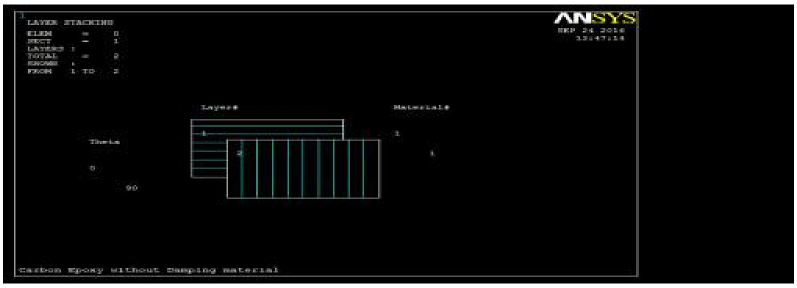

Figure 5: Stacking Sequence of Carbon Epoxy

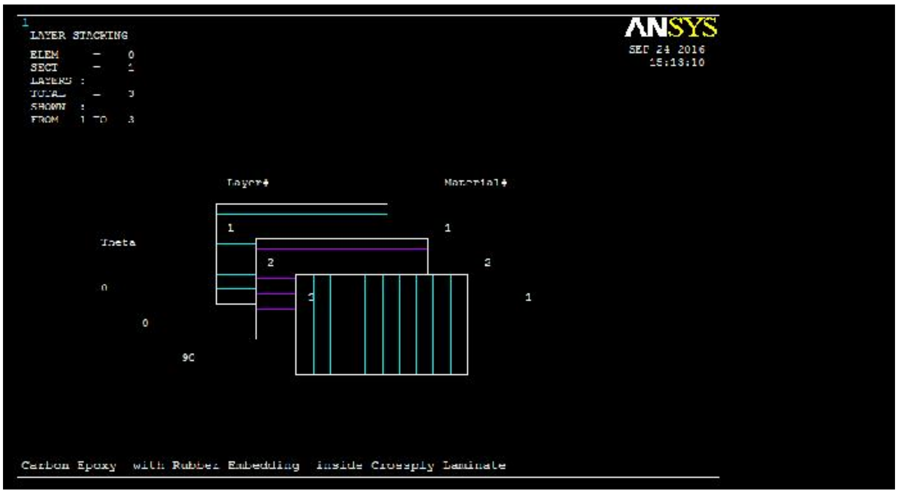

Figure 7: Carbon Epoxy with Rubber embedded inside the cross ply laminate

The staking sequence of cross ply lamina carbon epoxy lamina has been shown in Figure 5. The cross ply lamina consider in this case is with a square dimensionof 0.1×0.1. The insertion of damped material e.g., rubber between cross-ply carbon epoxy lamina is as shown in Figure 6.

4. RESULTS AND DISCUSSIONS:

Modal analysis for free vibration case has been performed on the carbon epoxy laminated plate without and with damping material rubber. The free vibration analysis, showing the first mode frequency and deformation of carbon epoxy laminated plate without damping material e.g., without rubber is as shown in Figure 7.Free vibration modal analysis frequency and deformation of using damping material in laminated carbon epoxy, layout with maximum and minimum deformation and frequency, has been shown in Figure 8.

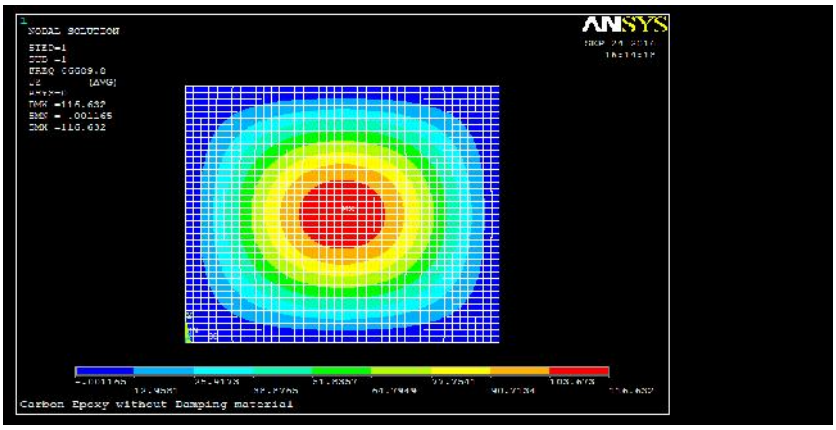

Figure 7: Frequency &deflection Carbon Epoxy Material without Rubber

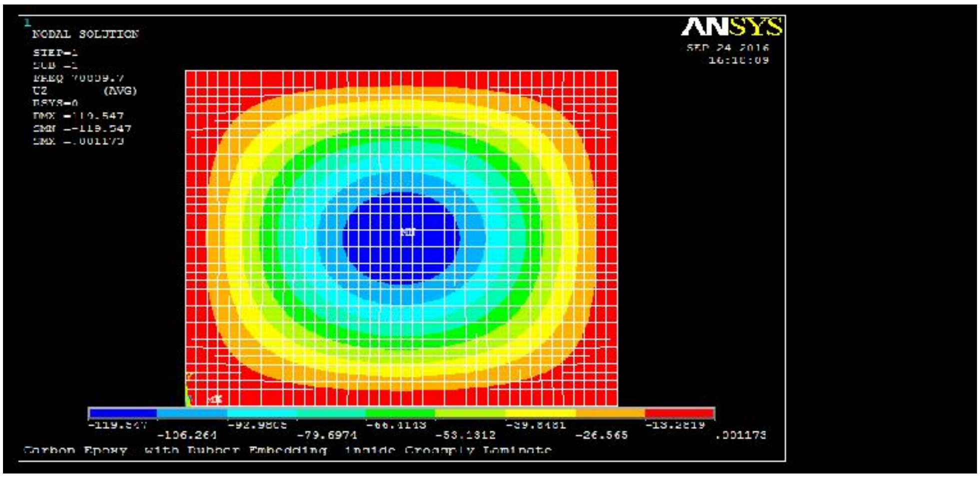

Figure 8:Frequency and deflection Carbon Epoxy with Rubber embedded inside the cross ply laminate

A comparison on the properties of carbon expoxy laminated plate without and with damped material is as shown in Table 3.

Table 3: Comparative analysis (in %) of various parameters of composite plate (without and with damping)

Parameters	Carbon Epoxy Laminated Plate without damped material	Carbon Epoxy Laminated Plate with damped material (rubber)	% of increase/decrease
Deflection (mm)	0.116	0.111	4% decrease
Frequency (kHz)	66.6	70	5% increase
Stress (kN/mm^2)	100	109	9 % increase

5. CONCLUSION:

Finite element analysis of laminated composite plate using without damping material and with damping material, has been performed. Carbon Epoxy has been chosen as the composite material of the plate, due to its high strength to weight ratio.For damping is rubber material has been taken. Structural analysis has been performed to verify the stress of the composite laminated plate, first without any damping material. In the subsequent analysis, damping material (rubber) has been embedded inside the plate and the stress has been calculated.A 9% increase was observed in stress while using the composite plate with damped material. Further modal analysis has been performed on both the cases (without and with damping material embedded inside the laminated composite plate), and the related frequency and deformation are obtained. There was a decrease of 4% in deformation and increase of 5%, observed while using the damping material. The increase in frequency is due increase in flexural stiffness of the laminated composite plate. So it is strongly felt by the authors that the damping material may be introduced, in addition to the composite material in structures like, railway bridge, and in other structures, which will minimize the deterioration of the structures over the years.

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