Modal Analysis of Thin Composite GLARE Plate

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Abstract: The modal analysis of thin composite GLARE (Glass Laminate Aluminum Reinforced Epoxy) plate is carried out to find natural frequencies and own mode shapes. For the modal analysis, a rectangular plate with dimensions 450 × 300 mm is fixed over the circumference. ABAQUS software is used to carry out a theoretical analysis of GLARE plate with a cross-ply (0/90) orientation. The first five natural frequencies and first five-mode shapes of the plate deflection are compared with the available experimental ones. These mode shapes and natural frequencies will be the basis for the manufacturing of composite GLARE plate in order to delay resonance.

Index Terms – thin composite GLARE plate, ABAQUS Software, FEA analysis.

I. INTRODUCTION

In the field of aerospace and mechanical, composite material and its hybrid versions have been subjects of permanent interest. After second world war, use of hybrid composite material got initiated in the aerospace industries. The research and innovation in the field of composites and its hybrid versions have achieved reduced weight in structural design, high stiffness to weight ratio. Compared to metal alloys, composite offers many advantages like high stiffness, fire resistance and moisture resistance. In real life application other two main achievement of composite are its better fatigue resistance and corrosion resistance. With all these advantages, composite structures have gained widespread application in the aerospace industries as well as mechanical industries. [1]

Along with that, the mostly used structural component in the field of aerospace as well as in mechanical is plate, because the plates can achieve high strength-to-weight ratio and they are subjected to high dynamic loads. [2] The material used is GLARE which is a fiber metal laminate (FML) composed of several very thin layers of metal (usually aluminum) interspersed with layers of glass-fiber pre-preg, bonded together with a matrix such as epoxy.

Fiber metal laminates have advantages of both metal and fiber-reinforced composites, like superior mechanical properties to the conventional lamina consisting only of fiber-reinforced lamina or isotropic aluminum alloys. FML provides high fatigue resistance which is achieved by intact bridging fibers in the wake of crack, so it restrains crack opening. Combination of metal alloys having high bearing strength and fiber reinforced composites having high strength and stiffness gives high strength to it. It also provides high fracture toughness than their constituent alloys. They are capable of absorbing high energy through localized fiber fracture and shear failure in the metal plies. Owing to epoxy based polymer matrix and low density aluminum sheets, they are a weight saving structural material compared to others. They also provide excellent moisture and corrosion resistance. [3]

Modal analysis of oscillating systems determines mode shapes and natural frequencies. These values can be determined by the simulation or experiment. The mode shapes and the natural frequencies are used to investigate the vibration of mechanical structures, to diagnose architectural and engineering constructions. It is one of the basic dynamics methods. The principle of modal analysis is based on the possibility of decomposition of oscillatory motion for partial parts. The resulting motion is created by superposing of these parts. Each part of the oscillating movement is characterized by its own frequency and the corresponding damping mode shape. A complete description of the dynamic mechanical system is obtained by determining the modal properties of the resulting parts.

II. THEORY BACKGROUND AND SOLUTION METHOD

The aim of the modal analysis is to find the natural frequencies and mode shapes of the system (parts). Modal, harmonic analysis is one of the dynamic analyzes, at solutions we are considering the inertia of the system. A mechanical system with one degree of freedom is presented in Figure 1.[4]

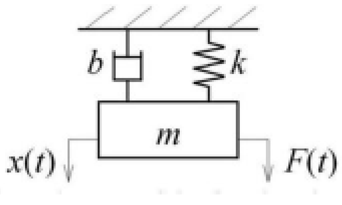


Figure 1: Schematic of the system with one degree of freedom

This system is characterized by its own mass m, stiffness k, damping b and excitation force F(t). The equation of motion of the system on figure 1 can be written as:

$$m\ddot{x}(t) + b\dot{x}(t) + kx(t) = F(t) \quad (1)$$

Where, x – deflection [m], $\dot{x}$ – speed [m/s], $\ddot{x}$ – acceleration [m/s^2], F – excitation force [N]

If we neglect the damping the equation (1) changes to form

$$m\ddot{x}(t) + kx(t) = F(t) \quad (2)$$

For solving the above mentioned differential equations motion we introduce a boundary conditions $x(0) = x_0$; $\dot{x}(0) = \dot{x}_0$; F(t) = 0. The equation (2) will have the form

$$m\ddot{x}(t) + \Omega^2 x(t) = 0 \quad (3)$$

Where, $\Omega^2 = k/m$

Solution of equation (3) is in the form

$$x(t) = A\sin(\Omega t + \phi) \tag{4}$$

Where, A – amplitude (m),Ω– own angular frequency (rad/s), ϕ – phase angle (rad)

The equation (5) is oscillation amplitude and the equation (6) is phase angle

$$A = \sqrt{\left(\frac{\dot{x}_0}{\Omega}\right)^2 + {x_0}^2} \tag{5}$$

$$\& \quad \tan\phi = \frac{x_0\Omega}{\dot{x}_0} \tag{6}$$

The system oscillates with angular frequency Ω. This angular frequency is called the natural frequency of the system. Each natural frequency of the system corresponds to one's own mode shape. Equation (3) can be written in matrix form,

$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = 0 \tag{7}$$

Where, **M** – mass matrix (kg), **K** – stiffness matrix (N/m), **x**(t) – displacement vector (m), $\ddot{\mathbf{x}}$(t) – vector of acceleration (m/s^2)

Displacement and acceleration is given by equation (8) and (9),

$$\mathbf{x}(t) = \boldsymbol{y}e^{i\omega t} \tag{8}$$

$$\& \quad \ddot{\mathbf{x}}(t) = -\Omega^2\boldsymbol{y}e^{i\omega t} \tag{9}$$

Where, *y* – eigenvector of system

Substituting (8) and (9) into the equations of motion in the matrix form (7) and after mathematical treatment, we get

$$(-\Omega^2\mathbf{My} + \mathbf{Ky})e^{i\omega t} = 0 \tag{10}$$

After modifying the equation (10) and substituting $\Omega^2 = \lambda$, we get

$$(\mathbf{K} - \lambda\mathbf{M})y = 0 \tag{11}$$

generalized eigenvalue problem.

Natural frequencies of the system - λ will be determined for a nontrivial solution of the system. Each eigenvalue λ have their own vector y. The seeking natural frequencies must meet the equation

$$det \mid \mathbf{K} - \lambda\mathbf{M} \mid = 0 \tag{12}$$

III. Analysis of Composite GLARE Plate

A] Pre-processing: In this stage, the model of the physical problem with composite plate dimensions 450 mm × 300 mm is created. This model is created graphically using ABAQUS/CAE. The graphical model is developed with the help of 3D deformable planner shell. The. The staking sequence and lay-up configuration of plate is shown below.

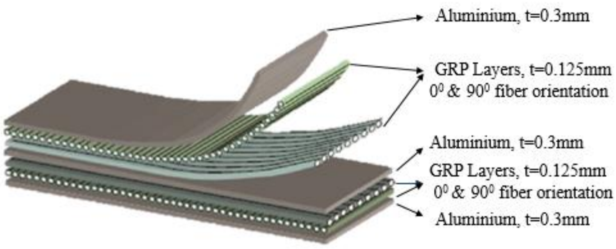


Figure 2: Composite laminated layup

The material properties of aluminum and glass fiber composite used for analysis are shown below.

- Aluminum

Young's modulus = 72.39 GPa., Poisson's ratio = 0.33, Density = 2700 Kg/m3, Thickness = 0.3 mm.

- Glass fibre composite

E_1 = 24.4 GPa., $E_2 = E_3$ = 4.73 GPa., $G_{12} = G_{23} = G_{13}$ = 1.68 GPa., $\nu_{12} = 0.098$, $\nu_{23} = \nu_{13} = 0.0575$, Density = 2000 Kg/m^3, Thickness = 0.5 mm.

After specifying material properties, boundary conditions are applied by clamping all sides of plate and meshing is done. For meshing quad elements in a number of 33750 elements were used because of the shell shape structure. The element size is taken as 2 mm × 2 mm as solution converges at that size.

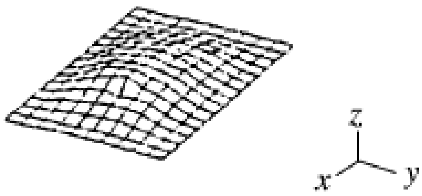
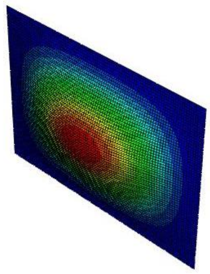
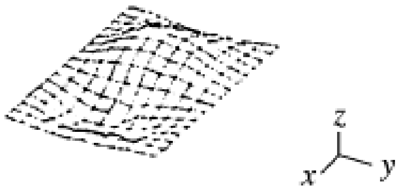
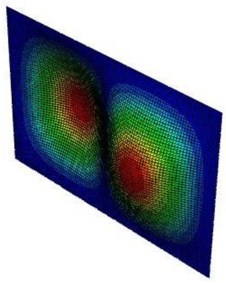
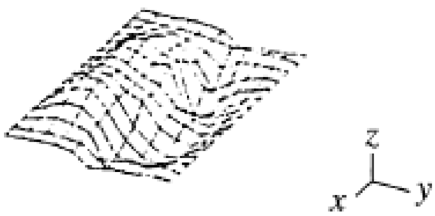
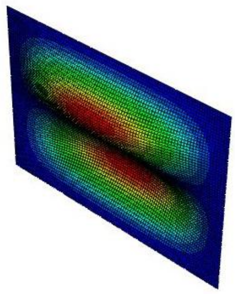
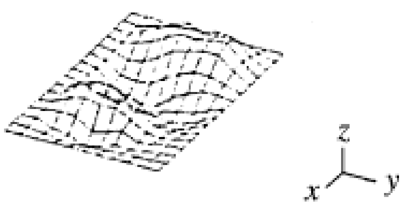
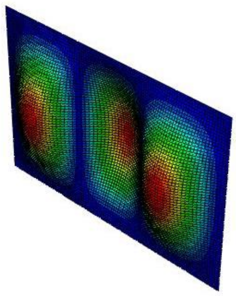
B] Simulation: The simulation, which normally is run as a background process, is the stage in which ABAQUS/Standard solves the numerical problem defined in the model. Depending on the complexity of this problem being analysed and the power of the computer being used, it takes a day to complete an analysis. The output from a modal analysis include natural frequencies, mode shapes and local displacements that are stored in binary files for post-processing. [5]

C] Post-processing: We evaluate the results once the simulation is completed and the natural frequencies, mode shapes and displacements have been calculated. The evaluation is generally done interactively using the Visualization module of ABAQUS/CAE. The Visualization module, which reads the neutral binary output database file, has a variety of options for displaying the results, including colour contour plots, animations, deformed shape plots, and X–Y plots. Here results of mode shapes are represented by deformed shape plots. [5]

IV. Results and discussion

The mode shapes obtained from ABAQUS simulation are compared with experimental mode shapes from Harras et. al. [1] as tabulated below.

Table 1: Comparison of Experimental and Theoretical mode shapes

Mode No.	Experimental	Theoretical
1		
2		
3		
4		

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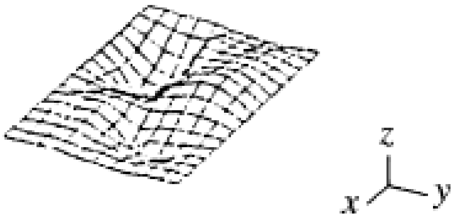

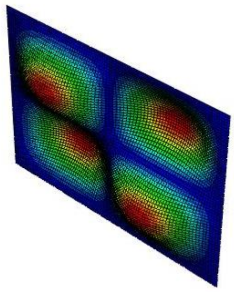

From the comparison, we clearly see that all the mode shapes obtained from ABAQUS simulation are exactly matches with experimental mode shapes from Harras et al. [1].

Now we compare corresponding natural frequencies.

Table 2: Comparison of natural frequencies (Hz)

Mode Number	Experimental	Theoretical
1	93.50	104.56
2	153	161.11
3	245	256.56
4	253	257.33
5	298	308.34

From the comparison, we see that the results of simulation show 2% to 10% deviation from experimental results.

V. Conclusion

In this paper, the modal response of rectangular thin composite GLARE plate was studied. Plate thickness, boundary conditions and fiber orientations, which affects the modal response of the plate was considered.

- The ABAQUS software is used to find natural frequencies and mode shapes. The results obtained are compared with available experimental results and they show 2% to 10% deviation from experimental results.
- By using (0/90) cross ply orientation, the stiffness of plate increases. Also, by increasing thickness of layers, the stiffness increases. So by varying thickness and cross ply orientation, stiffness can be varied which varies the natural frequencies of plate.
- This study helps designers to design GLARE plate in order to delay resonance by increasing natural frequencies, depending on the applications. Also, this will be helpful for finding optimum thickness and optimum orientation of fiber direction, to get desired mode shapes.

Reference

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