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Vibration Analysis and Damping Characteristics of Laminated Composite with Cut-Out

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Abstract- Advantages of fibrous composites and lamination are combined in laminated fiber-strengthened composites. Fiber-reinforced materials are used in the construction of each layer. The fibers in each lamina are laid out differently to impart different qualities and levels of stiffness. So, the most favored perspective with fibre reinforced composite materials is that, the with right lamination processes, quality and rigid solidity may be achieved in a specific direction as per the needs of the design. In this paper FEM analysis of laminated composite plate has been done.

Keywords- FEM analysis, laminated fiber-strengthened composites, fibre reinforced composite materials.

I. INTRODUCTION

The integrating at least two separate components, composite materials produce a collection of materials. The purpose is to produce superior mechanical properties, such as erosion resistance, high temperature resistance, heat conductivity, stiffness, lightweight, and aesthetics. The fibre and the framework (material that surrounds the filaments) must be superbly coupled for the material to function as a complete (Classical Lamination Theory-CLT).

Lamination is a method of integrating the best features of constituent layers and binding them together to provide a more valued result. Covers, like a variety of other constructions, can have openings to meet a variety of requirements. The existence of a bolt is an undeniable justification for its existence. Mechanical qualities of each layer are supplied in two methods, taking into account two distinct materials: strengthening bars (filaments) and encompassing materials (grid material).

Advantages of fibrous composites and lamination are combined in laminated fiber-strengthened composites. Fiber-reinforced materials are used in the construction of each layer. The fibers in each lamina are laid out differently to impart different qualities and levels of stiffness. So, the most favored perspective with fibre reinforced composite materials is that, the with right lamination processes, quality and rigid solidity may be achieved in a specific direction as per the needs of the design.

Plates are flat surfaces with varying sizes and thin thickness. When subjected to loads, they can bend in a transverse direction. These plates can be connected mathematically using straight or curved lines. The boundary conditions for plates can be free, simply supported, or fixed. The forces acting on plates are usually perpendicular to their surface, both in static and dynamic situations. Plates have similar load-bearing capacity as bars or links.

Complete plate enclosure without additional covering is necessary for many constructions including ships and containers, which results in significant material and labour savings.

II. COMPOSITE MATERIALS

A composite material is one that contains constituents derived from more than one starting material. There are several desirable properties, including mechanical strength, corrosion resistance, high temperature resistance, heat conductivity, stiffness, light weight, and beauty. According to the Classical Lamination Theory (CLT), a material's performance depends on the integrity of the connections between its constituent parts, the fibres and the matrix.

Lamination is a method for improving the performance of a material by maximising the advantages of its component layers and bonding materials. Like many other kinds of structures, laminates may have holes in them. One obvious function is to hold a bolt. Reinforcing bars (fibres) and surrounding materials are used to deliver the mechanical properties of each layer in two directions (matrix material).

In its original incarnation, yoga is meant to assist in spiritual growth. Yoga's function in health promotion and illness prevention and treatment has become increasingly well-known. While a physical postures, controlled breathing, and guided relaxation are all part of the yoga practice, the focus will be on the underlying concepts, which are globally relevant and directly benefit mental health. Composite constructions often include various types of holes to facilitate assembly, accommodate components and units, pass cables, allow for inspection and maintenance, and enable attachment to other parts. However, the presence of these cut-outs leads to the development of gradient stresses and deformations in their surrounding areas. Additionally, the thickness parameter inherently influences the higher vibration modes.

Laminated composite plates are widely utilized in various industries due to their advantageous characteristics, such as lightweight, high specific strength, and stiffness. They find extensive applications in aircraft and spacecraft, civil engineering structures like water storage facilities, marine vehicles like ships, and even nuclear power plants. One notable example of their usage is in the construction of aircraft wing structures. Skew laminated composite plates are just one among many modern applications of these plates. Weight reduction and easier assembly are two of the most common reasons for using cutouts in designs. They must additionally pass a damage examination, as well as have enough ventilation, electrical, or fuel lines. Dynamic component behavior must be studied by structural engineers.

Layers of fibre composite materials are bonded together to form composite laminates, which boast desirable technical properties like stiffness (in both planes), strength, thermal expansion coefficient, and bending stiffness. Aerospace, maritime vehicles, automotive, chemical, and nuclear engineering are just few of the many areas that are finding widespread use for laminated composite structures. There are several uses for cutouts in construction: assembling components, providing ventilation and weight savings for the structure while allowing access to other parts of the design, inspecting damage and running fuel and electrical lines through a building.

Liquid holding structures on the bottom plate necessitate its presence. Plate constructions with cutouts can have a significant impact on the reaction to undesirable vibrations and other factors during their service lifetimes, which are well recognized. The cutaway plates have a lower total weight, which has an effect on the vibration response. Since laminated composite constructions with cutouts are prone to vibration, more study is needed.

III. MODAL ANALYSIS

Modal analysis is a method used in structural design for identifying vibrational characteristics like natural frequencies and mode shapes. A spectrum analysis, harmonic response analysis, or transient dynamic analysis could be used as a jumping off point. Knowing the geometry, mass distribution, stiffness, and boundary conditions of a structure allows one to deduce its dynamic behaviour, which is represented by a frequency spectrum with an infinite number of natural frequencies and mode forms. In general, a linear dynamic system's equation of motion is

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\} = \{F(t)\} \quad \textbf{equation (1)}$$

Where, [M] = mass matrix, [C] = damping matrix, [K] = stiffness matrix, {F(t)} = time varying load Vector, $\ddot{u}$ = nodal acceleration vector, $\dot{u}$ = nodal velocity vector and u = nodal displacement Vector. For free vibration the equation (1) becomes

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\} = 0 \quad \textbf{equation (2)}$$

Linear structures that are not damped will continue to oscillate endlessly with the same mode shape but varying amplitudes once they are shaped. Natural frequencies are the suitable frequencies, while mode shapes are the oscillation forms.

The equation (2) is reduced to for undamped linear structures:

$$[M]\{\ddot{u}\}+[K]\{u\} = 0 \quad \textbf{equation (3)}$$

The structure is considered to vibrate freely in a harmonic form specified by when no external loads are applied:

U(t) = ϕsin(ωt+θ) equation (4)

IV. LITERATURE SURVEY

Vishnuchaitanya et. al. (2017) It was looked at what it would mean for the hole area ratio and the length to height ratio to change for various hole shapes. The purpose of this study is to locate the optimum location for the hole. ANSYS software is used to analyse the plates under a number of different boundary conditions and lamination orientations. The investigation used a Shell99 cluster with eight nodes. Both the CFFF and CFCF boundary conditions are taken into account, along with length to height ratios of 50 and 200. The ratio of hole area to total area is held steady at 0.04 throughout the trial. There are two separate levels of cover: four and eight, each with six different orientations. At greater vibration methods, the impact of the thickness parameter is unavoidable. In this study, he considers the dynamic behaviour of several overlays with various holes.

Alshammari and Kassab (2016) examined experimentally and computationally the free vibration of a composite skew plate. The ANSYS software is used to numerically determine the free vibration properties. There is also a correlation between these analyses. We spoke about how the free vibration properties of isotropic skew plates change depending on the skew point, the thickness of the plate, the shape of the focal gap, and the ratio of the gap zone to the plate territory. There are substantial connections between the test and numerical outcomes, as evidenced by the similarities in the data. Generally, the characteristic frequencies rise as the skew point rises, while the normal frequencies rise with plate thickness and fall with opening territory. Three states of openings (round, square, and triangular) were considered; the regular recurrence provides the best incentive for the roundabout gap, while the base provides the best reward for the triangular gap.

Helloty (2016) "studied the free vibration reaction of hardened coated composite plates at typical frequencies and mode shapes, accounting for the effects of stiffener arrangement, layer count, and limit conditions." There are six kinds of rectangular stiffener arrangements used, and two types of limit conditions are considered: just and clipped upheld. Using the restricted component framework ANSYS16, we conduct in-depth analyses of the effects of stiffener arrangement, layer count, and boundary conditions on the free vibration reaction of solidified covered composite plates.

The free vibration of skew laminated composite plates with circular cut-out was studied by Vivek (2016) using ANSYS and the finite element method in accordance with the first order shear deformation theory. The simulations made use of eight-noded isoperimetric shell elements. Equally effective are the use of supported and clamped boundary conditions for the same. The outcomes were presented in conjunction with composite plates containing circular cutouts inclined at 15 degrees and 30 degrees.

Reddy et al. (2016) investigated the vibration properties of jute cloth reinforced hybrid polymer matrix composites. A polymer resin containing 15% CNSL and 15% polyester resin is used to strengthen these fibres. An experimental trial was performed to learn the mode shape, damping, and natural frequency. A controlled experimental setup was employed to validate the calculated natural frequency of a composite material composed of a jute fabric and polymer matrix. An ANSYS model was utilized for this purpose.

Pingulkar and Suresha (2016) Considered are 8-ply cantilevered plates with a 2-to-1 plate aspect ratio and a volume fraction of fibres in the range from 0.3 to 0.6. We use literature data to verify our calculations of the natural frequencies and mode shapes. They found out that they shared many interests and values. The study also looked at how the natural frequencies and mode shapes were affected by various matrix compositions, hybridization processes, and laminate stacking sequences. It was discovered that differences in the matrix material and the fibre volume percentage affect the natural frequencies of laminated composite plates. In addition, the outermost layer's orientation and hybridization were found to have a considerable impact on the natural frequencies.

Beena and Aiswarya (2015) investigated the dynamic performance of laminated composite plates with and without cut-outs, as well as the effects on plate free vibration. The numerical data is displayed and explained. The plates are analysed using the ANSYS programme.

Maithry and Rao (2015) The dynamic response of laminated composite plates subjected to time-varying excitations was investigated. Multiple laminated plates with fixed edges and holes placed at different positions were examined, while maintaining consistent length/height ratios and hole area ratios. The plates were modeled and analyzed for their dynamic behavior using the ANSYS 13.0 software. Ultimately, based on various response metrics, recommendations were made regarding the optimal fiber orientation for the laminated plates.

Kumar et al. (2015) examined Glass/Epoxy composite plate free vibration. Plates made of woven glass fibre and epoxy matrix are composite materials that require a hand-layup procedure to create. Instron 1195 tensile testing was utilised to document the plate's elastic properties. A Fast Fourier Transform Analyzer, PULSE lab shop, impact hammer, and contact accelerometer were used in experimental research of the modal analysis technique to obtain the results of Frequency Response Functions. First-order shear deformation theory and finite element analysis both corroborated the findings. The effects of different geometrical parameters on woven fibre composite plates are studied using free-free type boundary conditions. These parameters include the number of layers, aspect ratio, and fibre orientation. Finally, they offer useful information for academics and engineers that are working on design applications based on this research.

Bhardwaj et al. (2015) The ANSYS APDL code was employed to validate and establish the first order shear deformation theory. The SHELL 281 element was utilized by generating a mesh for the model. The natural frequency was computed using the Block-Lanczos technique. Through iterations, the obtained results were compared with literature data.

Patil et al. (2014) reported a vibration analysis of a composite plate that took into account various boundary conditions. Plates are normally subjected to a variety of stress conditions that generate transverse displacement. The findings are then displayed to demonstrate the importance of the problem being applied to several plates in order to confirm free vibration conditions. As a result, 3 ply laminates were considered, and the findings were compared to those of an isotropic plate.

kushwaha and Vimal (2014) In our study, we employed a finite element model to thoroughly analyse the vibrational properties of laminated composite ratio plates. We investigated how the number of layers, plate thickness ratio, boundary conditions, aspect ratio, and fibre orientation in laminated composite plates could affect these properties. We looked at the effects of several thickness ratios (h/b=0.001, 0.01, 0.05, 0.1, and 0.2) and aspect ratios (a/b=1, 1.5, 2, and 2.5) on rectangular plates. The subject of free vibration analysis for composite square plates with varied numbers of lamina layers—3, 5, 7, and 9—was also investigated, taking both cross- and angle-ply arrangements into account. The frequency of vibration increases as the number of layers and fibre orientation angle increase, but reduces as the size ratio and thickness to width ratio grow. Under certain boundary circumstances, natural frequencies and mode shapes are connected. The study compares composite laminated plates that are thin and thick.

According to **Kalita et al. (2013),** the principal stresses were reduced by placing symmetric auxiliary holes around the core square cutout in an orthotropic plate. They decided to look into the possibility that small auxiliary holes could simply remove a little bit of material from the orthotropic plate. Using a parametric method, we investigated how the separation of auxiliary holes from the core cutout affected the effectiveness of stress mitigation. However, FEM ANSYS is used due to the complexity of such a scenario. Orthotropic plates having all-edge fixed-type boundary conditions have their findings graphically represented.

V. RESEARCH METHODOLOGY

In the current analysis, the laminate dimensions considered are "l" and "b," both measuring 500 mm. The length of the minor axis is designated as "d" and is equal to 100 mm. Furthermore, the major axis of the ellipse is taken to be twice the length of the minor axis.

1. Material Properties:

Applications in civil, marine, aeronautical, and mechanical engineering are really just a few of the many places that may find composite materials in use. This widespread the using composites indicate a promising future for the economy. Graphite and epoxy were employed in its construction. Table 1 illustrates the material properties of graphite-epoxy.

Table 1. Material properties of graphite-epoxy.

Material Constant	Ex	Ey	Ez	Gxy	Gyz	Gxz	υxy	υyz	υxz	ρ
Values	172.72 GPa	6.909 GPa	6.909 GPa	3.45 GPa	3.45 GPa	1.38 GPa	0.25	0.25	0.25	1500 Kg/m3

2. Modal Analysis:

ANSYS's modal analysis is a linear analysis technique commonly used in engineering. Various methods can be employed for mode extraction, including Block Lanczos, Supernode, PCG Lanczos, reduced, unsymmetric, damped, and QR damped methods. In the present research, the Lanczos Block method is utilized to tackle problems involving symmetric eigenvalues and a large number of eigenvalues. Fig 1 illustrates the layout of modeling procedure through flow chart.

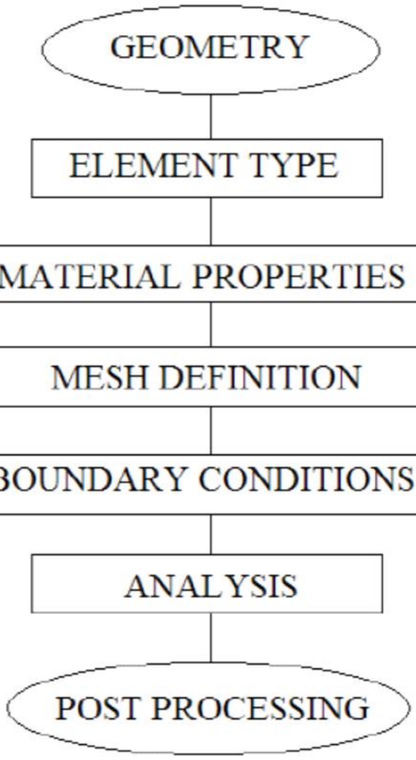

Fig 1. Layout of modeling procedure.

3. Modeling Of Square Laminate Plate:

The modeling of plate is accomplished by the use of ANSYS under ACP design modeller. The model of plate was created based on the size. Fig 4.4 depicts the square laminate plate in design modeller.

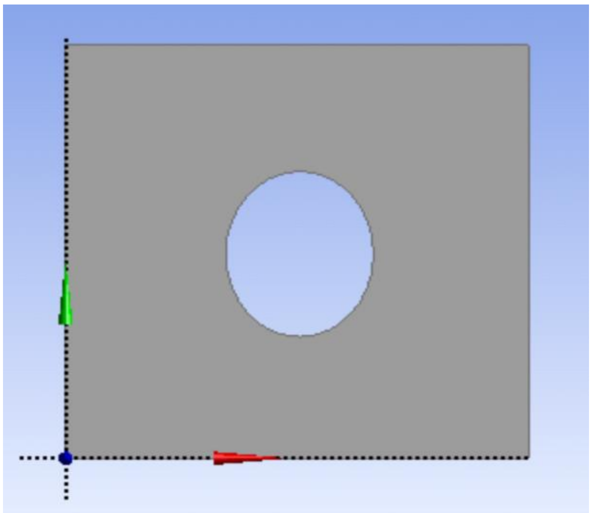

Fig 2. Square laminate plate in design modeler.

Ansys-Analysis of Systems workbench software helps us to combine or integrate data across engineering simulation for creating more precise models. Ansys Workbench organizes all of your simulation data in one location, making it simpler to make more informed design decisions. Data management across all of your Ansys products is simple. Fig 3 illustrates the ACP pre post model analysis workbench.

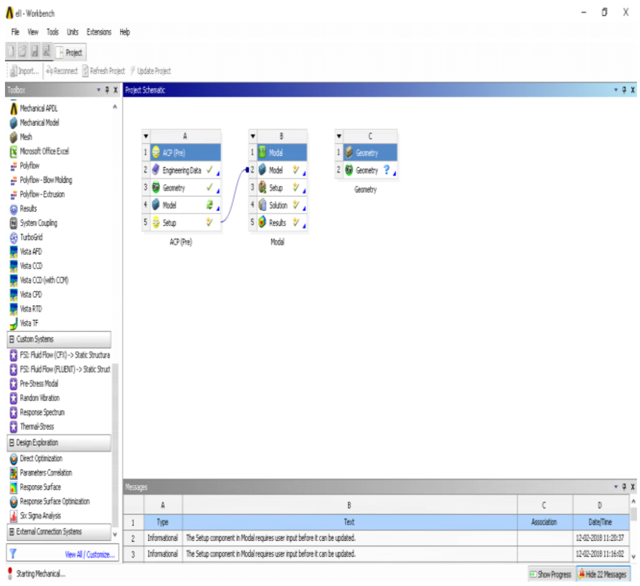

Fig 3. ACP pre post with model analysis.

VI. RESULTS AND DISCUSSION

1. Effect of Boundary Conditions:

The natural frequency of vibration for the CCCC plate is maximum, while it is lowest for the CFFF plate, as shown in table 5.1. FCFC plates have values that are in the middle. The fluctuation in natural frequencies with boundary conditions is depicted in figure 5.5.

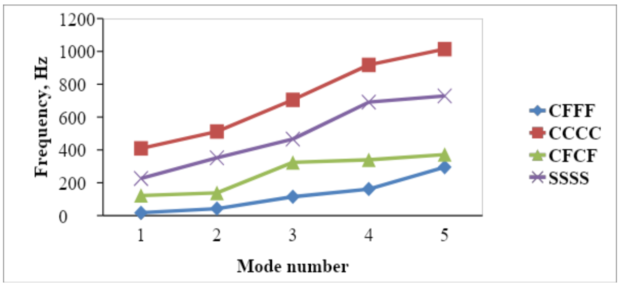

Fig 4. Variation in natural frequencies (Hz) for different boundary conditions.

2. Effect of Fiber Orientation:

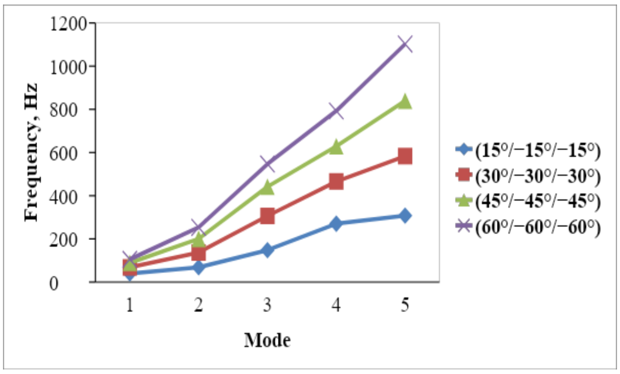

Fig 5. Variation in natural frequencies (Hz) for CFFF square cross ply plate with varying fiber orientation.

VII. CONCLUSION

The cut-out plate is found to be responsive to imposed boundary conditions. It can be seen that the CCCC plate has the highest natural frequency of vibration, while the CFFF plate has the lowest. FCFC plates display a range of values. Orientation of fibers are ranged from (15°/15°/15°/15°) to (60°/60°/60°/60°). It was found that the fundamental frequencies of fibers increased with increasing fibre orientation angle.

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