Effect of Cut-out Shape on Free Vibration of Glass Fiber Epoxy Composite Plates

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***Abstract*—Composite laminates posse's outstanding mechanical property like high stiffness with light weight. Because of such property industry now a day is also encourages the use of composites over other conventional materials for structural purposes. Keeping that in mind, it is utmost important to determine the static and vibrational characteristics of composite plates. Composite plates used as structural elements are generally subjected to various shapes, sizes and design of cut-outs. This paper will give emphasis on combined experimental and numerical study of free vibration of glass fibre epoxy composite plates. Composites plates having circular, rectangular, Triangular and mainly elliptical cut-outs with same cross-section area were manufactured. To analyse effect of cut-out area, same plates with reduced cut-out area were also prepared. In next step natural frequencies and mode shapes for each of these plates were find out for various boundary conditions using Finite element analysis. Result of analysis will clearly indicate which shape of cut-out is more feasible and safe in application point of view. It is found that, cut-out area doesn't make any difference in effect of cut-out shape.**

***Index Terms*—Composite Laminates, Cut-outs, Free vibration analysis.**

I. INTRODUCTION

COMPOSITE materials have properties like high specific strength and stiffness also their flexible anisotropic property can be tailored as per the requirements of applications. Thus, they have found a variety of applications in many engineering fields, such as in aerospace, automobile etc. An important parameter in the dynamic analysis of composite plates is the determination of their natural frequencies and mode shapes. This is important because composite plates generally operate in complex environmental conditions and are frequently subjected to a variety of dynamic excitations.Cut out is an integral part of almost every structural element including laminated composite plates. Cutouts are necessary for assembling the components, damage inspection, access ports, electrical and fuel lines, opening in a structure, provide ventilation and to reduce weight. These structures are exposed to the undesirable vibration, extra amount of deflection during their service life and again these plate structures having cutout may change the responses considerably. The plates having the cutouts reduce the total weight which in turn affects the vibration response. Similarly it also reduces the total stiffness and the bending behavior changes automatically.

Cut-outs in structural members like plates tend to change its dynamic characteristics to some extent. This change is obvious whenever the structure is exposed to large vibrations. Many a times these cut-outs may lead to failure under lower stress and also sometimes due to undesired resonance. So it is utmost necessary to predict the resonant frequencies of these structures with cut-outs. The extensive range of practical applications of cut-outs in plates requires a better understanding of the vibrations and stability properties of laminated plates with cut-outs. S. B. Singh and Himanshu Chawla [2] studied dynamic characteristics of glass fiber reinforced polymer laminates with cutouts. It is an experimental investigation of the effect of cutouts on the natural frequency and damping of the plate. Conclusion drawn from this study is natural frequency decreases while damping coefficient increases with increase in the size of cutout.

An experimental and finite element study on free vibration of skew plates was done, by C. V. Srinivasa et al. [3]. The natural frequencies were determined using NASTRAN software and comparison made between the experimental values and the finite element solution. The natural frequencies generally increase with an increase in the skew angle for any given value of aspect ratio. Ronald F. Gibson [4] has studied the use of modal vibration response measurements to characterize, the mechanical properties of fiber-reinforced composite materials and structures. It is shown that modal testing in either a single mode or multiple modes of vibration can be used to determine elastic moduli and damping factors of composites and their constituents under various environmental conditions.

M. Ganapathi et al. [5], presented paper in which the free vibrations characteristics of simply supported anisotropic composite laminates are investigated using analytical approach. Rizal Zahari et al. [6] performed an experimental investigation to determine the tensile behavior and failure modes of unbalanced woven C-glass-epoxy composites laminated panels. From study, it was discovered that cross ply laminates had the highest ultimate load and that increasing the cut-out size reduced the ultimate load of the panels. Hakim S. Sultan Aljibori et al. [7] presented an experimental study of the behavior of woven glass fiber/epoxy composite laminated panels under compression. It has been observed that cross-ply laminates possess the greatest ultimate load as compared to other types of ply stacking sequences and orientations.

In present work, composite laminate of Glass-fiber and Epoxy is manufactured. This plate is then cut using water-jet technique to desired dimensions. Further, Material properties are found out by tensile testing. These properties are used in Ansys for numerical analysis. Modal analysis of composite plates with and without cut-out is carried out for two boundary conditions. Results obtained are promising and are explained below.

II. Manufacturing and Cutting of Composite Plate

A. Manufacturing of Composite Plate

A key ingredient in the successful production application of a material or a component is a cost-effective and reliable manufacturing method. Cost effectiveness depends largely on the rate of production, and reliability requires a uniform quality from part to part. Hand lay-up and Spray lay-up are the two most simple and oldest techniques for composite fabrication. Among the two Hand lay-up is the most labour specific and the crude method. To manufacture composite plate, materials used were E-glass woven roving as reinforcement, Epoxy as resin, Hardener as catalyst, polyvinyl alcohol as a releasing agent. Fig.1 shows single layer of Woven Glass-fibre. Woven roving Glass-Fibre sheet of 120gsm was provided by Owens Corning. Epoxy XR-125 and hardener K-6 was provided by Atul Limited, Mumbai.

Fig. 1.Woven roving glass fiber sheet

Many a time a mould is also used in hand lay-up method. It is generally used whenever the composite is not directly joined with the structure. Moulds come in various shape, sizes starting from a flat sheet to having infinite curves and corners. Before fabrication the mould is first prepared with the application of releasing agent so that after hardening the composite does not sticks to the mould. Then reinforcements are cut and laid in the mould as per requirements. Then resin is catalysed and added to the fibre. A brush or roller is used to perfectly compact the layers and squeeze out excess resin. Hand lay-up process is further modified to compressive moulding process. This method is widely used in industries.

B. Fabrication Process

The glass fibre roll is cut into squares of 30 cm x 30 cm. Then according to the number of layers of composite plate to be made, that many number of fibre sheets are to be weighed.

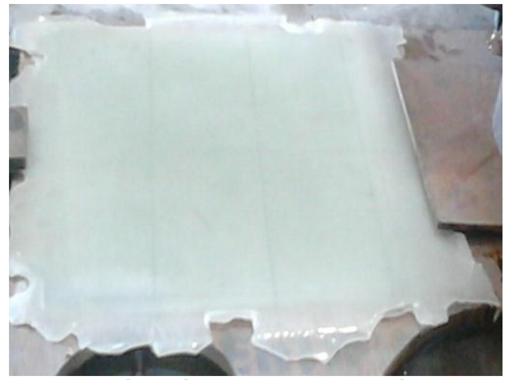

Fig. 2.Glass-Fiber Epoxy composite plate

Here, we have taken 30 layers of Glass-fibre laminates. The epoxy was taken in 1:1 ratio as that of the woven glass fibre sheets. To the epoxy 10% of the hardener was added and mixed thoroughly. On clean and smooth plywood a polythene sheet was spread and the spray of the releasing agent were applied on it. Then a layer of epoxy was applied on the sheet. Over it glass fibre layer was spread and pressed thoroughly by using roller. Again a layer of epoxy was kept along with a sheet of glass fibre over it and rolled it again. This process was carried out for all the layers. Stacking sequence $[0^0/90^0]$ of layers was maintained here. This whole arrangement was kept for 24 hours for hardening and after that cut it to desired size. Thickness of single layer of Glass- fibre is 0.15mm and average thickness of Glass-fibre composite plate is 4.5mm. Fig.2 shows Glass-Fiber Epoxy Composite Plate.

C. Cutting of Composite Plate

Cutting of composite plate was done with water-jet cutting technique. Nine plates of 150 mm width and 100mm height were cut from main plate. Since the objective of paper is to find effect of cut-out shape on free vibration analysis of composite plate, on each plate cut-out has to be made. Thus, four cut-out shapes were chosen, namely Rectangular, Circular, Triangular and Elliptical. Area of cut-out must be same, so that it becomes possible to find effect of shape on plate vibration. Here, area of each plate is 1500mm^2. On four plates cut-out of area 900mm^2 is made and one plate is maintained without cut-out.

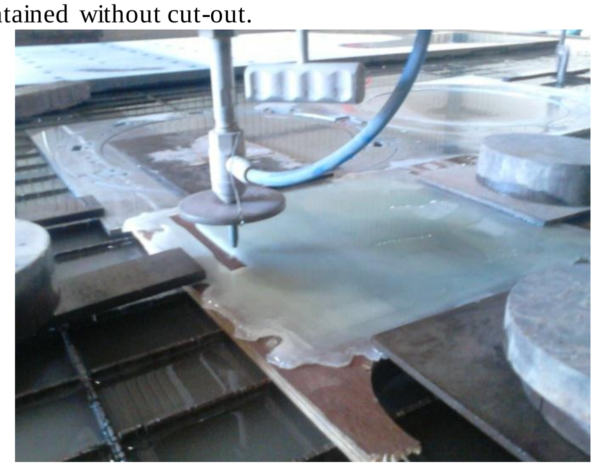

Fig. 3.Water-jet cutting

Another objective of paper is to find effect of cut-out area on same property i.e. natural frequency. To find this, cut-out area is reduced by 20%. So on another four plates, cutout of $720mm^2$ is made. Tensile test specimens were also cut from main plate. Fig.3 shows cutting of main plate using water-jet cutting machine.

III. Evaluation of Material Properties

In order to find tensile modulus of composite plates, Standard dog bone shaped samples were tested in an Instron 5500 machine with capacity of 200 kN. Tensile test were carried out using eight samples which were produced by cutting initial plate with water-jet machine. The constants are determined experimentally as described in ASTM standard: D 638-02 [8]. Fig. 4 shows the experimental tensile test.

Fig. 4.Tensile test for finding material properties

The modulus of elasticity E_1 was calculated by applying tensile force along the direction of fiber; similarly E_2 is calculated by applying tensile force perpendicular to the direction of glass fiber. While to calculate the shear modulus, tensile testing of specimen was done with fiber direction $45^0$to the axis of plate. Then the shear modulus is calculated by use of modulus transformation as in Eq. (1) [1].

$$G_{12} = \frac{1}{\frac{4}{Ex} - \frac{1}{E1} - \frac{1}{E2} + \frac{2\upsilon 12}{E1}} \quad (1)$$

The material properties of plate are given in Table I.

TABLE I
Material Properties of Plate

Modulus of Elasticity, E_1	17.4 GPa
Modulus of Elasticity, E_2	17.4 GPa
Modulus of Elasticity, E_3	5.36 GPa
Shear Modulus, G_{12}	3.5Gpa
Shear Modulus, G_{12}	1.9595 GPa
Shear Modulus, G_{12}	1.9595 GPa
Poisson ratio, υ_{12}	0.283
Poisson ratio, υ_{13}	0.283

III. Finite Element Solution

Finite element analysis was made for obtaining the first five natural frequencies using ANSYS software. CQUAD4 181 (four-noded isoparametric curved shell element) was employed as it gives better results. Five plates were modeled (four with cut-outs and one without cut-out). Each of this plate are analyzed for two boundary conditions namely, Cantilever and fixed. For cantilever condition, one side was fixed (CFFF) where as for fixed condition two opposite sides were fixed (CFCF). Stacking sequence of 30 layered composite plate is shown in Fig.5

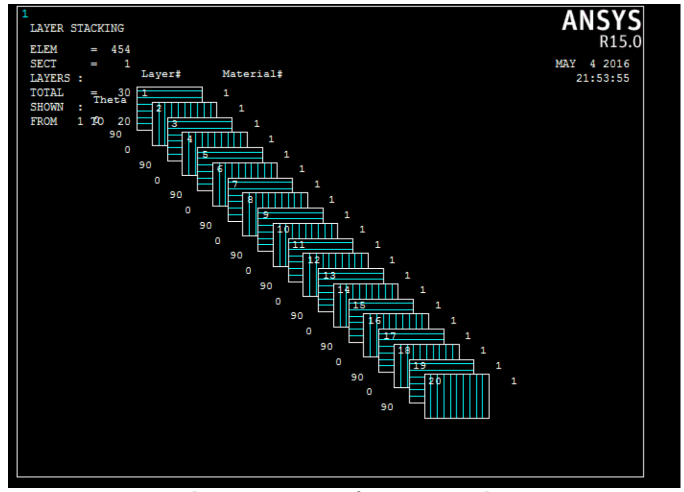

Fig. 5.Fiber Orientation of Composite plate

IV. Experimentation

Free vibration testing to find natural frequency of composite plates with cut-out was found out using FFT analyzer at G. S. Moze College of Engineering, Pune for two boundary conditions. FFT analyzer of 'Brüel & Kjær' was used. Tri-axial accelerometer was used though only uni-axial accelerometer is sufficient to give desired results. Fig 6 shows Experimental set up.

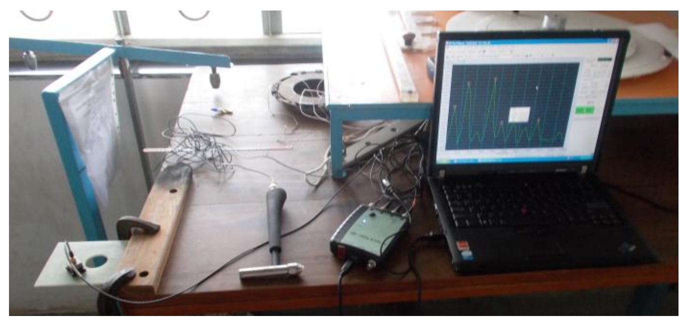

Fig. 6.Experimental Set-up

Experimental procedure is as explained below:

1. Fix the composite plate in the frame as per the required end conditions.
2. Fix the accelerometer to the plate by Glue.
3. The impact hammer is to be keep ready for excitation.
4. In the same time the accelerometers and hammer must be connected to the FFT Analyser .
5. Run the software in a computer connected to the FFT Analyser and the template is to be created to measure the frequency response.
6. Then the plate is excited using the impact hammer.
7. The response is detected and the FRF is obtained on the screen.

Five set of experiments for each boundary condition and for every cut-out type was carried out. The average values of natural frequencies are shown in Table IV and V.

V. RESULTS AND DISCUSSION

Modal analysis and calculation of natural frequency for each plate which having cut-out and without cut-out was done using ANSYS parametric design language (APDL). Working frequency range was 0 Hz to 1000Hz and number of modes to extract was 5. The modal frequencies of laminated plates for both boundary conditions, obtained by FEA, are shown in tables II and III.

TABLE II
NATURAL FREQUENCIES FOR CFFF BOUNDARY CONDITION
(CUTOUT AREA=900MM^2)

Cut-out Shape	Natural Frequency (Hz) 1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
Circular	42.917	112.37	263.25	411.34	612.29
Rectangular	46.535	129.88	277.14	456.49	650.23
Triangular	42.223	110.36	249.70	401.56	587.18
Elliptical	64.256	140.11	333.66	507.65	690.29

TABLE III
NATURAL FREQUENCIES FOR CFCF BOUNDARY CONDITION
(CUTOUT AREA=900MM^2)

Cut-out Shape	Natural Frequency (Hz) 1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
Circular	181.03	205.08	466.78	496.54	506.25
Rectangular	178.49	242.03	461.06	468.42	538.05
Triangular	193.23	234.67	477.68	493.43	569.44
Elliptical	160.71	193.03	396.11	414.57	468.37

The average values of results obtained by experimentation are explained in following Tables IV and V.

TABLE IV
NATURAL FREQUENCIES FOR CFFF BOUNDARY CONDITION
(CUTOUT AREA=900MM^2)

Cut-out Shape	Natural Frequency (Hz) 1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
Circular	39.06	138.43	351.6	460.83	601.6
Rectangular	46.88	156.2	281.267	382.83	625
Triangular	45.61	119.26	195.3	453.13	554.6
Elliptical	78.13	156.26	320.3	421.9	623.40

TABLE V
NATURAL FREQUENCIES FOR CFCF BOUNDARY CONDITION
(CUTOUT AREA=900MM^2)

Cut-out Shape	Natural Frequency (Hz) 1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
Circular	117.9	273.43	367.2	531.3	742.2
Rectangular	140.6	289.06	382.83	468.8	781.26
Triangular	148.4	257.8	390.63	476.56	648.46
Elliptical	178.3	248.43	312.5	382.7	640.63

From table II, III, IV and V following observation can be made:

1) Natural frequencies for fixed plate are higher than cantilever plate for all modes.
2) In cantilever boundary condition, natural frequency is smaller for plates having Triangular cut-out for all modes.
3) For fixed boundary condition, natural frequency is minimum for plate with elliptical cut-out for all modes.
4) FEA results for cantilever condition shows that, plates with elliptical cut-out posses higher natural frequencies than others.
5) Experimental results vary approximately 10% to 15% from FEA results.

IV. CONCLUSION

Free vibration analysis of Glass-Fiber Epoxy composite plates with and without cut-out was carried out. Plate was manufactured using Hand lay-up technique and cut into desired shape by water-jet machining. Modal analysis of these plates was done using ANSYS APDL software. Four type of cut-out shapes, Circular, Rectangular, Triangular and elliptical, were selected. Area of cut-out was maintained constant for all cut-out shapes. From results, one can see that, there is no drastic effect of cut-out shape is observed on natural frequency. But for more precise applications, these minute change also makes difference. In cantilever boundary condition, natural frequency is smaller for plates having Triangular cut-out for all modes. Whereas, for fixed boundary condition, natural frequency is minimum for plate with elliptical cut-out for all modes. Thus, for cantilever applications triangular cut-outs are feasible. On the other hand, for fixed boundary condition, elliptical cut-out must be preferred.

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