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Free Vibration of Laminated Composite Plates with Cut-Out

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ABSTRACT

The laminated composite plate are basics components of structure used in various field of engineering such as turbine blades, airplane wing and helicopter blades as well as many others in civil, automotive and ship industries etc. due to their excellent high stiffness to weight ratio and strength to weight ratio. Cut-outs are provided in structure for venting, reducing weight and passage of electrical wires. Most of the structures are subjected to severe dynamic loading during their service life. This may lead to change the dynamics response of the structure. The presences of cut-outs not only reduce the strength of composite plate but also alter the dynamics characteristics of composite plate. Therefore, it necessitates predicting the dynamics responses of laminated composite plates with cut-outs with cost effective and good accuracy of these complex structures. This present paper deals with combined numerical and experimental approach on dynamics characteristics of laminated composite plate with square cut-outs. The laminated composite plates are made by using hand lay-up method. Bidirectional glass fibres are used as reinforcement and polyester resin as matrix for composite plate. The experimental dynamics test has been carried out by using different dimensions of plate with various design parameters such as cut out ratio (D/d ratio), position of cut out, aspect ratio (a/b ratio), no of layers, ply orientations under different boundary conditions.

INTRODUCTION

Composite materials are structural materials which are obtained by combination of two or more different constituents on a macroscopic scale. There are two phases of composite such as reinforcing phase and matrix phase. The materials of reinforcing phase are in the form of fibres, particles or flakes and embedded in the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. The properties of composite materials are derived from its constituents, geometry and distributions of phases. Some of the composite materials such as plywood and reinforced concrete are being used for a long time. In general, composite materials may be fibrous, laminated and particulate. The composite materials inherit the superior qualities of the combining materials such as excellent high strength to weight ratio, high stiffness to weight ratio, low weight, long fatigue life, resistance to corrosion, good thermal conductivity and low specific density. So that fibre reinforced laminated are being increasing extensively in many engineering application. The elements such as plates and shell have been successfully implementation in real structures. For designers and engineers composites act as a solution for structural problems such as crack prevention.

REVIEW OF LITERATURE

Paramasivam (1973) used a technique to investigate the influence of square cut-out on the natural frequencies of isotropic plates under different end conditions (simply supported and clamped) using the finite difference method. Aksu and Ali (1976) formulated a theory to examine the vibration behaviors of isotropic and orthotropic plates with one or two rectangular cut-outs. The rectangular plate is used for this study.

Lee et al. (1987) analyzed the rectangular composite plates with centrally located rectangular shape cut-outs under simply supported condition. He predicted the natural frequency of composite plate with cut-out by using Rayleigh principle. Bicos and Spring (1989) used finite element method to derive equations for vibration analysis of shells and plates with and without cut-outs. Also, he developed a computer program to calculate the natural frequencies of rectangular plates and cylindrical panels with three different end conditions such as free, clamped and simply supported.

Ramakrishna et al. (1992) analyzed the laminated composite plates with centrally located circular cut-outs. A computer program is established for determining the fundamental frequencies of composite plate by using a hybrid-stress finite element. Also, he considered the influence of ply orientations, width-to-thickness ratio, hole-size and aspect ratio on the fundamental frequencies.

Lee and Lim (1992) analyzed free vibration behaviors' of isotropic and orthotropic square plates with a square cut-out under simply supported condition which is subjected to an in plane force based on the Rayleigh method.

Boay (1996) presented numerical and experimental results on vibration analysis of laminated plates with centrally located circular cut-outs.

Sabir and Davies (1997) determined the natural frequencies of flat square composite plates with eccentrically located square cut-outs based on finite element method. Laminated plates are subjected to in-plane uniaxial or biaxial compression or uniformly distributed shear along the four outer edges under simply supported or clamped end conditions.

Siva Kumar et al. (1999) examined the vibration characteristics of laminated plates with cut-outs under large oscillations. He used Ritz finite element model and got results for laminated composite plates with holes of various shapes such as circle, square, rectangular and ellipse. Chen et al. (2000) studied the vibration analysis of symmetrically thick laminated, doubly connected plates of arbitrary plate perimeter for the outer boundary and a hole defined by a super-elliptical equation which is accomplished to define a rectangular and an ellipse.

Hota and Padhi (2007) studied the example related to vibration of laminated plate with holes and results obtained from this study are presented together with published literature. Udar and Datta (2007) investigated on dynamics instability responses of simply supported laminated composite doubly curved panel with circular cut- out. They considered various design parameters such as no of layers, non-uniform edge loading, damping and width to thickness ratio etc.
Poore et al (2008) examined a semi analytical solution method for evaluating the natural frequency of laminated cylindrical shells with centrally located circular cut-out.

MATHEMATICAL FORMULATION

Governing Differential Equations

The differential equations of motion are obtained by considering a differential element of shell panel as shown in Fig:

This figure indicates internal forces of an element such as membrane forces Nx , Ny and Nxy , shearing forces are Qx

And Qy and the moment of resultants are Mx , M y and M xy .

Constitutive Equations

The composite panel is constituted of thin layers composite laminates. The matrix materials are embedded with fibres. Each layer is considered as homogeneous and orthotropic. The laminated fibre plate is consisting of a number of thin laminates as shown in Fig: 2.The principle material axes are shown by 1 and 2 and modulus of elasticity of a laminated plate along these directions are E1 and E2 respectively.

Governing Equation for Free Vibration Analysis

The finite element formulation is established for the free vibration response of laminated composite plates with cut-out based on the first order shear deformation theory. An eight- nodded plate element is considered in the present work with six degrees of freedom i.e. u, v.

MODELLING USING ANSYS

Introduction

ANSYS, Finite Element Analysis (FEA) software is being generally used by engineer worldwide. ANSYS can be employed in virtually all the field of engineering such as structural, thermal and fluid mechanics etc. In this present work, ANSYS 14.5 is used to model the laminated composite plate to calculate the natural frequencies and deformed shapes of plates.

In this sub sections, the details of the ANSYS modeling are described. The terms related to ANSYS and the steps to be followed are discussed below.

Modal Analysis: It is a linear analysis. There are various mode of extraction such as Block Lanczos, Super node, PCG Lanc zos, reduced, unsymmetrical, damped, and QR damped are available. Block Lanczos mode of extraction is considered in the present modal analysis.

1. Solution: It includes assigning loads, applying boundary conditions and solving the modal analysis. The following table 1 indicates the constraints which are used in various boundary conditions. The constrains for different boundary conditions are presented in table 1. The loading and boundary condition of plate using ANSYS.
2. Post processing: This step includes viewing of the results and plotting mode shapes. Also, the deformed shape and un-deformed shape of plate can be plotted. The mode shape of laminated composite plate with cutout under cuff boundary condition in ANSYS.

EXPERIMENTAL PROGRAMME

Introduction

In this chapter the details of the experimental works are done on the vibration analysis of composite plate with cut-outs. The materials properties of the laminated composite plate are found out by tensile test as per ASTM D3039/ D3039M (2008) guidelines to characterize the laminated plate. The results obtained in experimental studies are compared with analytical predication.

Materials

The following materials were used for preparation of laminated composite plate

- Woven glass fibre
- Epoxy

- Hardener
- Polyvinyl alcohol spray.

Production of Laminated Composite Specimen for Tensile Test

The percentage of fibre and matrix was taken in a proportion of 50:50 by weight. The hand lay-up process was used in this proposed works for fabrication of the laminated composite plate. This hand lay-up process is simplest method. In this process the resin is placed along with reinforcement against finished surface of an open mould. The glass fibre acts as reinforcement and resin acts as matrix. The glass fibres were cut into required shape and size for preparation of laminated plate. The matrix was prepared by using 8% of epoxy. A flat plywood platform was selected. Then, a plastic sheet was kept on the plywood and the releasing agent was sprayed on the plastic sheet by using spray gun. The resin was spread uniformly over the plastic sheet by using brush. Then the first layer of glass fibre was laid. Before laying resin on the first layer of glass fibre, a steel roller was used to remove air which may be entrapped. This process was continuation till all the eight layers are placed. Again a plastics sheet was covered the top of plate by applying releasing agent inside the sheet. Then a heavy flat metal rigid platform was kept on the top of the plate for compressing purposed.

The casting is cured under room temperature for 48 hrs. Then releasing sheet was removed from mould. The specimens were cut up to 250mmx25mm from the sheet of eight layers ply laminated as per ASTM D2344/D2344M (2006) specification by diamond cutter. The average thickness of laminated composite plate is found to be 3mm.

Determination of Material Constants

Laminate composite plate are orthotropic in nature which are defined by material constant i.e. E1, E2, G12 and v12. To perform the tensile test of specimens, an INSTRON 1195 UTM (as shown in fig.10) is used. The dimension of tensile test is given below in table 2. These specimens were tested which are shown in fig.9 for determination of mean values of material constant. The specimen was subjected to load in the INSTRON 1195UTM as described in ASTM standard D3039/D3039M (2008) at the rate of 0.2mm/minutes. The cracks were appeared in specimen during tensile test.

Reparation of Laminated Composite Plate for Vibration Testing

The preparation procedure for the composite plate for vibration analysis was same as that of plate preparation for tensile testing. Three different sizes of plate sample such as 235mmx235mm, 235mmx156.6mm and 235mmx117.5mm are prepared and cut into different cut-out ratio (d/D ratio) 0.0, 0.1, 0.2, 0.3 and 0.4 by using hacksaw for vibration test.

Equipment for Vibration Test

The following apparatus used in free vibration test

- Modal hammer
- Accelerometer
- FFT Analyzer
- PULSE software.

Procedure for Modal Testing

As per required boundary condition, laminated composite plate was fitted. The FFT analyzer, laptop, modal hammer and accelerometer were connected. The pulse lab shop version 10.0 was inserted to the laptop. An accelerometer was fixed to the plate by bee wax. The excitation is generated by means of modal hammer. The vibration generated by hammer was sensed by accelerometer. Then, the FFT analyzer was processed this signal and obtained the frequency spectrum. The spectrum analyzer was investigated the input and output signal and transmitted the resulting FRF to computer. The output signals are obtained on the analyzer screen using pulse software. The natural frequencies of the plate were measured from the FRF graph.

RESULTS AND DISCUSSION

Introduction

Free vibration analysis of laminated composite plate with cut-outs is analytically studied by using ANSYS software. The effect of different parameters such as aspect ratio (a/b), position of cut-out, no of layers, orientation and cut-out ratio(d/D) under different boundary conditions. The experimental results on free vibration of laminated plate with cut -outs are verified with numerically using ANSYS. Vibration analysis of this study is presented as following

1. Comparison with previous results.
2. Experimental and numerical results.

Modal Analysis

Cut-out may influence the dynamic behaviors of laminated composite structures. That’s why in this present study, natural frequencies of composite plate with cut out are calculated both numerically and experimental programmed. The effects of different parameters such as cut-out ratio (d/D ratio), no of layers, position of cut-out, aspect ratio (a/b ratio), different boundary condition and ply orientation on natural frequency of square cut-out plate were studied. The numerical results of modal analysis are compared with other existing literature.

CONCLUSION

The present study is related with the effect of the free vibration behaviors’ on laminated composite plates with cut-outs. The finite element package ANSYS is used to investigate the laminated composite plate with cut-outs. The experimental results of free vibration behaviors of laminated composite plate with cut-outs are compared with numerical ones by considering the effect of various parameters such as cut-out ratio (d/D ratio), aspect ratio (a/b ratio), fibre orientation, no of layers , position of cut-out and different boundary conditions etc. From this analysis, we can be established the following remarks during the investigation of free vibration behaviors' of laminated composite plate with cut-outs.

- The numerical results from ANSYS software showed in good agreement with experimental ones on vibration of laminated plates.
- The natural frequencies of plates increases with increase in aspect ratio (a/b) of plates by keeping the cut-out ratio (d/D ratio) constant.
- By keeping aspect ratio (a/b ratio) constant, as the cut-out ratio (d/D ratio) increases from 0.0 to 0.4 the fundamental frequency of composite plate decreases under CFFF and SFSF boundary conditions. But fundamental frequency decreases up to cut-out ratio (d/D ratio) equals to 0.2 under CFCF. Further fundamental frequency increases on increase of cut-out ratio d/D ratio. Since localization of stress concentration is reduced by providing the multiple holes around the central cut-out
- Natural frequency of composite plate with square cut-out is maximum at centre and minimum at corner position irrespective of CFFF and SFSF boundary conditions.
- It is observed that natural frequency of composite plate with central cut-out without multiple holes is more than the natural frequency of plate with multiple holes.
- The fundamental frequencies of composite plate with fixed cut-out ratio increase with increase in no of layers due to bending stretching coupling.
- By changing the ply orientation of laminates, it changes the dynamics characteristics of the plates, that is different frequencies for same geometry, mass and end
- Conditions. As the ply orientation increases, the natural frequency decreases and maximum natural frequency occurs at 00.
- The natural frequency of laminated plate with holes varies against different end conditions. It shows that the natural frequency under CFCF boundary condition is the maximum due to clamped at two opposite edges. However, the CFFF supported laminated composite plates shows the minimum frequency among three boundary conditions tested.

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