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Vibration and Buckling Analysis of Composite Plate

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ABSTRACT

Composite materials are being increasingly used in automotive, civil, marine, and especially weight sensitive aerospace application, primarily because of its specific strength and stiffness, This necessitates studies on vibration and buckling behavior of the structures. The present paper is mostly experimental study based on vibration measurement and buckling behavior of industry driven woven fiber composite panels for different layer thickness. The effects of different geometry, boundary conditions, aspect ratio and type of fiber on the natural frequencies of vibration of woven fiber composite panels are studied in this investigation. The effects of variation in fiber parameters on the natural frequencies are also investigated. Experiments have also been conducted to study the vibration and buckling characteristics of carbon/glass hybrid plates for different lamination sequence and percentage of carbon and glass fiber. A finite element package, ANSYS 16.0 was used to obtain the numerical results and plot the mode shapes for various modes of vibration. The free vibration characteristics are studied with First Fourier Transform (FFT) analyzer, accelerometer using impact hammer excitation.

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I. INTRODUCTION

A structural composite is consisting of two or more phases on a microscopic scale and their mechanical performance/properties are designed to be superior to those of the constituent materials acting independently. Out of the two phases one is said fibre/reinforcement usually discontinuous, stiffer and stronger. The second one is less stiff weaker and continuous phase namely, matrix phase. The properties of a composite depend on the properties of the constituents, their geometry and the distribution of the phase. Composite system includes concrete reinforced with steel and epoxy reinforced with graphite fibres, etc. Laminated composite structures are being increasingly used in many industries such as aerospace, marine, and automobile due to their high strength to weight ratio, high stiffness to weight ratio, low weight and resistances to electrochemical corrosion, good electrical and thermal conductivity and aesthetics.

The computation of natural frequencies and buckling load is important to predict the behaviour of structures under dynamic loads. Modal analysis is used for prediction of dynamic properties of structures. The deviation of natural frequencies is an indication of the presence of invisible defect that cannot be determined otherwise. This study is also necessary in order to avoid resonance of large structures under dynamic loading. During designing of structures subjected to compressive loading, knowledge of buckling characteristics of the comprising elements is necessary in order to prevent overloading of the structure.

II. REVIEW OF LITERATURE

Huang *et al.* (2004) used higher order shear deformation plate theory based on micromechanical model to explain the effect of temperature and moisture on the non-linear vibration and dynamic response of shear deformable laminates.

Botelho *et al.* (2005) presented the influence of hygrothermal conditioning on the natural frequencies of glass/epoxy, aluminum and Glare laminates.

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Lo *et al.* (2010) analysed the response of laminated composite plates to temperature and moisture concentration variation by incorporating refined higher order theory and discrete Kirchoff quadrilateral thin plate element.

Panda *et al*. (2013) conducted numerical as well as experimental studies on vibration characteristics of delaminated composite plates under hygrothermal conditioning. In this study they presented the effects of temperature, moisture, delamination size and boundary conditions on the modal frequencies of woven fibre Glass/Epoxy composite plates. From the reviewed literature it was observed that experimental studies on hygrothermal effects on vibration characteristics of carbon composite panels are scare in open source literature. The available studies mostly revolved around glass fibre composites. In the present study, the behaviour of carbon fibre composite plates are studied using experimental techniques and the obtained results were validated using finite element method.

III. OBJECTIVE AND SCOPE OF PRESENT STUDY

The objective of this research is to study experimentally the vibration and buckling characteristics of composite laminates. Studies are conducted on CFRP as well as glass-carbon/epoxy composite plates. The obtained results are compared with the theoretical values based on FEM. The present study can be split into three different modules as below.

1. Vibration of laminated carbon composite plates

2. Buckling of laminated carbon composite plates

3. Glass-carbon/epoxy hybrid plates

The effects of different parameters including number of layers, aspect ratio, support conditions and effect of fiber on the vibration characteristics of industry driven woven fibre carbon composite panels are investigated. The mode shapes for different boundary conditions are to be obtained using finite element package, ANSYS 15.0. The variation in the buckling loads with change in the number of layers of carbon fibre is observed. The effect of lamination sequence and percentage composition of carbon fibre on natural frequencies and critical buckling load of glass-carbon/epoxy hybrid plates is also studied.

IV. EXPERIMENTAL EVALUATION

i. Fabrication Method:

Specimens were cast using hand layup technique as shown in Figure 4. In hand lay-up method, liquid resin was placed along with industry driven woven carbon fiber against finished surface of an open mould. The percentage of fiber and matrix was taken as 50:50 in weight for fabrication of the plates. Lamination started with the application of a gel coat made up of epoxy resin and 8% hardener (Ciba-Geigy, Araldite HY556 and Hardener HY951) deposited on the mould by brush. Any air which may be entrapped was removed using steel rollers. After completion of all layers, again a plastic sheet was covered the top of last ply by applying polyvinyl alcohol inside the sheet as releasing agent. Again one flat ply board and a heavy flat metal rigid platform were kept top of the plate for compressing purpose.

Fig.1: Hand Lay Up Technique

ii. Setup and Test Procedure for free vibration test of composite plates:

The connections of FFT analyzer, laptop, transducers, modal hammer, and cables to the system were done as per the guidance manual. The plate was excited in a selected point by means of Impact hammer. The resulting vibrations of the specimens on the selected point were measured by an accelerometer mounted on the specimen by means of bees wax. The plates were placed as per the required boundary conditions. The various boundary conditions under study are as follows:

1. Cantilever

2. Simply supported on boundary

Fig.2: Modal Vibration Test Picture

iii. Setup and Test Procedure for Buckling Test:

A frame was fabricated to keep two opposite sides clamped and the other two sides in free condition. The specimen was loaded to failure in INSTRON 1195 by applying axial compression as can be seen from figure 8. The top and bottom edges were restrained against translation and rotation using clamping screws. For axial loading the specimen was placed between two extremely stiff machine heads. The lower machine head was fixed during the test and the upper head was moved downwards by servo-hydraulic cylinder. All plates were loaded at a constant crosshead speed of 0.5 mm/min. The compressive load versus compressive extension curve was plotted by the system connected to the machine, as shown in figure 9. The critical buckling load was

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determined at the point where the curve deviated from its linearity.

Fig.3: Carbon fibre composite plate subjected to axial compression

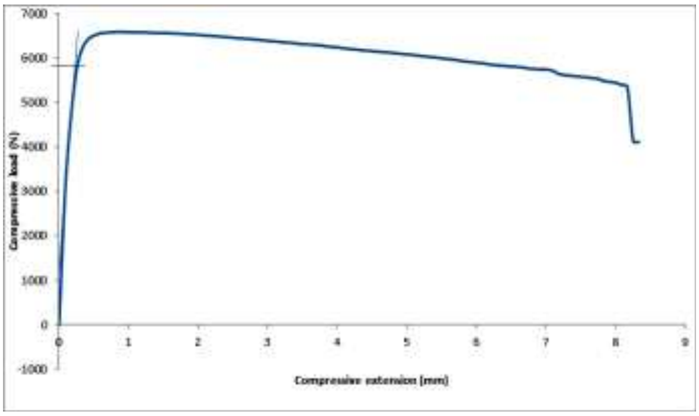

Fig.4: Graph of Compressive load Vs Displacement

Finite Element Modeling

The CFRP plate was modeled using a commercially available finite element package, ANSYS 16.0 according to ANSYS user's manual. The natural frequencies and mode shapes are obtained by modal analysis. The element type used is SHELL281 which is an 8 noded structural shell, The boundary conditions of Cantilever, Simply Supported were introduced by limiting the degrees of freedom at each node.

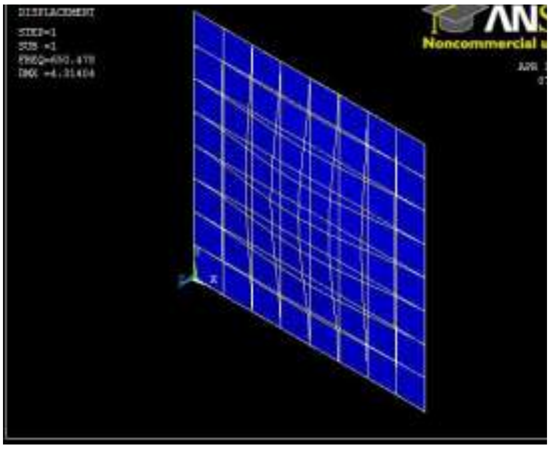

Fig.5: Deformed Shape

V. RESULTS AND DISCUSSION

Modal frequencies obtained experimentally and those obtained from FEM analysis for the first four lowest frequencies for free-free boundary conditions are obtained. The experimental values are close to the values obtained from FEM analysis with a maximum deviation of 20%.

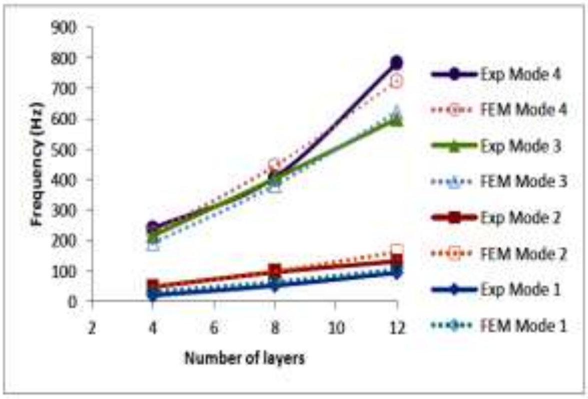

Fig.6: Variation of natural frequency with number of layers for CFFF support condition

Figure 6 presents a graphical representation of the predicted as well as experimental results for Cantilever condition. The shape of the graph shows a marked similarity with the previous ones suggesting that the increase in thickness leads to an increase in stiffness which in turn is the reason for the increase in frequency. It is also observed that the frequencies in case of cantilever support are less than that of Simply support condition. Another irregularity observed is the difference in values of 2nd and 3rd lowest frequencies which is found similar in the earlier case.

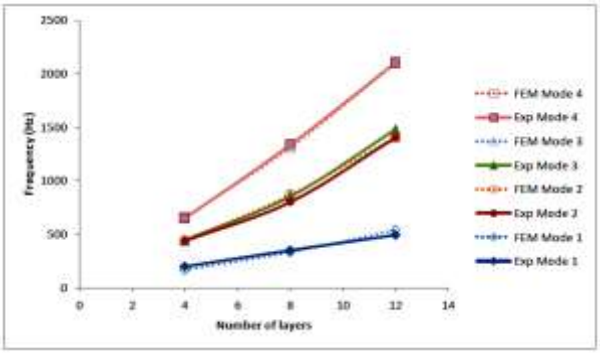

Fig.7: Variation of natural frequency with number of layers for simply supported condition

Figure 7 presents a graphical representation of the predicted as well as experimental results for SS boundary condition. It is observed that the modal frequencies increase with the increase in number of layers. The average increase in frequency is found to be 90 % and 208 % as the thickness increases from 4 layers to 8 and 12 layers respectively.

The buckling loads were found experimentally and analytically for square composite laminates in CFCF boundary condition. The analytical values were found to be in good agreement with the experimental values. From the results obtained it was observed that buckling loads increased with increase in the number of layers of carbon fibre in CFRP plates, as can be seen in figure 8. This can attributed to

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bending, stretching and coupling effects in composite laminates.

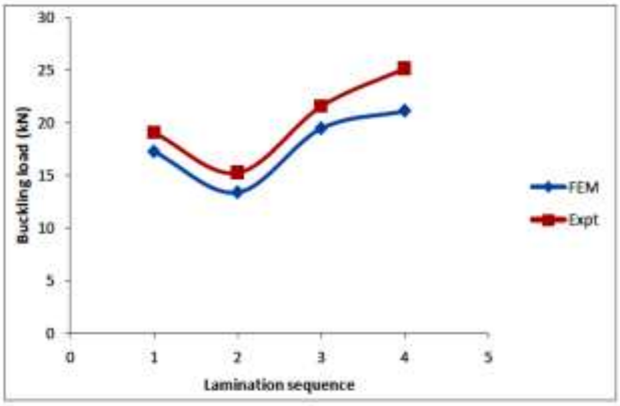

Fig.8: Variation of buckling load with lamination sequence of CFRP plates in CFCF boundary condition with 25 % carbon fibre

VI. CONCLUSION

The obtained results were validated and the mode shapes for various modes of vibration were determined using finite element package, ANSYS 16.0. The critical buckling load was determined for the laminates. A special case of hybrid laminates was studied to understand the effect of lamination sequence on the vibration and buckling characteristics of carbon-glass/epoxy composite plates.

Results are presented for the vibration and buckling characteristics of carbon/epoxy composites plates and carbon-glass/epoxy laminates. The effects of various geometrical parameters like size, aspect ratio, and boundary conditions on the natural frequencies of vibration has been analysed. The effects of temperature and moisture conditioning on the vibration characteristics of CFRP plates are also studied. Results for fatigue testing have also been presented.

From the experiments it was observed that

a. The frequency of vibration was noted to be highest for fully clamped condition and lowest for cantilever boundary condition which can be attributed to the increased stiffness of supports.
b. It has been observed that buckling loads increased with increase in the number of layers of carbon fibre in CFRP plates.
c. Plies possessing higher modulus of elasticity when present on the outermost layer, gives maximum buckling load.

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