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Static and Vibration Analysis of Composite Beams Using Finite Element Methods

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ABSTRACT:

Beams are widely used structural members and its dynamic characteristics under loading is of great importance and vital for study. Thus, the purpose of the present thesis paper is to carry out an efficient and accurate simulation for static and modal analysis of uniform beam using Ansys. Displacement and frequencies of cantilever beam are studied with distributed as well as surface load. Composite materials have interesting properties such as high strength to weight ratio, ease of fabrication, good electrical and thermal properties compared to metals. A composite material consists of layers of a composite mixture consisting of matrix and fibers. Each layer may have similar or dissimilar material properties with different fiber orientations under varying stacking sequence. There are many open issues relating to design of these laminated composites. In this project a cantilever composite beam with both upper and lower surfaces symmetrically bonded by piezoelectric ceramic and the beam is made up of t300/976 graphite/epoxy composites.

INTRODUCTION

A combination of two or more materials with different properties, or a system composed of two or more physically distinct phases separated by a distinct interface whose combination produces aggregate properties that are superior in many ways, to its individual constituents. A new material with combination of two or more material can provide enhanced properties that produce a synergetic effect [1]. In composite materials there are two constituents one is matrix and other is reinforcement. The constituents which is continuous and present in greater quantity is called matrix. The main functions of the matrix is to holds or bind the fibre together, distribute the load evenly between the fibres, protect the fibre from mechanical and environmental damage and also carry interlaminar shear. While the other constituent is reinforcement; its primary objective is to enhance the mechanical properties e.g. stiffness, strength etc. The mechanical property depends upon the shape and dimensions of reinforcement [1]. On the basis of type matrix material, composites can be grouped into three main categories, polymer, metallic and ceramic. While on the basis of reinforcement classification of composite is shown in Figure 1.1 below:

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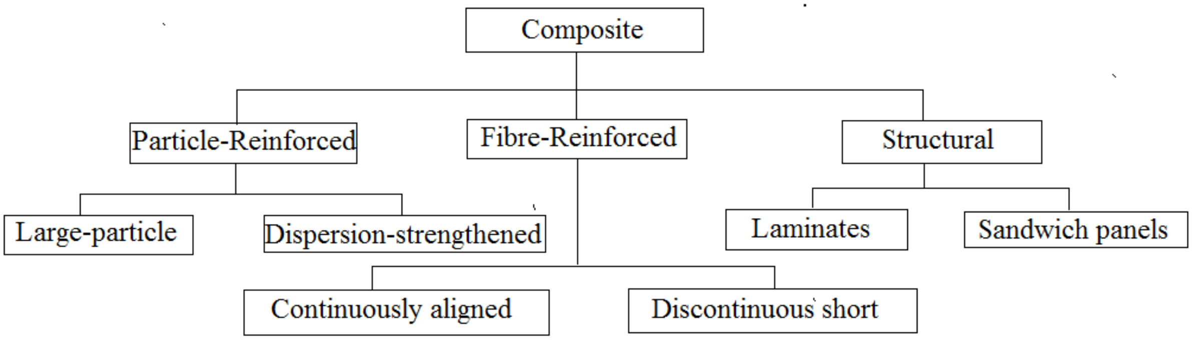

Figure 1.1 Classification of composite based on the type of reinforcement [1]

Beams have always been used extensively in building materials and structures. Depending on the application and working environment they are frequently under dynamic loading condition. Hence, from the standpoint of proper functioning and safety, study of response of these structural elements under dynamic loading is of utmost importance. Dynamic analysis of a structure or structural element consists of two different aspects, namely, free and forced vibration studies. The main purpose of a free vibration analysis is to predict the natural frequencies of various vibration modes of the component under no load and loaded conditions. The natural frequencies of the structure under some form of static loading are generally known as loaded natural frequencies. Determination of these frequencies is important to avoid resonance condition, where the external excitation frequency coincides with the system natural frequencies. At resonance condition, the element vibrates with large amplitude resulting in deterioration of structural health. This deterioration usually causes local increase in flexibility, which is a serious threat to life and performance of structural component. Thus in last two decades the study and analysis of natural frequencies in normal and loaded conditions has become increasingly important. From design point of view, maximum vibration amplitude must be limited to a suitable amount for a structure to perform safely

1.1 VIBRATION AND FREQUENCY

Zero-value displacement is the only load that is valid in a typical modal analysis constraint. If a nonzero displacement constraint is given as input, the program will assign the DOF with a zero-value constraint. Other loads are ignored even if they are specified.

Natural Frequency: All structures have a natural frequency with which they oscillate. If a structure under normal condition is subjected to an excitation which is close to its natural frequency, the structure starts oscillating with large amplitude than in normal condition. By studying the results obtained from a modal analysis it can be ascertained whether a model requires either more or less damping for it to prevent failures in future in its life. Modal analysis can also be used to find out the frequency at which resonance will occur, and thus modify the design of the structure, under specific constraints.

Modes of Vibration and Mode shapes: A structural element is a continuous system and can vibrate in many different ways. These different ways of vibration each have their own frequency, which is determined by moving mass in that

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mode, and the restoring force that tries to return that specific distortion of the body back to its equilibrium position. Each of these different ways of vibrating is known as a mode of vibration of the system. Each mode is assigned a number and the lowest frequency at which a system vibrates after all external loads are removed is assigned as mode 1 or fundamental mode. A mode of vibration is characterized by a modal frequency and a mode shape. Each mode is entirely independent of all other modes. Thus all modes have different frequencies and different mode shapes. In the study of vibration in engineering, the expected shape/curvature (or displacement) of a system at a particular mode due to vibration is the mode shape. Thus the mode shape always describes the time-to-time curvature of the system under vibration where the magnitude of the curvature continuously changes. The mode shape depends on two factors:

1) Shape (Geometrical parameters) of the system
2) Boundary conditions of the system.

Laminated Composite Structures

A laminate is constructed by stacking a number of laminas in the thickness (z) direction. Each layer is thin and may have different fiber orientation. The fiber orientation, stacking arrangements and material properties influence the response from the laminate. The theory of lamination is same whether the composite structure may be a plate, a beam or a shell.

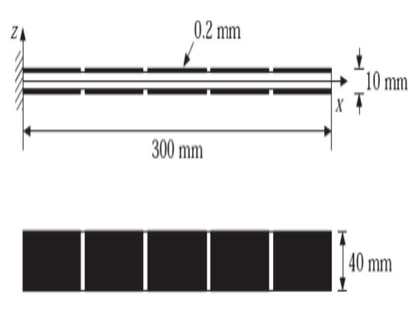
The following assumptions are made in formulations:

(i) The middle plane of the plate is taken as the reference plane.
(ii) The laminated plate consists of arbitrary number of homogeneous, linearly elastic orthotropic layers perfectly bonded to each other.
(iii) The analysis follows linear constitutive relations i.e.obeys generalized Hooke's law for the material.
(iv) The lateral displacements are small compared to plate thickness.
(v) Normal strain in z-direction is neglected.

1.2 WHY MODAL ANALYSIS?

One of the uses of modal analysis is to determine the vibration response characteristics (natural frequencies and mode shapes) that a structural element or the machine component shows during run time, while it is being designed. It is also a starting point for further study of another, more detailed, dynamic analysis, such as a transient dynamic analysis or a harmonic response analysis and a spectrum analysis. Modal analysis is also often used to determine the natural frequency and mode shape of a structure. The natural frequencies and mode shapes play a vital role in the design of a structure for dynamic loading conditions.

Material Properties of Composite Material:



A cantilever composite beam with both upper and lower surfaces symmetrically bonded by piezoelectric ceramics

The beam is made up of t300/976 graphite/epoxy composites and the piezoceramics is PZT G1195N. the adhesive layers are neglected. The total thickness of the composite beam is 4.2mm and each layer has the same thickness (10mm) and thickness of each piezo-layer is 0.2mm

2.REVIEW:

Engineering structures work frequently under dynamic excitations. The type of excitation may vary but the results of these excitations are shown generally in the form of the vibrations. Vibrations can be attributed as an unwanted for many engineering structures due to precision losses, noise, waste of energy, etc. and should be kept under control for lightweight structures. Attempts at solving these problems have recently stimulated extensive research into smart structures and systems. A smart structure can be defined as a structure with bonded or embedded sensors and actuators with an associated control system, which enables the structure to respond simultaneously to external stimuli exerted on it and then suppress undesired effects. Smart structures have found application in monitoring and controlling the deformation of the structures in a variety of engineering systems. Advances in smart materials technology have produced much smaller actuators and sensors high integrity in structures and an increase in the application of smart materials for passive and active structural damping. Several investigators have developed analytical and numerical, linear and non-linear models for the response of integrated piezoelectric structures.

This section brief-outs the various earlier works done in the area of laminated composite material. These are grouped under four broad headings. More recently, Hajianmaleki[1] presented a review of analysis of laminated composite structures used in recent decades.

Laminated Beams

Many authors analyzed the laminated beam structures.

Yildirim [2] used stiffness method for the solution of the purely in-plane free vibration problem of symmetric cross-ply laminated beams. The rotary inertia, axial and transverse shear deformation effects are considered in the mathematical model by the first-order shear 8

Plates

Sahoo and Singh [8] proposed a new trigonometric zigzag theory for the static analysis of laminated composite and sandwich plates. This theory considers shear strain shape function assuming the non-linear distribution of in-plane displacement across the thickness. It satisfies the shear-stress-free boundary conditions at top and bottom surfaces of the plate as well as the continuity of transverse shear stress at the layer interfaces obviating the need of an artificial shear correction factor.

Rarani *et al*. [9] used analytical and finite element methods for prediction of buckling behavior, including critical buckling load and modes of failure of thin laminated composites with different stacking sequences. A semi-analytical Rayleigh–Ritz approach is first developed to calculate the critical buckling loads of square composite laminates with SFSF (S: simply-support, F: free) boundary conditions. Then, these laminates are simulated under axially compression loading using the commercial finite element software, ABAQUS. Critical buckling loads and failure modes are predicted by both eigenvalue linear and nonlinear analysis.

Alnefaie [10] developed a 3D-FE model of delaminated fiber reinforced composite plates to analyse their dynamics. Natural frequencies and modal displacements are calculated for various case studies for different dimensions and delamination characteristics. Numerical results showed a good agreement with available experimental data. A new proposed model shows enhancement of the accuracy of the results.

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Sino *et al.* [11] worked on the dynamic instability of an internally damped rotating composite shaft. A homogenized finite element beam model, which takes into account internal damping, is introduced and then used to evaluate natural frequencies and instability thresholds. The influence of laminate parameters: stacking sequences, fiber orientation, transversal shear effect on natural frequencies and instability thresholds of the shaft are studied. The results are compared to those obtained by using equivalent modulus beam theory (EMBT), modified EMBT and layer wise beam theory (LBT).

Optimization issues and dynamics

Topal [12] presented a multi objective optimization of laminated cylindrical shells to maximize a weighted sum of the frequency and buckling load under external load. The layer fiber orientation is used as the design variable and the multi-objective optimization is formulated as the weighted [11] Topal and Uzman[13] proposed a multiobjective optimization of symmetrically angle-ply square laminated plates subjected to biaxial compressive and uniform thermal loads. The design objective is the maximization of the buckling load for weighted sum of the biaxial compressive and thermal loads. The design variable is the fiber orientations in the layers. The performance index is formulated as the weighted sum of individual objectives in order to obtain optimal solutions of the design problem. The first-order shear deformation theory (FSDT) is used in the mathematical formulation of buckling analysis of laminated plates. Roos and Bakis [14] analysed the flexible matrix composites which consist of low modulus elastomers such as polyurethanes which are reinforced with high-stiffness continuous fibers such as carbon. This fiber–resin system is more compliant compared to typical rigid matrix composites and hence allows for higher design flexibility. Continuous, single-piece FMC driveshafts can be used for helicopter applications. Authors employed an optimization tool using a genetic algorithm approach to determine the best combination of stacking sequence, number of plies and number of in-span bearings for a minimum-weight, spinning, and misaligned FMC helicopter driveshaft. In order to gain more insight into designing driveshafts, various loading scenarios are analyzed and the effect of misalignment of the shaft is investigated. This is the first time that a self-heating analysis of a driveshaft with frequency- and temperature-dependent

material properties is incorporated within a design optimization model. For two different helicopter drivelines, weight savings of about 20% are shown to be possible by replacing existing multi-segmented metallic drivelines with FMC drivelines.

Sadr and Bargh [15] studied the fundamental frequency optimization of symmetrically laminated composite plates using the combination of Elitist- Genetic algorithm(E-GA) and finite strip method(FSM). The design variables are the number of layers, the fiber orientation angles, edge conditions and plate length/width ratios.

Kayikci and Sonmez [16] studied and optimized the natural frequency response of symmetrically laminated composite plates. An analytical model accounting for bending–twisting effects was used to determine the laminate natural frequency. Two different problems, fundamental frequency maximization and frequency separation maximization, were considered. Fiber orientation angles were chosen as design variables. Because of the existence of numerous local optimums, a global search algorithm, a variant of simulated annealing, was utilized to find the optimal designs. Results were obtained for different plate aspect ratios. Effects of the number of design variables and the range of values they may take on the optimal frequency were investigated. Problems in which fiber angles showed uncertainty were considered. Optimal frequency response of laminates subjected to static loads was also investigated.

Khandan *et al*.[17] researched and added an extra term to the optimisation penalty function in order to consider the transverse shear effect. This modified penalty function leads to a new methodology whereby the thickness of laminated plate is minimised by optimizing the fiber orientations for different load cases. Therefore the effect of transverse shear forces is considered in this study.

CONCLUSION

In today's world composite material usage has been increased due to its low weight ratio and high strength when compared to whole single metal body or alloy materials. In this project we used a cantilever composite beam with both upper and lower surfaces and symmetrically bonded by piezoelectric ceramic coating, and then structural and modal analysis is done under required boundary condition, And the conclusion is drawn. Composite design is designed using CATIA V5 R20 and analysis is done in ANSYS 16 in structural and modal workbench. We first designed a rectangle bar in CATIA with required dimensions and then it is imported in ANSYS 16 work bench for further structural and modal workbench...later on the same process is repeated with coating. After thorough analysis we conclude that by applying piezoelectric ceramic coating there is change in deformation, von mises stress and strain. We even observed very low damping frequency in modal workbench with very low deformation. We conclude that by applying piezoelectric ceramic coating to cantilever composite beam there is a lot of difference in deformation and stress factors, so it is suggestible.

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