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Modal Analysis of Organic-matrix Composites with different % of Si_3N_4

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Abstract— Modal analysis is a process to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It has become a major alternative to provide a helpful contribution in understanding control of many vibration phenomena which encountered in practice. In this paper, work is carried out on organic- matric composites having different % of Si_3N_4 for use in Aeronautical industry. The main idea behind this work is to replace the existing material with composite material with same width, thickness and improved load carrying capacity. By using composite materials the weight is reduced drastically. In the present work two composite materials with three variaton are considered. They are Epoxy with 0%, 6%, 10% Si_3N_4 and carbon/Epoxy, with 0%, 6%, 10% Si_3N_4. The modal analysis is carried out theoretically for finding the natural frequencies for all the composition of the composite for the first ten modes. To validate the theoretical modal analysis, modal analysis is conducted in ANSYS software for the first ten modes. Modeling is done using Catia V5R20 and analysis is done using Ansys 15 software. The Ansys results are almost coincide with theoretical modal analysis values.

Index Terms— Ansys, Carbon/Epoxy composite, Catia, Epoxy composite, FEM, Modal Analysis, Mode shape, Natural frequency and Si_3N_4.

1. INTRODUCTION

Composite materials are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. The primary functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc.

In engineering field vibration behavior of an element plays a key role without which it is incomplete. Resonance is a key aspect in dynamic analysis, which is the frequency of any system matches with the natural frequency of the system which may lead to catastrophes or system failure. Modal analysis has become a major alternative to provide a helpful contribution in understanding control of many vibration phenomena which encountered in practice [1]. A new finite element model for laminated composite beams, the model includes sufficient degrees of freedom to allow the cross-sections of each lamina to deform into a shape which includes up through cubic terms in thickness co-ordinate. The element consequently admits shear deformation up through quadratic terms for each lamina but not interfacial slip or delamination [2].

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Higher order shear deformation theory is used for the analysis of composite beams. Nine nodes are parametric elements are used in the analysis. Natural frequencies of composite beam are compared for different stacking sequences, different (l/h) ratios and different boundary conditions. They had shown that natural frequency decreases with an increase in ply angle and a decrease in (l/h) ratio [3].The symbolic computation technique to analyze the free vibration of generally layered composite beam on the basis of a first-order shear deformation theory. The model used considering the effect of poisson ratio, coupled extensional, bending and torsional deformations as well as rotary inertia [4]. It has investigated the free vibration of axially laminated composite Timoshenko beams using dynamic stiffness matrix method. This is accomplished by developing an exact dynamic stiffness matrix of a composite beam with the effects of axial force, shear deformation and rotatory inertia taken into account. The effects of axial force, shear deformation and rotator inertia on the natural frequencies are demonstrated. The theory developed has applications to composite wings and helicopter blades [5].

The finite element model to investigate the natural frequencies and mode shapes of the laminated composites. The FE model needed all lamina had the same lateral displacement at a typical cross-section, but allowed each lamina to rotate to a different amount from the other. The transverse shear deformations were included [6]. The effects of the location and depth of the cracks, and the volume fraction and orientation of the fibers on the natural frequencies and mode shapes of the beam with transverse non-propagating open cracks, were explored. The results of the study leaded to conclusions that, presented method was adequate for the vibration analysis of cracked cantilever composite beams, and by using the drop in the natural frequencies and the change in the mode shapes, the presence and nature of cracks in a structure can be detected [7].

They had done free vibration analysis of a cross-ply laminated composite beam on Pasternak Foundation. The model is designed in such a way that it can be used for single-stepped cross

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section. For the first time to-date, the same analysis was conducted for a single-stepped LCB on Pasternak foundation. Stiffness and mass matrices of a cross-ply LCB on Pasternak foundation using the energy method are computed [9]. The cracks can be present in structures due to their limited fatigue strengths or due to the manufacturing processes. These cracks open for a part of the cycle and close when the vibration reverses its direction. These cracks will grow over time, as the load reversals continue, and may reach a point where they pose a threat to the integrity of the structure. As a result, all such structures must be carefully maintained and more generally, SHM denotes a reliable system with the ability to detect and interpret adverse "change" in a structure due to damage or normal operation. [10].

The finite beam element was formulated using the composite element method with a one-member–one-element configuration with cracks where the interaction effect between cracks in the same element was automatically included. The accuracy and convergence speed of the proposed model in computation were compared with existing models and experimental results. [11].The effects of crack depth and location, fiber orientation, and fiber volume fraction on the flexibility and consequently on natural frequency and mode shapes for cracked fiber-reinforced composite beams are investigated [12]. Vibration is a mechanical oscillation about a reference position. Any system has certain characteristics to be fulfilled before it will vibrate. To put in simple words, every system has a stable position in which all forces are equivalent and when this equilibrium is disturbed, the system will try to regain its stable position To remain stable, structure exhibits vibration at different magnitude when excited, the degree of vibration varies from point to point (node to node), due to the variation of dynamic responses of the structure and the external forces applied Therefore, vibration may also be described as the physical manifestation of the interchange between kinetic and potential energy [13].

The mechanical properties of aluminum and fiber (Nylon and Glass fiber reinforcement plastic) are measured a universal testing machine. The three-dimensional finite element models of composite beam with and without cracks are constructed and then computational modal analysis on ANSYS-14 is then performed to generate natural frequencies and mode shapes [14] They considered geometric non-linearity and have solved the expression using Variation Iteration Method (VIM). Also the different nonlinear frequencies have been considered for different shapes of modes [15].

For the present work, Organic Matrix composite materials (i.e., Epoxy and carbon fiber) is used because of their low density and high strength to weight ratio which proved their adaptability for the modern material field. Silicon nitride is used as reinforcement material because of its mechanical behavior at high temperature. The composite Composition used in this work is,

- Epoxy
- Epoxy with 6% Si3N4
- Epoxy with 10% Si3N4
- Carbon/epoxy
- Carbon/epoxy with 6% Si3N4
- Carbon/epoxy with 10% Si3N4

Problem Formulations: The specimen (dimension 100x100x20 mm) has been designed in Catia V5R20 software and Modal analysis is done using ANSYS 15. The condition used for analysis is two end of specimen is fixed (fixed free fixed free).

2. Modal Analysis

Modal analysis is a worldwide used methodology that allows fast and reliable identification of system dynamics in complex structures. Modal analysis refers to measuring and predicting the mode shapes and frequencies of a structure. Modal analysis is performed using finite element modeling software Ansys.

2.1 Theoretical calculations of Modal Analysis:

The formula to calculate natural frequency is

$$\omega_i = \frac{\lambda_i}{l^2}\sqrt{\frac{EI}{m/l}} \qquad (1)$$

Where,

ω_i= Natural frequency (Hz)

E= Modulus of Elasticity (GPa)

I= Moment of inertia (mm^4)

ρ= Density (Kg/m^3)

A= Area of the Specimen

λi= βnℓ= the value for 10 mode is given in table 1

The property of the Specimen is given in table 2

TABLE 1

Λ$_I$ For First 10 Modes

λ_i	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode	6th Mode	7th Mode	8th Mode	9th Mode	10th Mode
Epoxy composite	3.76	4.25	6.18	6.65	8.61	9.24	11.05	11.33	11.37	11.46
Carbon/Epoxy composite	4.78	6.42	6.75	9.79	10.47	10.84	12.4	12.41	13.67	14.38

By using above equation (1) mode shapes have been calculated theoretically

TABLE 2

Properties Of Composite Material

Property	SI unit	Epoxy Composite			Carbon/ Epoxy Composite		
		0% of Si_3N_4	6% of Si_3N_4	10% of Si_3N_4	0% of Si_3N_4	6% of Si_3N_4	10% of Si_3N_4
Density (ρ)	Kg/m^3	1132	1250	1315	1360	1410	1445
Modulus of elasticity (E)	Gpa	3.67	20.60	30.00	36.034	43.630	48.360
Poisson's ratio (μ)	-	0.296	0.293	0.291	0.336	0.334	0.332

For Epoxy composite 1st Mode natural frequency

$$\omega_1 = \frac{3.76}{l^2}\sqrt{\frac{EI}{m/l}}$$

$$\omega_1 = \frac{3.76}{.1^2}\sqrt{\frac{3.67\times 10^9 \times 1.667\times 10^{-6}}{.2264/.1}}$$

$$\omega_1 = \frac{19546}{2\times\pi}$$

$$\omega_1 = 3111\ Hz$$

Similarly, for remaining materials theoretical calculations are done and are tabulated in table 3

2.2 Modal Analysis using Ansys:

Modal analysis is a technique used to obtain Eigen value and Eigen vectors under forced vibration. The natural frequencies and mode shapes of composite are as shown in figure 1 and 2 respectively

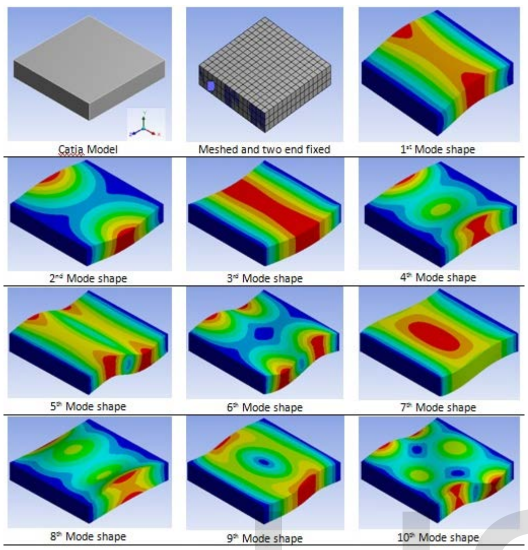

Fig. 1. The mode shape of natural frequencies of Epoxy composite

The mode shape obtain for Epoxy composite is as shown in figure 1 and the value are tabulated in table 3

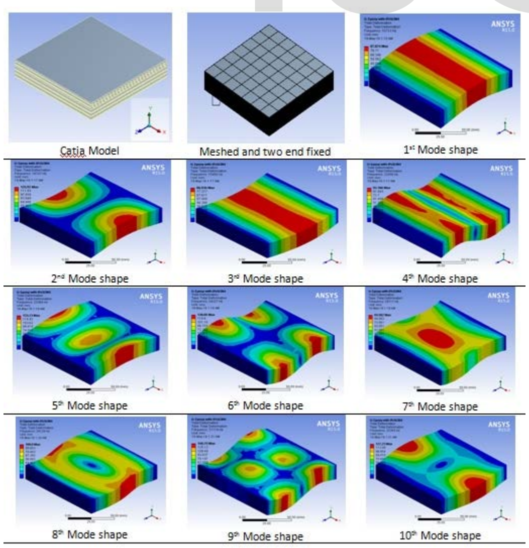

Fig. 2. The mode shape of natural frequencies of Carbon- Epoxy composite

The mode shape obtain for carbon/Epoxy composite is as shown in figure 2 and the value are tabulated in table 3

3. Result And Discussion

First theatrical modal analysis is done problem material and values are compared with the analysis result. Theoretical and Ansys result calculated in the table 3 observed that all theoretical modal analysis results coincide with Ansys values. The modal analysis Frequency also represented graphically for all material in figure 3.

TABLE 3
COMPARISON OF MODAL ANSYS RESULT

Mode shape	Frequency[Hz]											
	Epoxy Composite						Woven carbon fiber- Epoxy Composite					
	0% Si_3N_4		6% Si_3N_4		10% Si_3N_4		0% Si_3N_4		6% Si_3N_4		10% Si_3N_4	
	Theoretical	ANSYS	Theoretical	ANSYS	Theoretical	ANSYS	Theoretical	ANSYS	Theoretical	ANSYS	Theoretical	ANSYS
1.	3111	3113.07	7014	7016.1	8252	8252.97	11092	10715.7	12006	12330	12529	13052.3
2.	3516	3521.13	7928	7940.33	9327	9343.67	14898	14718.3	16126	16448	16828	16943
3.	5113	5108.13	11528	11527.3	13563	13571	15664	15464	16955	17050	17693	18090.3
4.	5502	5505.67	12404	12413	14595	14604.3	22718	21955.3	24591	25250.7	25662	26719
5.	7123	7127.97	16060	16071	18896	18909.7	24296	23313	26299	27145.3	27444	28838.7
6.	7645	7646.47	17235	17245.3	20279	20295.3	25155	24247	27228	27983	28414	29640.3
7.	9142	9142.67	20612	20607.3	24251	24241.7	28775	29111.7	31147	30981	32503	31907.3
8.	9374	9375.27	21134	21133	24866	24861	28798	29117.3	31172	31001.3	32530	31940.7
9.	9407	9399.13	21209	21200.7	24953	24951.7	31722	30903	34337	35466.3	35832	36533
10.	9481	9477.47	21376	21375.3	25151	25154.7	33369	33290.7	36120	36013.3	37693	37982.3

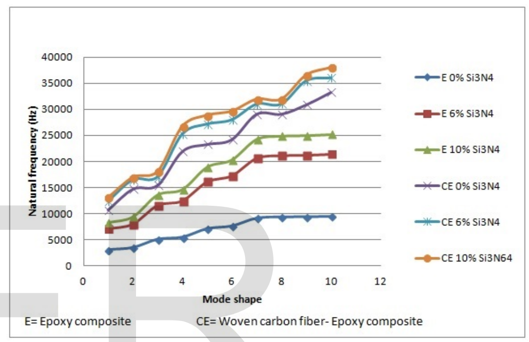

Fig. 3. Comparison of Modal analysis results

4 Conclusion

In this paper work modal analysis for different composites materials is carried out using Ansys and compared with theoretical values.

From the research, natural frequency of the composite is known which is high when compared with conventional material used and also provide wide frequency range to work during machining to avoid resonance so we could get good results.

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