Vibration Analysis of Composite Cantilever Beam with Surface-Crack

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Abstract - Composite beam, column and struts like components are essential constituents of many structures and utilized generally in heavy machines, flying machine and light weight constructions. In present study.The main focus is on the study of vibration analysis because in any structure dynamic attributes varies with many factors like in case of composites angle of fiber orientation, fiber volume fraction affects the natural frequencies and mode shapes. In present investigation, ANSYS is used to study the variation in dynamic attributes in the presence of surface-crack by varying fiber volume fraction and angle of orientation of fibers. The present examination demonstrates that the most noteworthy distinction in frequencies happens when the angle of orientation of fibers is equal to zero degrees.

Keywords – Dynamic attributes, Fiber orientation, Fiber Volume Fraction, Natural Frequencies, ANSYS, Surface-Crack

1. INTRODUCTION

After industrialization, the discovery of new materials brought the evolution in the field of aerospace, aviation, naval ship and other industry. First alloys obsolete the metal due to their some unique properties which are not in metals but after some time composite material obsolete alloys due to amazing properties which can't be present in metal as well in alloy also like chemically resistant, high fatigue strength, high strength, good flexibility, good fabrication capability, and most important property which makes composite a special material for aerospace industry i.e. high strength to weight ratio. In any type of structure, there are two types of loading conditions static and dynamic, so the structure can fail either by static or dynamic loading condition.In different types of defects crack is generally drastic and dangerous defect which may be the cause of the vital and major collapse of any construction**.**The dynamic attributes such as natural frequency, modes of vibration of structures have been the subject of many studies due to several major accidents in past history like Tacoma narrow bridge disaster in which whole bridge collapse due to resonance condition. This type of study becomes more important when a structure has some cracks because due to the presence of the crack, stiffness of structure decreases which affects the dynamic behavior of a structure. In the present investigation, vibration analysis of cantilever composite beam has done with the help of finite element solver ANSYS. Every structure has a unique value of natural frequency on which structure starts to vibrate in the absence of repetitive or dynamic loading. For any structure condition of resonance is very dangerous in which frequency of externally applied load matches the value of the natural frequency of structure which leads to excessive deflection which causes catastrophic failure of the structure. In the presence of the crack, stiffness of structure decreases which affects the dynamic behavior of a structure due to which the value of natural frequency decreases which is dangerous so at the time of application the value of natural frequency must be known and condition of resonance should be avoided. In present study effect of angle of orientation of fibers and fiber volume fraction on the dynamic behavior of cantilever composite beam is studied.

2. MATERIAL AND MODEL

In the present investigation, a composite cantilever beam is taken on which vibration analysis has done. The beam is made of unidirectional graphite fiber-reinforced polyamide composite. The length, width and height are taken 1.0 m, 0.05 m and 0.025 m respectively as taken by Krawczuk & Ostachowicz (1995), the present analysis is done by using finite element solver ANSYS and the results are validated by Krawczuk & Ostachowicz (1995).

In the present analysis, three natural frequencies are calculated by ANSYS and again these lowest three frequencies are normalized by using the following expression which is also used by Krawczuk & Ostachowicz (1995).

$$\omega_n(\alpha) = L\sqrt{\omega(\alpha)/\sqrt{S_{11}I/\rho A}}$$

Where L is beam length, $\omega(\alpha)$ is the natural frequency in radian/second, A is an area of the cross-section of the cantilever beam, I is the moment of inertia, ρ is density of beam material, S_{11} is elastic constant and $\omega_n(\alpha)$ is dimensionless natural frequency.

Table-1: Properties of graphite fiber-reinforced polyamide composite

Modulus of Elasticity	E_m	2.756 Gpa
	E_f	275.6 GPa
Modulus of Rigidity	G_m	1.036 GPa
	G_f	114.8 GPa

Poisson's Ratio	ν_m	0.33
	ν_f	0.2
Mass Density	ρ_m	1600 kg/m^3
	ρ_f	1900 kg/m^3

3. PREVIOUS WORK

Dimarogonas (1996) revealed a great exposure to the vibration of the structure having cracks. This researcher covered a wide assortment of regions that included beam with cracks, coupled frameworks, flexible rotors, shafts, turbine rotors and sharp edges, pipes and shells, empirical investigation of machines with crack and bars and plates with a critical collection of references.

Banerjee (2001) gave exact relations for the governing equation of frequency and mode shapes of composite Timoshenko beam with cantilever end conditions in the explicit analysis frame by utilizing typical calculation. The impact of material coupling between the torsional and bending modes of deformation together with the impacts of shear distortion and rotatory inertia is considered while defining the hypothesis. The expressions for the mode shapes were additionally determined in an explicit form utilizing typical calculation.

Gaith (2011) executed a continuous cracked beam vibration hypothesis for the lateral vibration of Euler–Bernoulli beams with single-edge open cracks. In this investigation, identification of cracks in the simply supported beam of graphite-epoxy is done.The effect of the position of crack, the relative depth of crack, the angle of orientation of fibers and fiber volume fraction on natural frequencies is studied**.**

A. Jafari-Talookolae (2017) developed a semi-analytical method to investigate the free response of the structure, method is taken in view of the variational formulation technique and calculating the weak form of the representing conditions by extremizing the objective function with respect to unknown components of displacement and Lagrange multipliers. Numerical problems are exhibited for both the semi-analytical and finite element method. The outcomes indicate incredible concurrence with the methods gotten by the full three-dimensional finite element model in ANSYS.

4. PROPOSED METHODOLOGY

In the present study, a cantilever composite beam with unidirectional fiber is taken which have a length, width and height are taken 1.0 m, 0.05 m and 0.025 m respectively. The

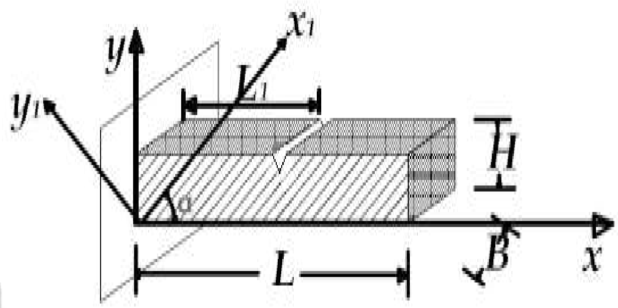

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Fig.1. Diagram of Cracked Composite Cantilever Beam

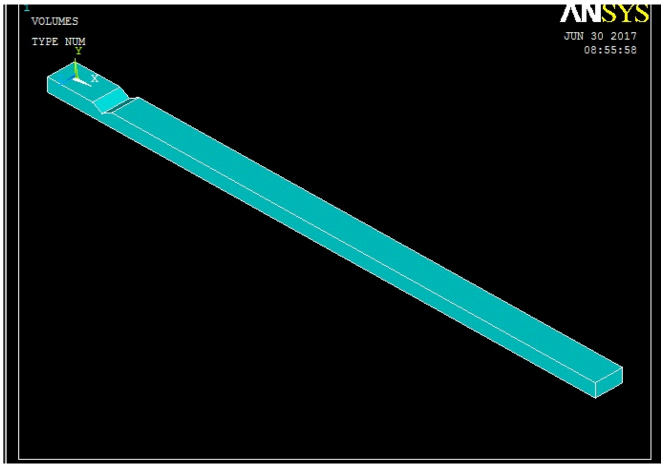

Fig.2. Cantilever Composite Beam modelled in ANSYS

In the present investigation, finite element method is used for which ANSYS use as finite element solver for study the dynamic characteristics of cantilever composite beam such as natural frequencies, mode of vibrations, mode shapes and damping factor with the effect of crack and without the effect of crack present in the beam.ANSYS has three steps which involve the whole analysis, before working in ANSYS all these steps should be known.

1. Preprocessing
2. Solution stage
3. Post-processing

In the present analysis, Solid Shell element is used which is represented by SOLSH 190 which provides the properties of both element Solid element and Shell element. Shell section provides great flexibility in the modelling of the laminated composite beam.

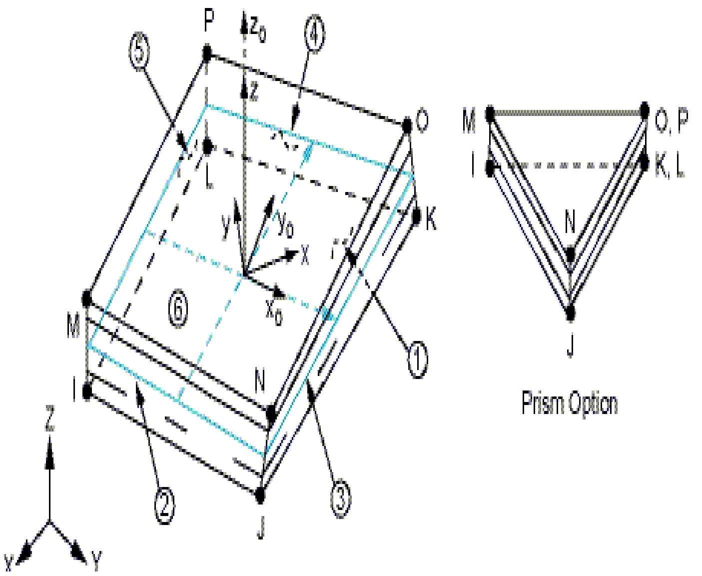

Fig.3. Geometry of SOLSH 190

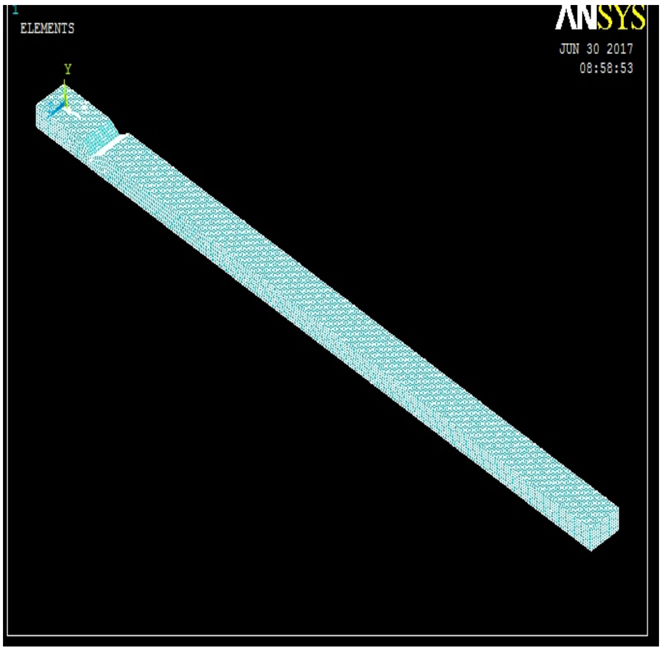

Fig.4. Cantilever Composite Beam meshed in ANSYS

5. SIMULATION/EXPERIMENTAL RESULTS

a) Comparison of Natural Frequencies of non-cracked cantilever composite beam calculated by ANSYS with Krawczuk & Ostachowicz Model

Table-2:First, Second and Third Natural Frequencies as a function of Angle of Fibers for Fiber Volume Fraction (V=0.1)

Angle of fibers (Degree)	Natural Frequencies for Beam without for Fiber Volume Fraction of 0.1		
	First Nat. Freq. (Rad/s)	Second Nat. Freq. (Rad/s)	Third Nat. Freq. (Rad/s)
0	1.8742	4.5578	7.5678
15	1.8240	4.5400	7.4841
30	1.6634	4.1530	6.9124
45	1.4523	3.6356	6.1729
60	1.2144	3.0228	5.0513
75	1.1142	2.7337	4.5690
90	1.0840	2.7045	4.5340

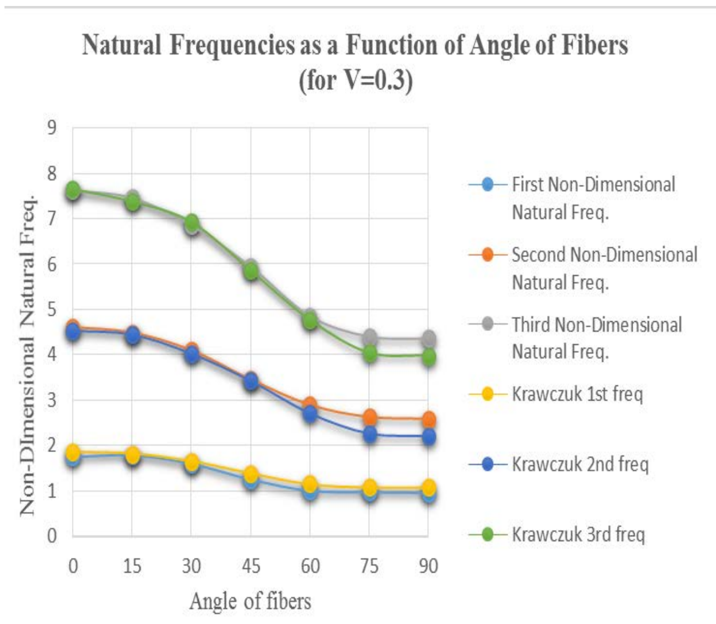

Fig.5. Comparison between the results of Present investigation and Krawczuk & Ostachowicz study

Table-3:First, Second and Third Natural Frequencies as a function of Angle of Fibers for Fiber Volume Fraction (V=0.3)

Angle of fibers (Degree)	Natural Frequencies forBeam without for Fiber Volume Fraction of 0.3		
	First Nat. Freq. (Rad/s)	Second Nat. Freq. (Rad/s)	Third Nat. Freq. (Rad/s)
0	1.8629	4.6053	7.6249
15	1.814	4.4875	7.3448
30	1.649	4.0983	6.8578
45	1.381	3.4563	5.7817
60	1.103	2.7656	4.6566
75	0.9838	2.3973	3.9863
90	0.9831	2.3261	3.8832

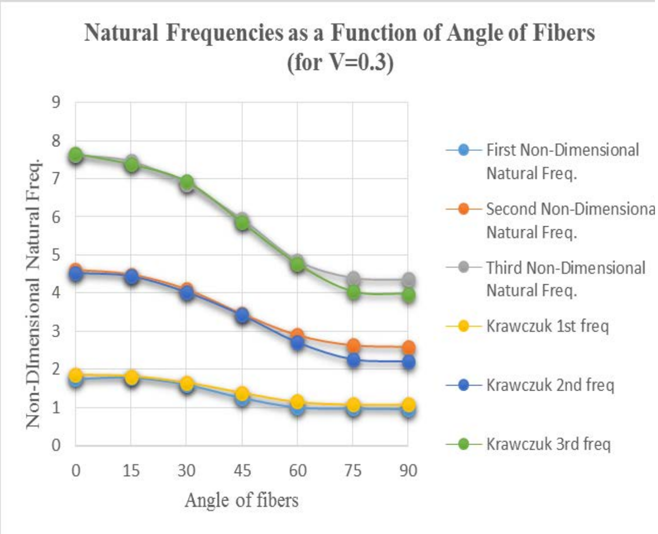

Fig.6. Comparison between the results of Present investigation and Krawczuk & Ostachowicz study

b) Effect of Volume Fraction on Natural Frequencies on Cracked Composite Beam

Table-4:First non-dimensional natural frequencies of the cracked composite beam as a function of fiber volume fraction V for different values of the crack depth a/H = 0.4, 0.6 (crack location L_1/L= 0.1)

Angle of Fiber (Degree)	Fiber Volume Fraction	First Non-Dimensional Natural Freq.	
		Relative Crack Depth a/H=0.4	Relative Crack Depth a/H=0.6
0	0	1.7726	1.6535
	0.1	1.7413	1.5576
	0.3	1.7126	1.5027
	0.5	1.7037	1.4916
	0.7	1.7264	1.5197
	0.9	1.7639	1.5934
	1	1.8028	1.7025

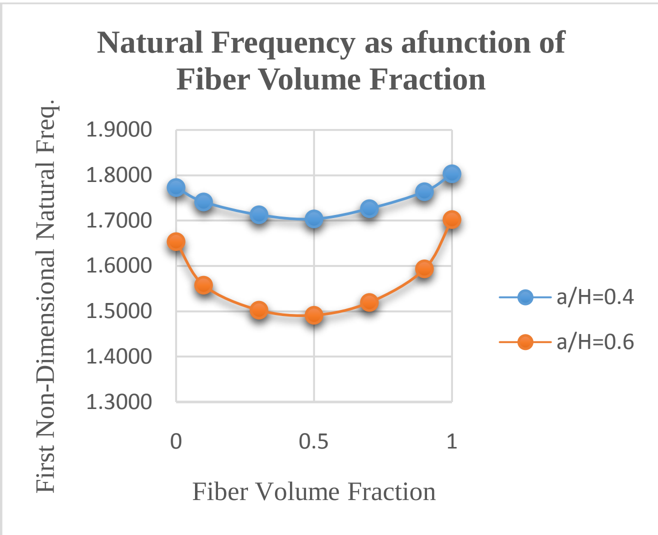

Fig.7. First non-dimensional natural frequencies of the cracked composite beam as a function of fiber volume fraction V for different values of the crack depth a/H = 0.4, 0.6 (angle of fibers α = 0 degree, crack location L_1/L = 0.1)

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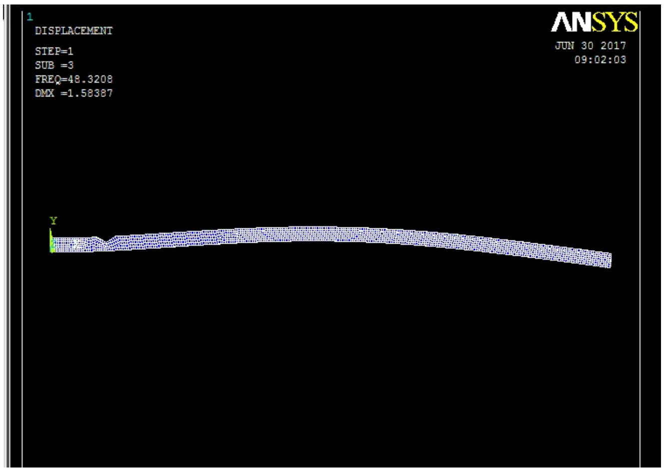

Figure 8. Mode Shape of Cantilever Composite Beam in ANSYS

Table-5:First non-dimensional natural frequencies of the cracked composite beam as a function of fiber volume fraction V for different values of the crack depth a/H = 0.4, 0.6 (crack location L_1/L= 0.1)

Angle of Fiber (Degree)	Fiber Volume Fraction	Second Non-Dimensional Natural Freq.	
		Relative Crack Depth a/H=0.4	Relative Crack Depth a/H=0.6
0	0	4.5175	4.4486
	0.1	4.5011	4.4279
	0.3	4.4862	4.3965
	0.5	4.4850	4.3911
	0.7	4.5165	4.4156
	0.9	4.5587	4.4724
	1	4.5857	4.5269

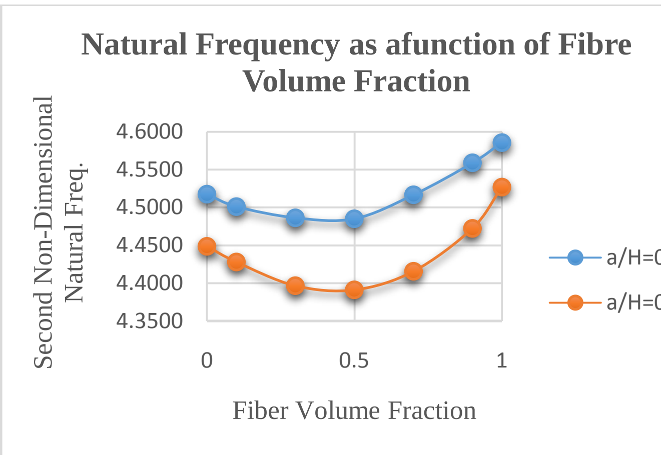

Fig.9. First non-dimensional natural frequencies of the cracked composite beam as a function of fiber volume fraction V for different values of the crack depth a/H = 0.4, 0.6 (angle of fibers α = 0 degree, crack location L_1/L = 0.1)

6. CONCLUSION

By the above analysis it is clear that dynamic behavior such as natural frequency and mode shape of any structure depends on fiber volume fraction as well as the angle of orientation of fibers. As the angle of fibers increase means 0^o to 90^o natural frequencies decrease which clears that for a composite beam fibers should make the minimum angle from the longitudinal axis. In the case of fiber volume fraction natural frequencies are minimum for fiber volume fraction V= 0.5 and maximum at volume fraction 1.

7. FUTURE SCOPES

Results of vibration analysis obtained utilizing ANSYS can be confirmed by leading experiments. A model can be developed for the dynamic behavior of the cantilever composite beam with transverse cracks which will be provided great exposure of the behavior of complex structure which is face by real life situations. The Vibration analysis for varying cross-section with hybrid composite can be done. The results can be utilized to develop a modal for dynamic behavior analysis some advance material like fiber metal laminates and functionally graded material.

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