Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Experimental and Numerical Analysis of Clamped-Clamped Composite Beam

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***Abstract*-The presence of cracks serves as a threat to the performance of structures and it affects the vibration signatures (Natural frequencies and mode shapes). The presence of crack in a structural member causes change in stiffness of that structure. The objective of this work is to evaluate the effect of crack location and crack depth on natural frequency of clamped-clamped composite beam of Glass Epoxy. Here transverse crack is created on the beam at 110 mm, 220 mm and 330 mm from fixed end, the depth of crack is varied as 2 mm, 4 mm and 6 mm. Numerical analysis is performed using commercially available finite element analysis software package ANSYS 16.5. A higher order 3-D shell element, SOLSH190 element is used in analysis. The result of the study concludes that, presence of crack changes the natural frequencies and the mode shape of vibration.**

Keywords: Crack, Composite, Clamped-Clamped, Experimental, Numerical.

Nomenclature:

w -Width of beam
h -Thickness of beam
a -Depth of crack
L -Length of beam
L_1-Distance of crack from left and support
E-Young's modulus
I -Moment of inertia of beam cross section
ρ-Mass density of beam
A-Cross-sectional area of beam
f_n-Natural frequency (Hz)

I. INTRODUCTION

Beams are the basic structural components; they can be used for different application such as in high speed machinery, aircraft and light weight structures. Composite materials are being used more frequently in many different engineering fields because of high strength, low weight, resistance to corrosion, impact resistance, and high fatigue strength. Cracks in a structure may be hazardous due to static or dynamic loadings; hence crack detection plays an important role for structural health monitoring applications.

There are several Non-destructive techniques (NDT's) available for detection of damage in the structure or mechanical component such as X-ray imaging, ultrasonic scans, infrared thermograph, and eddy current can identify damages. But their adoption becomes difficult because somehow they are difficult to implement and some of them are impractical in many cases such as in service aircraft testing, long pipelines in power plants and railway tracks etc.

It is essential to detect the damage as quick as possible to monitor, evaluate and repair the structure if necessary. To achieve this it is possible to rely on method based on vibration test.

I. LITERATURE REVIEW

Kisa [1] studied effect of crack on the dynamic characteristics of composed cantilever beam made of graphite fiber-reinforced polyamide using FEM and component synthesis method. Ertuğrul et al. [2] obtained information about the location and depth of cracks in cracked beams by analyzing the vibrations as a result of impact shocks. Vigneshwaran and Behera [3] studied dynamic characteristic of beam with multiple breathing cracks. Chondros et al. [4] has analyzed the lateral vibration of cracked Euler-Bernoulli beams with single or double edge cracks to predict dynamic response of simply support beam. Chalah-Rezgui et al. [5] investigated free vibration analysis of beam with constant geometrical and mechanical properties having one to two overhangs based on assumptions of Euiler-Bernoulli theory. Maiti and Sinha [6] used higher order shear deformation theory for the analysis of composite beams different stacking sequences, different (l/h) ratios and different boundary conditions were considered for analysis. Krishnaswamy [7] have studied the free vibration of LCBs including the effects of transverse shear and rotary inertia. Dynamic equations governing the free vibration of laminated composite beams are developed using Hamilton's principle. Banerjee [8] has investigated the free vibration of axially laminated composite Timoshenko beams using dynamic stiffness matrix method. 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.

II. THEORY OF FREE VIBRATION OF BEAM

The natural frequency for free-free vibrations of beam in general is given as [9]

$$f_n = \frac{1}{2\pi}\alpha^2\sqrt{\frac{EI}{\rho AL^4}}$$

If a structure is defective, there is a change in the stiffness and damping of the structure in the region of the defect. A reduction in stiffness (EI) implies a reduction in the natural frequencies of vibration.

Major characteristics of structures, which undergo change due to presence of crack, are

- The natural frequency
- The amplitude response due to vibration
- The mode shapes

Hence it is possible to use natural frequency measurements to detect cracks.

III. EXPERIMENTAL ANALYSIS

A composite beam of E Glass Epoxy with dimensions 550mm×50mm×10mm is used for analysis. The transverse cracks were created at different locations with varying depths by using Hack saw [32 teeth per inch]. The beam is excited for free vibrations to obtain the natural frequencies. The beam is clamped on a table with the help of clamping device arrangement (baby vice). The impact is applied by striking the hammer at different positions. During free vibrations, the dynamic responses of the beam are measured through the accelerometer as shown in figure. For this test, the position of accelerometer is also varied in order to extract the signals of vibration. The layout of the sensors on the test specimen is depicted in Figure A data acquisition system i.e. vibration analyzer is used to record and transfer measured data to the user interference (laptop) for post processing. Frequency response functions (FRFs) were obtained and analyzed.

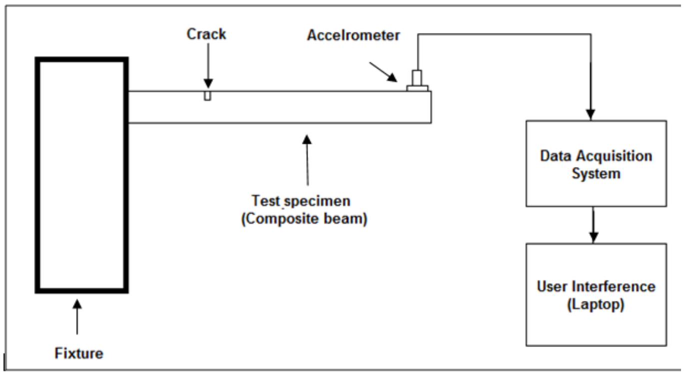


Fig.1 Block diagram of experimental setup

A. *Steps in experimental analysis*

1. A composite beam of E Glass Epoxy was used as a cantilever beam.
2. For cantilever beam the fixed end was made by fixing the beam with the help of baby vise fixed on the table.
3. The connections of the accelerometer, impact hammer, vibration analyzer and user interference (laptop) were properly made.
4. The cantilever beam was struck with an impact hammer and is excited by means of it.
5. Accelerometer was placed at the different positions on the cantilever beam, to measure the vibration response.
6. All the data was recorded and obtained from the vibrating beam with the help of accelerometer attached to it.
7. The experiments were repeated to check the repeatability of the experimentation.
8. The whole set of data was recorded and then the data was imported into the user interference (Laptop). Further processing and analysis was done using Virtual unit VA4 Pro software. The signal obtained from the data acquisition system is used to extract the mode frequencies
9. Repeat impact testing procedures and calculate the natural frequency of the structure by varying following parameters such as,
    a) Location of crack.
    b) Depth of crack.

Fig.2 Experimental setup for crack detection in clamped-clamped beam

IV. NUMERICAL ANALYSIS

Finite Element Analysis (FEA) approach is widely used these days for numerical analysis. ANSYS is commercial finite element software package which has capability to analyze a wide range of different problems. Modal Analysis is a tool used to determine vibration characteristics or natural frequencies of a mechanical structure. It can also be used for dynamic analysis, harmonic response, and transient dynamic analysis. Modal analysis in ANSYS® is linear analysis. The proposed work is concentrated on determination of natural frequency of vibration. A Composite beam of dimensions 550mm×50mm×10mm with 20 layers of epoxy glass fibers having thickness 0.5mm is modeled using ANSYS 16.2. The material properties for woven glass fabric are considered as E_{11}=25GPa, E_{22}=25GPa, E_{33}=0.6E_{11}, μ=0.2 and modulus of rigidity G=4GPa.The natural frequency and mode shapes for cantilever conditions with and without crack were analyzed for varying crack depth and crack locations. Following procedures for a cracked composite beam were followed for the analysis-

A. *Steps in numerical analysis*

1. Geometry modeling of composite beam.
2. Selection of element type (here SOLSH190 element of 3D modeling is used).

3. Applying material properties to composite beam (Material modeling > Orthotropic properties)
4. Section Lay-up of composite beam. Specify the thickness of layer (0.5mm), orientation (0/90 orientation), number of integration points.
5. Meshing of model.
6. Apply boundary conditions (one end fixed for cantilever structure) and define number of modes to be extracted.
7. Solution.
8. Perform post processing to read and plot result.

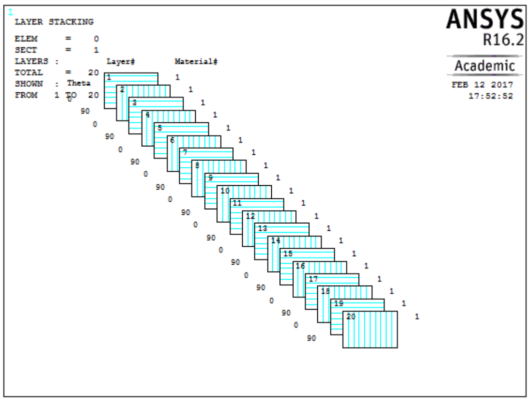


Fig.3 Layers stacking in ANSYS.

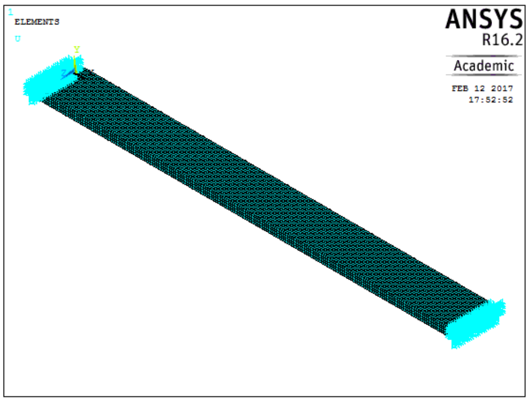


Fig.4 Meshed composite clamped-clamped beam model.

V. RESULTS AND DISCUSSION

The results obtained from the experimental and numerical analysis on cracked composite plate for crack depth 2 mm, 4 mm and 6 mm. The length of the crack is also varied as 110mm, 220mm and 330mm from left hand support. The 1st, 2nd and 3rd mode natural frequencies in case of both cracked and uncracked composite beams for cantilever condition are shown in Table-

Crack Location (mm)	Crack Depth (mm)	Experimental			Numerical		
		ω_1 (Hz)	ω_2 (Hz)	ω_3 (Hz)	ω_1 (Hz)	ω_2 (Hz)	ω_3 (Hz)
Uncracked	-	142	398.5	570	148.73	406.97	574.98
110	2	141.5	399	568	148.64	405.05	573.42
	4	140	392.5	565.5	148.65	399.22	571.24
	6	138.5	381	560	148.65	386.36	569.27
220	2	140	395	569.5	147.77	406.00	574.63
	4	138	396.5	570	144.72	403.60	574.57
	6	132	390	568	137.99	398.53	574.53
330	2	140.5	393	568.5	148.25	403.78	574.18
	4	140	390	566	146.85	394.04	573.34
	6	135	368.5	563.5	143.60	374.71	572.62

Table 1 Natural frequency for both Uncracked and cracked composite clamped-clamped beam.

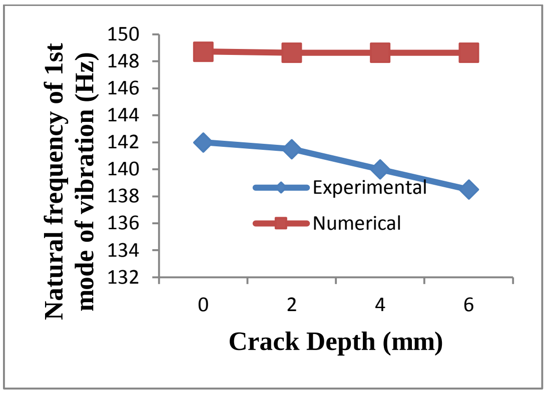


Fig.5 First mode natural frequencies Vs Crack depth for Crack location 110 mm. (Clamped-clamped)

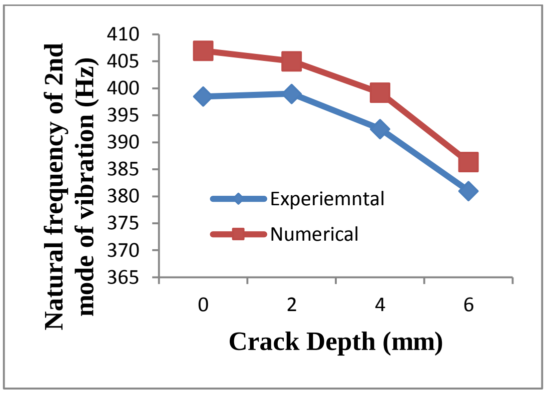


Fig.6 Second mode natural frequencies Vs Crack depth for Crack location 110 mm. (Clamped-clamped)

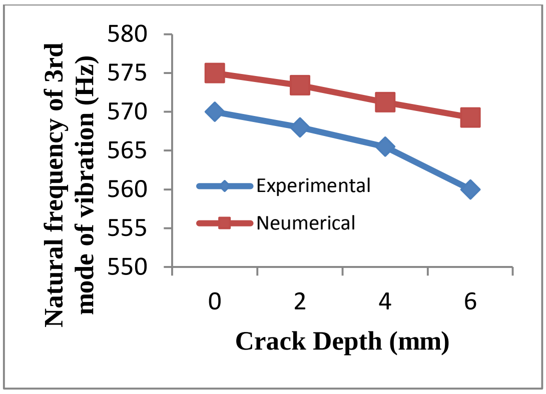
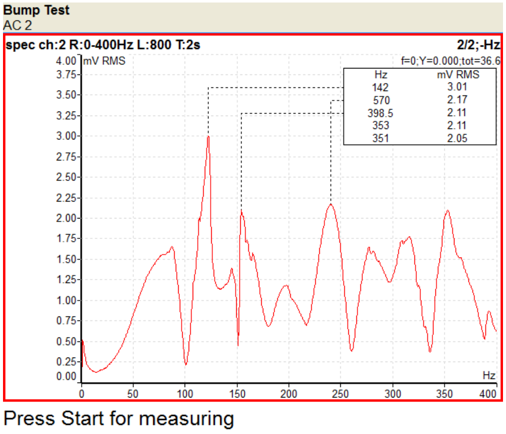


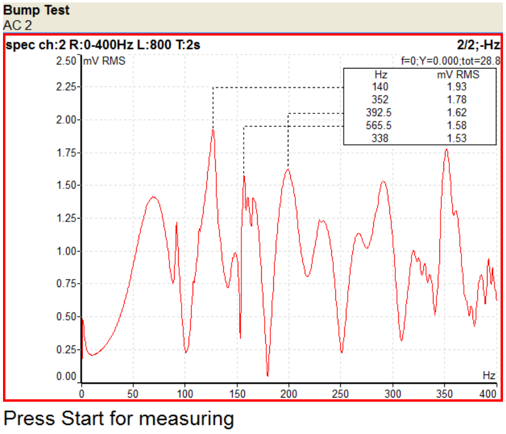
Fig.7 Third mode natural frequencies Vs Crack depth for Crack location 110 mm. (Clamped-clamped)



Hz	mV RMS
142	3.01
570	2.17
398.5	2.11
353	2.11
351	2.05

Press Start for measuring

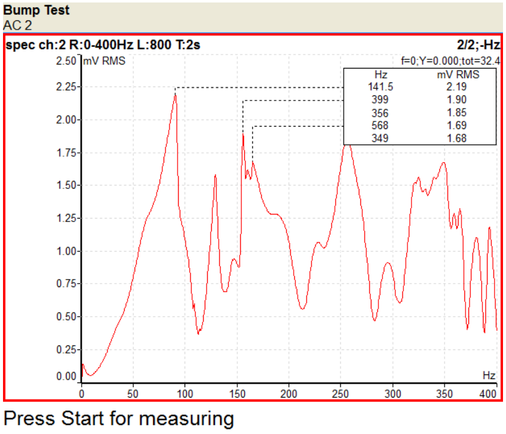
Fig.8 FRF of Uncracked clamped-clamped beam.



Hz	mV RMS
140	1.93
352	1.78
392.5	1.62
565.5	1.58
338	1.53

Press Start for measuring

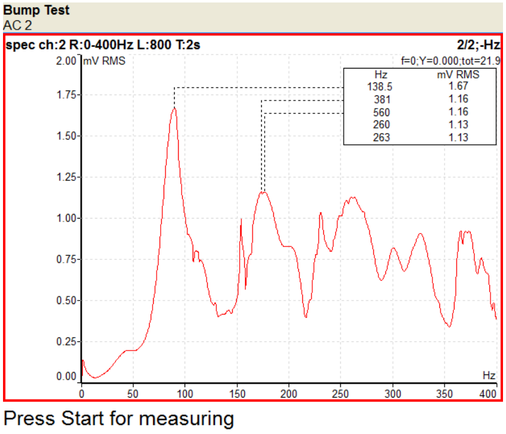
Fig.9 FRF of cracked clamped-clamped beam at 110mm and depth 4mm.



Hz	mV RMS
141.5	2.19
399	1.90
356	1.85
568	1.69
349	1.68

Press Start for measuring

Fig.10 FRF of cracked clamped-clamped beam at 110mm and depth 2mm.



Hz	mV RMS
138.5	1.67
381	1.16
560	1.16
260	1.13
263	1.13

Press Start for measuring

Fig.11 FRF of cracked clamped-clamped beam at 110mm and depth 6mm.

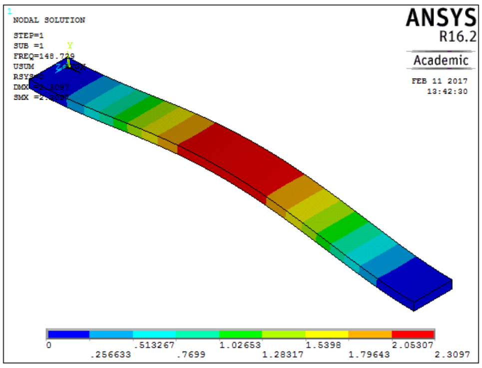


Fig.12 Deformed shape for 1st mode of vibration of composite clamped-clamped beam without crack.

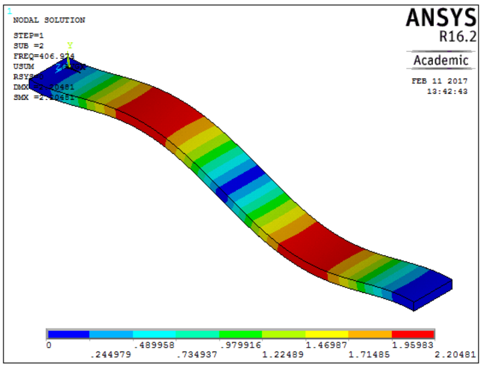


Fig.13 Deformed shape for 2nd mode of vibration of composite clamped-clamped beam without crack.

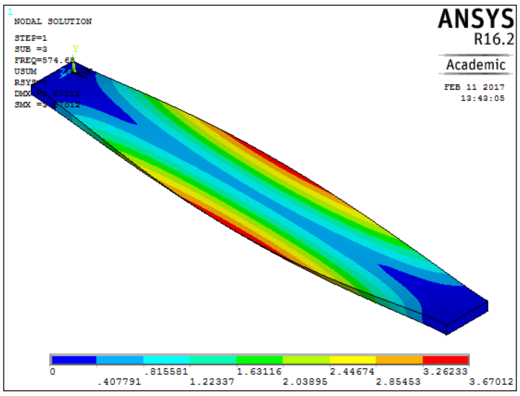


Fig.14 Deformed shape for 3rd mode of vibration of composite clamped-clamped beam without crack.

I. CONCLUSION

It can be seen that the natural frequencies for clamped-clamped conditions decrease with the introduction of a crack. It can be concluded that the natural frequency of vibration of the composite plate decreases with increase in depth of the crack. The natural frequency of the beam decreases with increase in length of the crack from left hand fixed end till the mid span of beam and again starts increasing towards right end.

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