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Dynamic Behavior of Fiber Reinforced Composite Beam With Crack

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ABSTRACT*: Composites have numerous applications in engineering field. In engineering design averting failure of composite material system has been a vital concern. Composite are subjected to numerous types of damage, mostly cracks and delamination. The presence of crack causes a variation in stiffness and it also affects the mechanical behavior of entire structure. Cracks are caused by fatigue under service conditions as a consequence of limited fatigue strength. Measurement of natural frequency can be taken as a tool to identify the presence of cracks which are propagated due to fluctuating stress conditions. In the present work an attempt has been made to find the natural frequencies of fiber reinforced composite cantilever beams with and without presence of a transverse surface crack. E-Glass fiber reinforced composite beams with epoxy resin having a volume fraction of 16.6% have been casted by hand lay-up method and are used for determination of natural frequencies of beams. The free vibration study is carried out by ATALON FFT analyzer, accelerometer and excitation by impact hammer. The DEWESOFT software is used to convert the responses from time domain to frequency domain and the Frequency Response Functions (FRF) are obtained. The experimental results are compared with numerical predictions using the FEM based software package ANSYS 16.2. The process of finding of natural frequencies is carried out for various crack depth ratios at various crack locations by both numerical and experimental methods. A good accord is observed between the experimental and ANSYS results.*

Keywords*: E-Glass fiber, Natural Frequency, Vibration Analysis, Transverse Crack, FFT Analyzer*

I. INTRODUCTION

The various properties of composite materials like high strength, low weight, resistance to corrosion, impact resistance and high fatigue strength increase their reputation. A composite material is the combination of two or more combined constituents which are combined at a macroscopic level and are not soluble each other. In that one is called as reinforcing phase, in which it is embedded is called as matrix. The reinforcing phase may be in the form of fibers, particles or flakes. Generally the materials in matrix phase are continuous. There are some examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, carbon fibers, glass fibers etc. Cracks present a serious threat to the performance of structures since most of the structural failuresare due to material fatigue. For this reason, methods allowing early detection and localization of cracks have beenthe subject of intensive investigation the last two decades. As a result, a variety of analytical, numerical andexperimental investigations now exist. Cracks found in structural elements have various causes. They may be fatiguecracks that take place under service conditions as a result of the limited fatigue strength. They may be also due tomechanical defects, as in the case of turbine blades of jet turbine engines. In these engines the cracks are caused bysand and small stones sucked from the surface of runway. Another group involves cracks which are inside thematerial. They are created as a result of manufacturing processes. The presence of vibrations on structures andmachine components leads to cyclic stresses resulting in material fatigue and failure. Most of the failures of presentequipment are due to material fatigue. It is very essential to detect the crack in structures& machine members fromvery early stage.

Transverse cracks are most common and reduce the cross section of the beam. They introduce a local flexibility in the stiffness of the beam due to strain energy concentration in the vicinity of the crack tip.

A new concept of theoretical analysis of composite cantilever beam under the free vibration with open cracks was developed by Murat Kisa [1].Fatigue life and depth of crack was detected in cantilever beam using frequency based method by KausharH.Borad et al [2].Deviation mode shape analysis and curvature mode shape analysis were used to detect the damage in composite beam by Oruganti et al [3].The damage detection of fiber reinforced polymer honeycomb sandwich beams was carried out by Qiao[4]. The damage detection and structural health monitoring procedures were developed. L.S. Dhamade et al [5] developed a sandwich material used for fabrication of aerospace body for its qualities like low weight, good fatigue strength, load bearing capacity and corrosion resistance. Krishnan Balsubramanaiam [6] developed a new combined concept for detection of transverse crack in a composite beam. Irshad A. Khan et al [7] in his work discussed RBFNN for damage diagnosis of cracked cantilever beams. An exact two dimensional analytical solution for free vibration analysis of simply supported piezoelectric adaptive plates was suggested by Benjenddou et al [8] and numerical validation of it by modal analysis of several hybrid plates with graphite epoxy substance and surface bonded piezoelectric layers. Yang et al. [9] conducted experiments to determine the vibration characteristics of hybrid carbon fiber composite pyramidal truss sandwich panel and also analytical models in ABAQUS to find the structural modal parameters including damping characteristics.

II.THEORETICAL ANALYSIS

In the present work E-Glass fiber reinforced composite beams of dimensions 600mm x 50mm x 6mm with volume fraction of 16.6% are casted by hand layup method. The beams are then subjected to free vibration for cantilever boundary condition by impact hammer. The free vibration study is carried out by ATALON FFT analyzer, accelerometer and excitation by impact hammer. The DEWESOFT software is used to convert the responses from time domain to frequency domain and the Frequency Response Functions (FRF) are obtained. The experimental results are compared with numerical predictions using the FEM based software package ANSYS 16.2. The process of finding of natural frequencies is carried out for various crack depth ratios at various crack locations by both numerical and experimental methods.

A composite is a structural material that consists of two or more constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The volume fraction of a fiber reinforced composite is defined as the ratio of volume of fiber to volume of composite.

$$V_f = \frac{W_f}{\rho_f} / \left(\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} \right) \text{ - - - - - - (1),} \quad \rho_c = \rho_f V_f + \rho_m V_m \text{ - - - - -(2)}$$

Where V_f = Volume fraction of the fiber,V_m= Volume fraction of matrix, W_f = Weight of the fiber, ρ_f = Density of the fiber, W_m = Weight of matrix, ρ_m = Density of the matrix ,ρ_c= Density of composite

The longitudinal young's Modulus $E_1 = E_f V_f + E_m V_m$ - - - - - - - (3)

Where E_1 = Longitudinal Young's Modulus, E_f = Young's Modulus of Fiber, V_f= Volume fraction of Fiber,E_m = Young's modulus of Matrix, V_m = Volume fraction of Matrix.

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \text{ - - - - - - - -(4)}$$

Where E_2 = Transverse Young's Modulus

$E_2 = E_3$, where E_3 = Transverse Young's Modulus in another transverse direction.

$G_f = \frac{E_f}{2(1+\vartheta_f)}$ - - - - - - - -(5), where G_f = Shear Modulus of the fiber, υ_f = Poisson's ratio of fiber

$G_m = \frac{E_m}{2(1+\vartheta_m)}$ - - - - - - -(6), where G_m = Shear Modulus of the matrix, υ_m = Poisson's ratio of matrix

$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$ - - - - - -(7), where G_{12} = Shear Modulus of the unidirectional composite beam.

$G_{23} = \frac{E_2}{2(1+\vartheta_{23})}$, - - - - - - (8), where G_{23} = transverse shear modulus, υ_{23}= Transverse Poisson's ratio

$\upsilon_{23} = \frac{K^* - mG_{23}}{K^* + mG_{23}}$ - - - - - - - -(9), where K* = Bulk Modulus of the Composite under longitudinal Plane Strain,

$$m = 1 + 4K^* \frac{\upsilon_{12}^2}{E_1}$$

$K^* = \frac{K_m(K_f+G_m)V_m + K_f(K_m+G_m)V_f}{(K_f+G_m)V_m + (K_m+G_m)V_f}$ - - - - -(10), Where K_f, K_m = Bulk Modulus of the fiber, matrix under longitudinal plane strain

$K_f = \frac{E_f}{2(1+\upsilon_f)(1-2\upsilon_f)}$ - - - - - -(11), $K_m = \frac{E_m}{2(1+\upsilon_m)(1-2\upsilon_m)}$ - - - - - -(12),

$\upsilon_{12} = \upsilon_f V_f + \upsilon_m V_m$ - - - - - -(13).

The first natural frequency of composite beam is given by

$$\omega_1 = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}} - - - - - (14)$$

Where ω_1= fundamental Natural frequency of the composite beam, E= Longitudinal Young's Modulus, I= Moment of Inertia of the Composite beam, ρ = Density of the beam, A= Area of Cross section, L= Length of the beam. The properties thus evaluated are tabulated in Table 1.

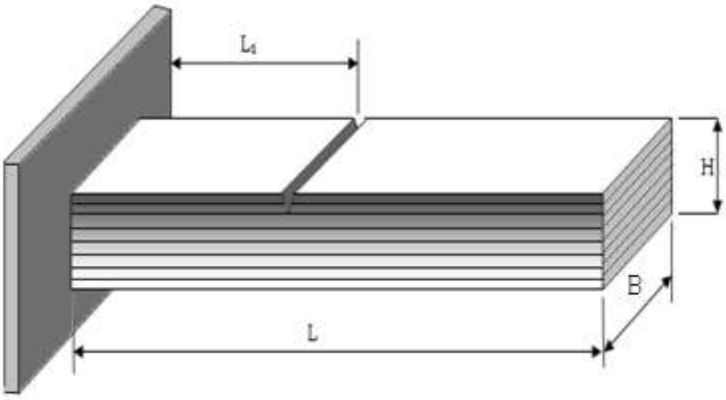


Fig:1. Composite Beam with Crack

Table 01: Properties of E-Glass Fiber Reinforced Composite Beam for 16.6% Volume Fraction.

S.No	Properties of Composite Beam	Value
01	E_1= Young"s Modulus in X- direction	16.9456 GPa
02	E_2= Young"s Modulus in Y- direction	04.0445 GPa
03	E_3= Young"s Modulus in Z- direction	04.0445 G Pa
04	G_{12}= Modulus of Rigidity in x-y Plane	1.5565 GPa
05	G_{23}= Modulus of Rigidity in y-z Plane	1.5758 GPa
06	G_{13}= Modulus of Rigidity in x-z Plane	1.5565 GPa
07	υ_{12}= Poisson's Ratio for x-y plane	0.2834
08	υ_{23}= Poisson's Ratio for y-z plane	0.524
09	υ_{13}= Poisson's Ratio for x-z plane	0.2834
10	ρ= Desity	142244 Kg/m^3

III. EXPERIMENTAL METHODOLOGY

The fiber reinforced composite beams consists of E-glass fiber reinforced in epoxy resin. The sequence of arrangement of E-glass fiber in each layer is one of the assessment parameters. These specimens were cast using hand layup technique as shown in figure 1.Open mould was used for casing of flat composite plate. The fabrication of composite was carried out by placing liquid resin along with the reinforcing fibers on the finished surface of the mould. The proportion of fiber and matrix was taken 27:73 percent by weight. The matrix comprised of gel coat made up of epoxy and 13% hardener HY150. Six layers of E-Glass fibers were used for preparation of the composite plate.

The casting of specimen was started with the deposition of gel coat on the plastic sheet placed over the open mould, with help of a brush. The releasing agent was sprayed on the plastic sheet before application of gel coat. The bottom most layer of reinforcement was provided by placing the fiber on the gel coat. Steel rollers were used to confirm that no air bubble was entrapped after which the next layer of E-Glass fiber which were cut earlier cut to required size were laid on the gel coat as per the sequence. The top most gel coat was laid at last and another plastic sheet sprayed with releasing agent. The whole arrangement was kept under a heavy flat metal rigid platform in normal room conditions for at least 24 hours for proper compression. The plate so obtained then moved for cutting it in to beams of required size. The process is shown in Fig.2.

The physical properties of fabricated composite beams such as density and thickness were measured. The weights of specimens were measured using digital weighing balance. A transverse crack of required 1mm depth was generated using small hacksaw at desired position say at 100mm distance from fixed end. Vibration test was conducted using accelerometer, impact hammer by giving connection to FFT analyzer. At first the accelerometer was mounted using wax on composite beam which was fixed as cantilever beam. The excitation was given with impact hammer and the excitations were transmitted to the FFT analyzer which can convert the vibrations from time domain to frequency domain. The frequencies were obtained from the peaks of the FRF spectrum which was extracted using DEWESOFT. The process of finding out these natural frequencies was repeated by increasing the depth of cut by further 1mm at each stage and up to 4mm depth of cut at the same location. Similarly by changing the position of crack the entire procedure was repeated for different crack depths at various required crack locations on the beam from fixed end. The Fig.3 shows the experimental set up.

Figure 2: Fabrication Process of E-Glass Fiber **Figure 3:** Vibration Analysis using FFT Analyzer

IV.SIMULATION USING ANSYS

In main Menu selection of Structural Analysis is done in preferences. In Pre Processor select Element type(SOLSH190) and material properties are defined with the help of material model menu. Orthotropic material properties have been considered and the values of various input parameters are given. In the next step is to create model of composite beam, the layered composite specifications including layer thickness, material, orientation and number of integration points through the thickness of the layers are specified via shell section commands. In modeling the composite beam model, the key points have been defined as per the required dimensions of the beam and these key points are joined to obtain lines from which area of the beam is generated using proper command. In order to create volume element, the area is extruded using extrude command. Now the process of fine meshing is carried out by using mesh tool. The necessary boundary conditions are imposed to form the cantilever composite beam by arresting all degrees of freedom at on end cross section of the beam. In solution stage the modal analysis type is chosen and Blocklanczos method is opted for natural frequency extraction. The solution command is operated to obtain results and results can be obtained from general post processor. The process is repeated at different crack depths for various crack positions along the beam.

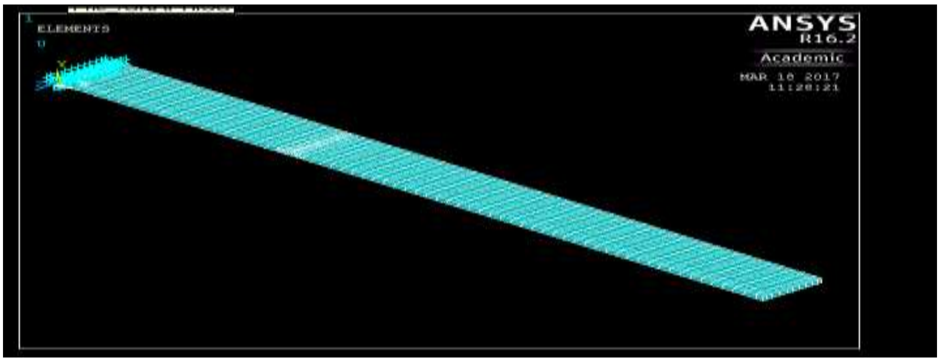


Figure 4: Composite Beam with Crack after Meshing

V. RESULTS AND DISCUSSION

Dynamic analysis of E-Glass fiber reinforced composite beams of dimensions 600mmx50mmx6mm have been considered for analysis. The natural frequencies of these beams have been found for cantilever beam boundary condition without and with a transverse surface crack.The process is carried out by both experimentation and simulation using ANSYS16.2. The process is repeated for various depths at different locations along the beam length. The results obtained are shown in graphs from Fig. 5 to Fig. 13. The variation of natural frequency with Crack Depth Ratio(CDR) at different Crack Positions(CP) is shown in from Fig.5 to Fig.9. It is observed that as the depth of the crack increases the natural frequency decreases. Similarly as the position of the crack changes from fixed end the natural frequency increasesfor the same crack depth. These variations are shown in from Fig.10 to Fig.13. These variations in natural frequencies are due to change in the stiffness of the composite beams due to presence of the crack, its intensity and location. A careful study of these changes supports to identify the presence of the cracks in structural members without disengaging the member from the system.

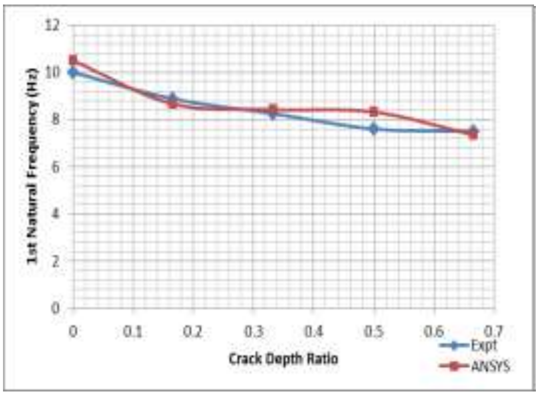


Figure5: CDR Vs Frequency at 0.166 CP

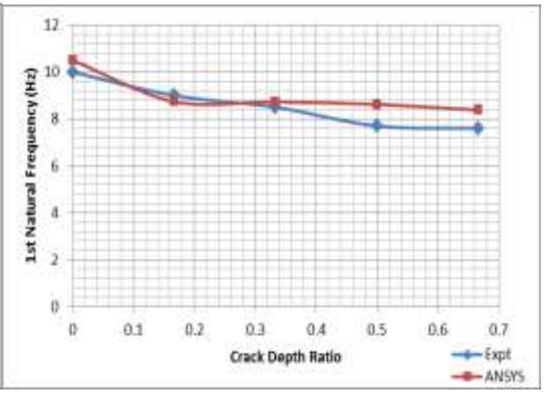


Figure.6: CDR Vs Frequency at 0.333 CP

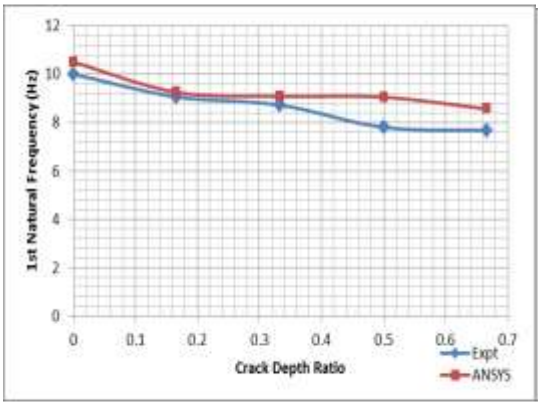


Figure.7: CDR Vs Frequency at 0.5 CP

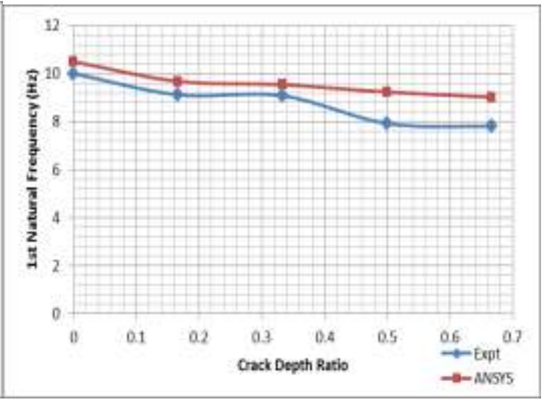
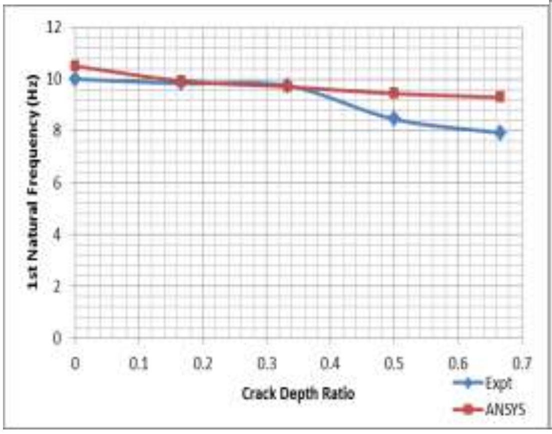


Figure8: CDR Vs Frequency at 0.666 CP



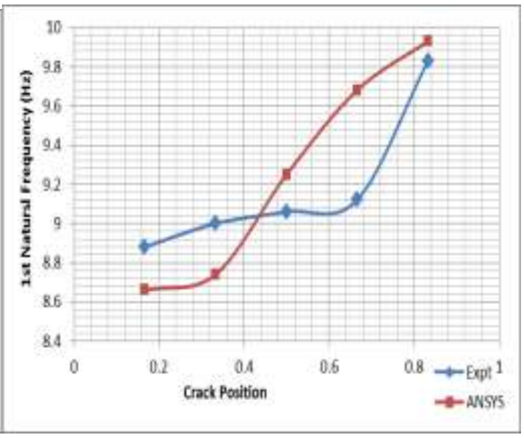
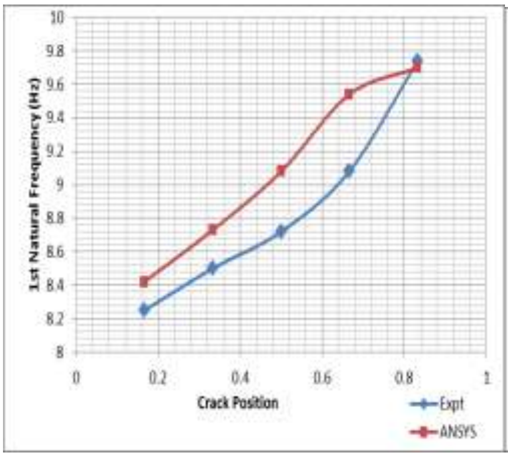


Figure.9: CDR Vs Frequency at 0.833 CP**Figure.10:** Variation of Natural Frequency along

The beam for 0.166 CDR



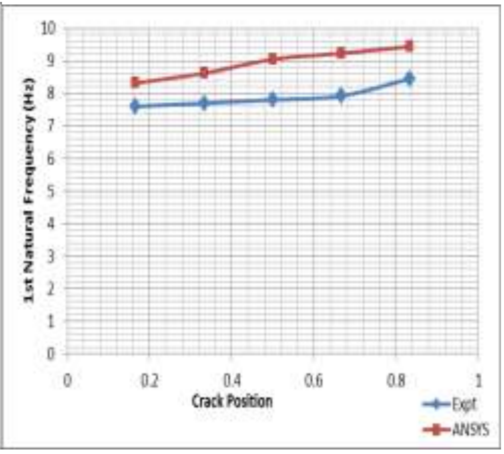


Figure11: Variation of Natural Frequency along the beam for 0.33 CDR **Figure 12:** Variation of Natural Frequency along the beam for 0.5 CDR

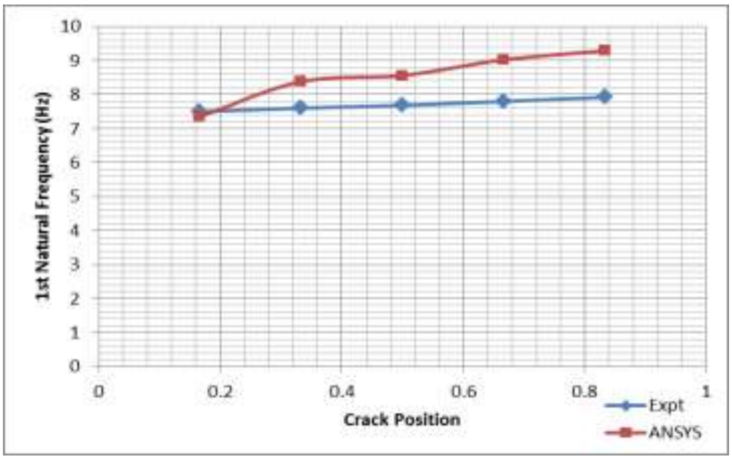


Figure13: Variation of Natural Frequency along the beam for 0.666CDR

VI.CONCLUSION

The following conclusions can be drawn from the current investigations of dynamic analysis of cracked composite beam of E-Glass fiber reinforced Epoxy resin. The fundamental natural frequency changes with the presence of crack in a beam. The natural frequency decreases with the increase of crack depth. It also changes with its position from fixed end of the composite beam for the same intensity of the crack. The analysis can be used to identify the presence of cracks in composite structural elements considering the natural frequency of uncracked ones. The study can be extended by simulation process using MATLAB. The effect of multiple crack condition can also be examined. Hence it can be concluded that the analysis can be used as a condition monitoring technique for monitoring of surface cracks developed in structural members during service condition without disengaging the elements from structure.

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