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Free Vibration Analysis of Fiber Woven Glass Polymer Composites Reinforced with Carbon Nano Tubes

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Abstract: Carbon nanotubes are used as structural material due to its promising properties such as mechanical strength, chemical stability, density and affinity with matrix. The modulus and stiffness of the CNT is yet to be ensured for structural engineering applications. Present study deals with the assessment of free vibration of fibre /matrix composite with various concentrations of multi walled carbon nanotubes. Tensile testing at room temperature reveled that addition of 0.2 % CNT yielded maximum strength and modulus among all the modified CNT composite systems. Free vibration analysis was carried out to study the natural frequency of the composites. Fractographic analysis figured out various failures modes of the composites at room temperature.
Keywords: Natural frequency, deaggregation, sonication, parametric analysis.

I. INTRODUCTION

The Fiber reinforced polymer composites are widespread in many structural applications viz. aerospace, sporting goods, automobile, civil and marine structures as they possess high specific moduli and specific strengths. The industries inclined towards the Fiber reinforced polymer composites due to their excellent in-plane and fiber dominant properties. However, the poor resin matrix and weak fiber matrix interfacial bond resulting weak in thickness properties, the FRP are suitable to limited applications. The better thickness properties are desirable to avoid delaminating problems of aerospace and military components. Since the CNTs were discovered by Iijima [1], the researchers made several attempts during past decade to reveal the mechanical behavior of nano tubes and CNT-reinforced composite materials [2,3].

New opportunities were offered to improve mechanical and multifunctional properties by the introduction of nanotechnology in the field of composite materials with nanoscale fillers such as carbon nanotubes (CNTs) and carbon nanofibers (CNFs) FRPs [4]. Nanofillers can be added into the FRPs to modify the properties of polymer matrix in consideration of their excellent Young's modulus, strength, extremely high aspect ratio, large surface area, magnificent thermal and electrical properties [5].

Natural frequencies and damping coefficients were evaluated for all tested materials and compared with numerical results. The natural frequency of glass epoxy composite is better than basalt epoxy composite. The natural frequency changes with the fiber orientation and end conditions of a material. The natural frequency of basalt woven fabric composite is higher than that of unidirectional composite as it possesses high stiffness. The damping coefficient of unidirectional laminate under cantilever configuration was decent as compared to woven laminate. This is due to high stiffness achieved by increased volume fraction of compression moulding[6].

The variety of applications viz. oscillators, charge detectors, clocks, field emission devices and sensors pushing the researchers to study the vibrations of CNTs. Elastic moduli and other aspects of mechanical behavior of CNTs were determined by electronic microscopic observations. Intense heating has been found in CNTs because of Microwave excitation. This motivation led to study the vibration characteristics of CNTs. The first mechanical study of CNTs was made by Schadler et al.[7] was to measure the stress-strain properties of MWCNT-epoxy composite in both tension and compression. The increase of elastic modulus was noticed with the addition of nanotubes by 5% wt. while there is no significant improvement in strength and toughness. Debonding occurs if either the nano-matrix interface fails or matrix fails due to large shear stresses near the interface. It was instructed to study the interaction between polymer and nanotube in the vicinity of the interface. However care must be taken as the relationship between nano tube binding energy and the IFSS. Lordi and Yao calculated both and developed a correlation [8]. It is also to be noted that, the type of bonding defines the matrix binding [9].

The interfacial interactions with nanotubes results in an interfacial region of polymer with morphology and properties different to the bulk (give reference here). McCarthy et al. [10] discussed the effect of fiber orientation, the flexural torsion vibration frequency was increased for the fiber angle of $\theta = \pm 45$; whereas maximum bending moment occurs at $\theta = 0°$. *Qiao and Zou* [11] developed a dynamic and versatile algebraic model for the free vibration analysis of thin walled FRP structures and as basis for the study in active control and damping of FRP structures . Naresh et.al [12] analytically evaluated the vibrational response of CNT reinforced composite beam. The governing differential equations of motion of CNT reinforced composite beam were described in finite element formulation. The addition of CNT in FRP composite increases natural frequency. While the natural frequency significantly increases with the aspect ratio. Muhammad et.al [13] studied the effect of voltage and spray times on the morphology of the woven hybrid CF-CNTs. Deposition of nano particles on fibre can be enhance the mechanical properties due to more number of interfaces. A. Boroujeni et.al [14] studied about enchance the in-plane and out-plane properties of fibre reinorced polymer composites by growing carbon nano tubes on carbon fibre.

II. METHODOLOGY

A. Material

The material is defined by a combination of matrix (epoxy resin) and nano-fillers (unidirectional glass fibers reinforcement and multi walled carbon nano tubes). The diglycidyl ether of bisphenol A (DGEBA) used as matrix, and triethylene tetra amine (TETA) used as hardener for curing. The multi walled CNTs having 6-9nm outer diameter and 5 µm length were used in the present study.

B. Dispersion of CNT in Epoxy

The solution processing method was adopted for the fabrication of polymer nanotube composite. This method facilitates the deaggregation and dispersion of CNT powder in solvent [15]. The laminate was fabricated by adding 0.1 percent of MWCNT to the epoxy resin. Dispersion involves three basic processes of stirring, sonication and degassing. Pre-calculated CNT was poured into acetone (150 ml). The acetone acts as a surfactant to disperse the nanotubes before mixing with polymer solution.

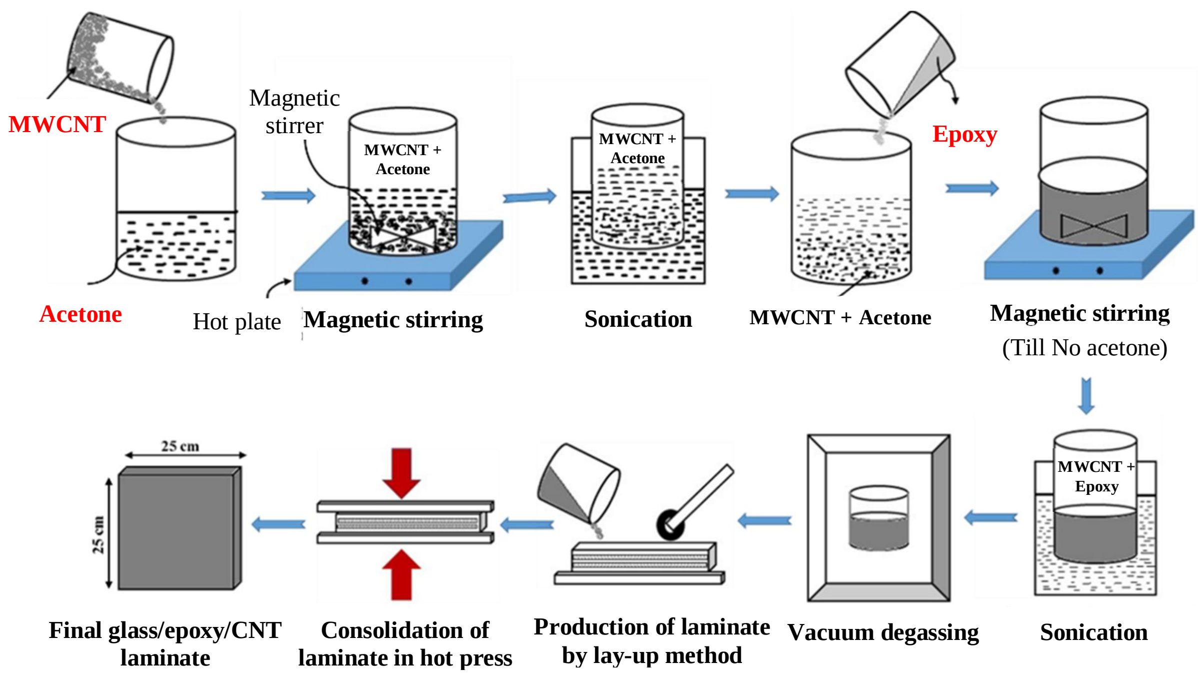

Figure 1: schematic of dispersion of CNT in epoxy and fabrication of CNT+GE laminate

Magnetic stirrer was used to stir the suspension at room temperature for 30 minutes at 1000rpm followed by sonication. Stirring and sonication helps CNT to disperse all over the suspension. Stirring of epoxy mixture was carried out for 1 hour at 70^0c at 1000 rpm. Sonication was done to evaporate acetone from the mixture at 70^0c. Vacuum degassing was done to remove air bubbles entrapped in the mixture during the process of dispersion.

C. Fabrication of Laminates

14 layers of glass fibers were taken and epoxy+CNT mixture was mixed with 10 wt.% of hardener i.e., TETA to solidify the epoxy at room temperature. Fiber and matrix were taken in 50-50 volume percentages respectively. Laminates were made by hand layup method followed by curing. In hot press laminates were cured by applying pressure of 1MPa at 60^0 C for 20 minutes. Plain glass epoxy plates were also made by same technique taking 14 layers of glass and mixture of epoxy and hardener. Samples were cut from laminates for tensile test, shear test and vibration test (ASTM: D638-08, D4762, D4065-12) by using heck saw followed by polishing for surface finish. These samples were post cured at 140^0C for 5 hours. Post curing improves strength and relieves internal stresses.[14]

III. MATERIAL CHARACTERIZATION

A. Determination of Material Constants

The characteristics of composite beam can be defined by four material constants they are E_1, E_2, G_{12}, υ_{12} where 1 and 2 are properties in principal directions. Elastic constants were determined by performing unidirectional tensile test and torsion test by cutting specimens according to ASTM standards: D3039 and D4762 respectively Elastic modulus and poisons ratio were determined by performing tensile test on INSTRON 1195 (Universal Testing Machine) at the rate of 5mm/min loading. Three replicate sample specimens were tested on UTM and mean values adopted. The concept of rule of mixture was adopted to calculate Poisson's ratio and density.

B. Vibration Test

Both the plates (GE, CNT+GE) were cast as cantilever beams by fixing one end to bench vice and left other end free according to classic theory of bending of thin plates with small deflections. The thickness of beam should be smaller than $1/5^{th}$ the largest dimension i.e., length but here it is even more reduced to keep resonant frequencies as low as possible thus assuring good vibration measurement.

C. Set-up & Procedure

A quick and simple method of hammer excitation is preferable. A sharp impact pulse corresponds to large frequency domain. The connections of FFT analyzer, laptop, transducers, and modal impact hammer were cabled to the system. The EDM (Engineering Data Management) software key was inserted to the port of the laptop. The laminate was excited in a selected point by means of small impact hammer, preferably at the fixed end. The input signal captured by a force transducer fixed on the hammer. The resulting vibrations of the laminate in a selected point are measured by an accelerometer (CoCo-80) was mounted on the laminate to the free end. The signal was then subsequently input to the second channel of the analyzer, where its frequency spectrum was also obtained. The response point was kept fixed at a particular point and the location of the excitation was varied throughout the plate. Both input and output signals are investigated by means of spectrum analyzer (CoCo-8) and resulting frequency response functions are transmitted to a computer for modal parameter extraction.

IV. RESULTS AND DISCUSSION

A. Tensile

Stress-strain curves for GE and GE composite with 0.2%, 0.4% and 0.6% of MWCNT are shown in fig.2

The variation of tensile strength with varying % of CNT on GE composite is shown in the fig.3. Tensile strengths of GE with 0% of CNT, GE with 0.2%, 0.4% and 0.6%s of CNT are reported in the table1 below.

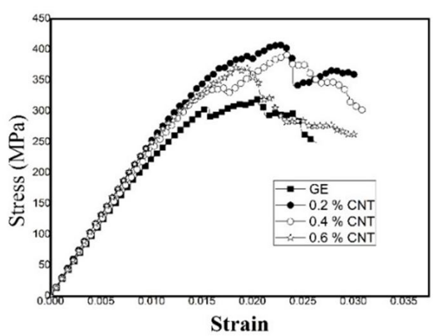

Fig 2: Tensile stress-strain curve for GE and GE-CNT

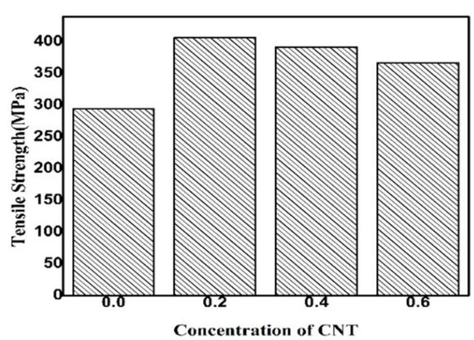

Fig: 3 Tensile strength in the laminate as a function of MWCNT

CNT Content	Strength (MPa)	Modulus (GPa)
0%	294.2±0.12	23.25±0.36
0.2%	406.45±0.23	28.16±0.51
0.4%	391.51±0.36	27.05±0.42
0.6%	366.57±0.18	27.43±0.59

Table1: Tensile properties of GE composite with varying CNT content

The through thickness properties of laminated composites are mostly governed by the matrix and/or interface/interphase. Thus suitable modification of the matrix and/or interface/interphase by nano-fillers is one of the possible ways to improve its flexural performance. For structural applications, load transfer from matrix to CNTs is the foremost aspect which enables CNTs to actively participate in the load carrying action.

Addition of 0.2% MWCNT to the GE resulted in enhancement of both modulus and strength by 17.5% and 27.6% respectively when tested at room temperature as shown in Fig. 3. This huge increment in strength might be attributed to the efficient stress transfer from the soft polymer matrix to the stiff MWCNT through the subtle CNT/polymer interface. The potential exploitation of CNTs in a composite can only be achieved if majority of the load could be transferred from the matrix to the nanotube. In case of CNT reinforced epoxy, the strength enhancement is a function of (i) CNT/epoxy interfacial bond strength and (ii) total available CNT/epoxy interfacial area. The CNT/epoxy interfacial bond strength is again influenced by the various types of physical, chemical and mechanical interaction between CNT and epoxy and these factors appear to be dependent on molecular nature of both components and independent of the CNT content in the composite.

B. Effect of Carbon Nanotubes Addition on the Natural Frequency of Epoxy and FRP Composites

The modal analysis was performed in two different boundary conditions (cantilever and simply supported) using Ansys for predicting the modal frequencies of GE (Glass Epoxy) and CNT+GE (Addition of carbon nanotubes in Glass Epoxy). The natural frequencies were computed from Finite Elemental method and compared with experimental results. The results have been compared for the woven glass fiber epoxy (GE) and CNT+Glass/Epoxy (CNT+GE) cantileverd composite laminates by modal hammer test method. Natural frequencies of GE and CNT+GE cantilever composite laminates were evaluated through experiments and finite elemental modal as well.

It can be seen from figures 4(a)–(d) that the natural frequency value of neat epoxy increases from 7.12 HZ to 125.52 HZ for cantilever condition, with the increase in mode shape from 1 to 4. The natural frequency values are higher for 0.6 wt% of CNT-GE composites compared to neat epoxy which can be seen from figures 4(a) - (d), (b) corresponding to 1st mode, 2nd mode and 3rd mode, and mode 4 respectively. Nanoparticles make the structure stiff, which is the reason for the enhancement in natural frequency. Specimens tested by simply supported end condition (figure 5) exhibit higher natural frequency values compared to specimens with those tested using other condition i.e. cantilever. A similar kind of trend was observed from figures 5 for simply support condition that is natural frequency increases with the increase in carbon nanotubes content. This can be attributed to an increase in interfacial friction between the epoxy matrix and nanoparticles

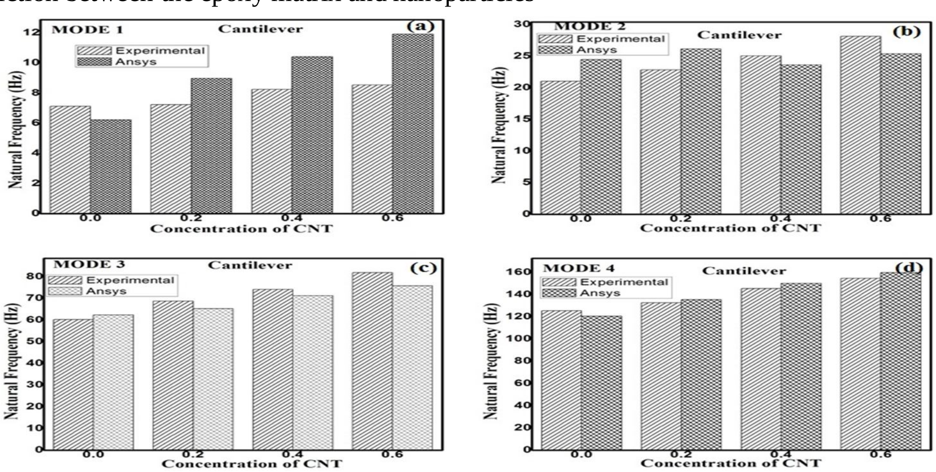

Fig 4: Natural frequency values for GE and CNT-GE at different modes.(Cantilever)

It can be inferred from the table 2 that, addition of CNT to the matrix improves the mechanical characteristics of laminate and thereby the natural frequency is improved as compared to GE laminate. Experimental results show an appropriate agreement to the numerical results/Fem results with an error band of ±10% and ±5% for GE plate and CNT+GE plates respectively.

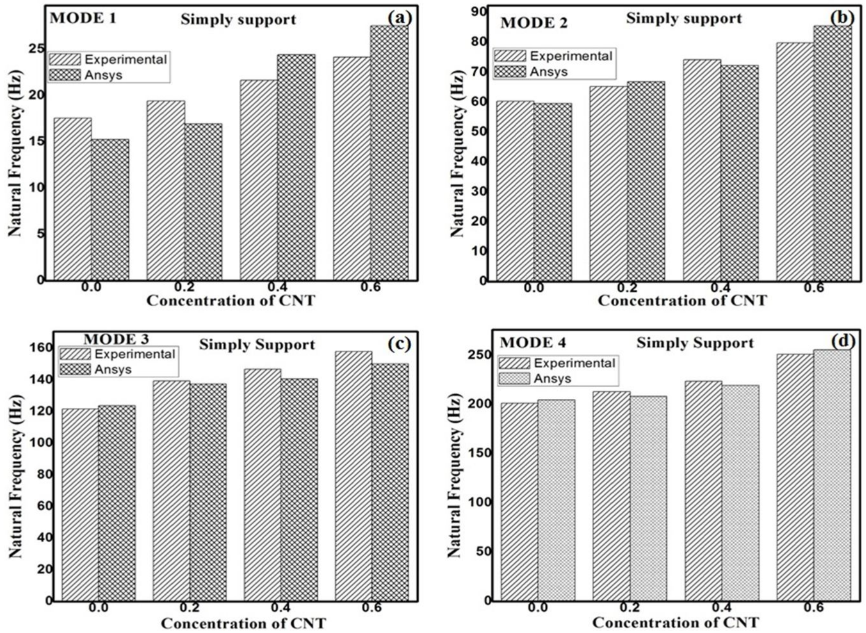

Fig5: Natural frequencies at different modes for GE and CNT+GE plate (Simply support)

A significant improvement of the natural frequency of GE laminate was noticed with the addition of CNT. As an example, addition 0.2 percentage of CNT (by weight fraction) to the GE laminate increases the natural frequency by 12 percentage. The change in natural frequencies at different mode numbers is illustrated in fig.2. Addition of CNT increases stiffness in the laminate which improves natural frequency. Further addition of CNT can improve the natural frequency. By review of literature [15] 0.2 wt. % addition of CNT in the matrix showed satisfying results in strength. ANSYS values are compared with experimental values and are given in table2.

Material System	Methodology	Cantilever				Simply support			
		Mode 1	Mode 2	Mode 3	Mode 4	Mode 1	Mode 2	Mode 3	Mode 4
GE	Experimental	7.12	21.02	60.26	125.52	17.57	60.31	121.57	201.28
0.2% CNT		7.23	22.84	68.71	132.62	19.42	65.21	139.39	212.98
0.4% CNT		8.24	25.06	74.18	145.36	21.64	74.15	146.87	223.47
0.6 %CNT		8.54	28.14	81.87	154.69	24.14	79.78	157.98	251.04
GE	ANSYS	6.22	24.47	62.32	120.58	15.24	59.52	123.63	204.53
0.2% CNT		8.98	26.14	65.23	135.48	16.93	66.84	137.41	208.27
0.4% CNT		10.41	23.63	71.29	150.05	24.39	72.24	140.63	219.32
0.6 %CNT		11.91	25.37	75.82	159.74	27.52	85.47	150.21	255.54

Table 2: Natural frequency values for different modes and boundary conditions of nano composites.

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It is also observed from figures 6-7 that natural frequency value increases by increasing the MWCNT content. These FRP based nano composites can be used in structural applications due to high damping ratios. Higher natural frequency value observed in 0.6%CNT+GE composite as compared to other composites from Table 2. A significant enhancement in natural frequency values with the addition of MWCTs into epoxy. The natural frequency values were higher for simply support boundary condition. In particular the high natural frequency values were obtained in fourth mode at simply supported boundary condition case as compared to other boundary conditions and other modes of FRP nano composites. The magnitude of natural frequency value was higher for 0.6%CNT+GE composite i.e.251.04 Hz.

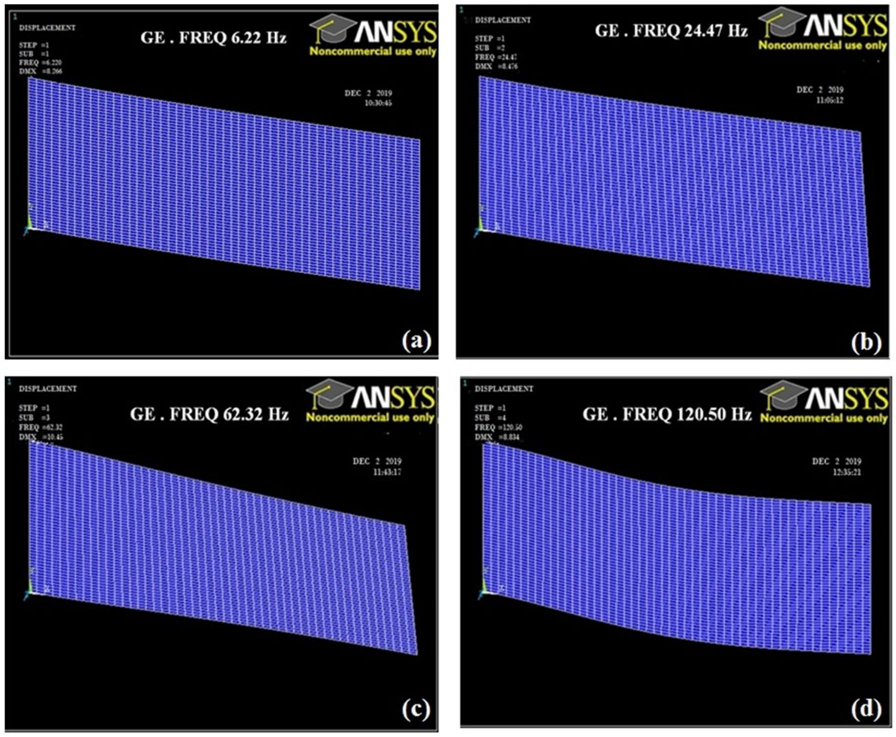

Fig 6: Mode shapes observed in ANSYS for GE plate

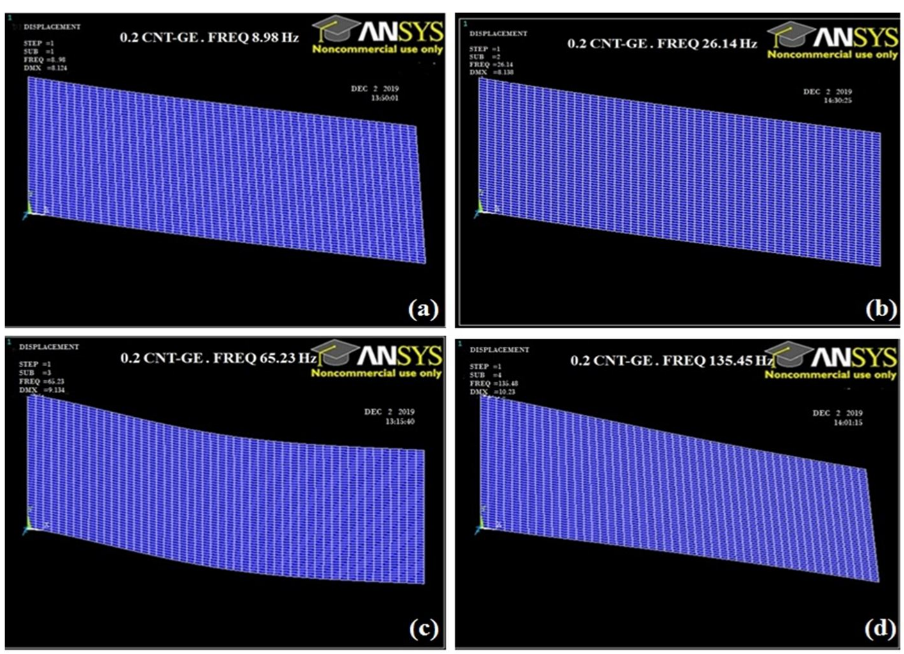

Fig 7: Mode shapes observed in ANSYS for 0.2CNT+GE plate

C. Fractography

To understand the micro and nano scale failure mechanisms, all fractured samples were analyzed post failure. Strengthening and toughening mechanisms at nanoscale can be modified with the addition of MWCNT to the epoxy.

Fig. 4 represents the delamination surfaces of the samples tested at room temperature. For GE composite very smooth fiber imprints were observed on the delamination front (Fig. 4(a)) whereas addition of MWCNT contents alter the imprint morphology.

All MWCNT–GE composites contain fiber imprints accompanied with matrix deformation on the delaminated surface as can be seen from Fig. 4(b)–(d). In case of 0.5% MWCNT–GE composite in-plane matrix break were observed as shown in Fig. 7(b) which may be contributing towards the loss of mechanical properties of 0.5% MWCNT–GE composites. It is observed that in Fig 4(c) the matrix screwing due to agglomeration of CNTs at particular location.

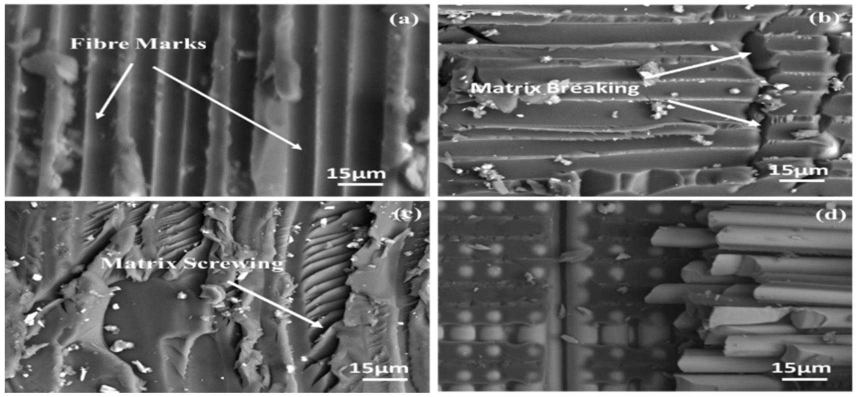

Fig4: Scanning Electron Microscopy images of the imprints on GE composite with (a) 0%, (b) 0.2%, (c) 0.4% and (d) 0.6% MWCNT content at Room Temperature.

Fig. 5 indicates the dispersion state of MWCNTs in the matrix of 0.2% and 0.6% MWCNT–GE laminated composites. The MWCNTs are mostly isolated from each other and uniformly distributed throughout the matrix of 0.2% MWCNT–GE composite (Fig. 5(a)) whereas in 0.5% MWCNT–GE composites, local bunches of MWCNTs are found which form agglomerates as shown in Fig. 5 (b).

The reduction of strength at higher MWCNT content can be attributed towards formation of these agglomerates, reducing the total CNT/epoxy interfacial area. The toughness increment in GE composite due to addition of 0.2% MWCNT may be attributed to the nanotube pullout and crack arresting link by nanotubes as can be seen from Fig. 5(d).

In FRP composites, most of the transverse mechanical properties are governed by the matrix and fiber/matrix interface. After morphological analysis of the modified polymer matrix in each GE/MWCNT composites, the fiber/matrix interface was analyzed for control GE and 0.2% MWCNT–GE composites.

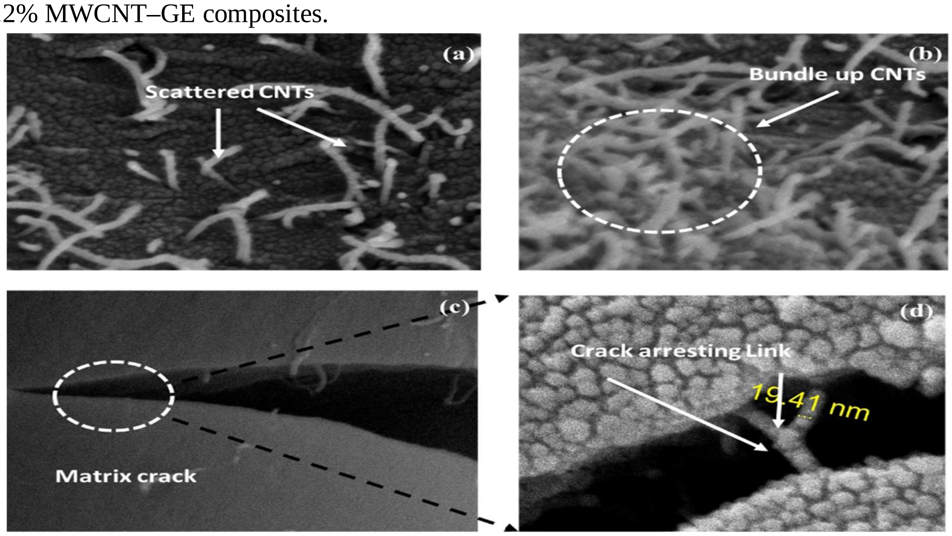

Fig5: Scattered of (a) 0.2%, (b) 0.7% MWCNT in GE composite, and (c) CNT pull out and crack arresting link by CNT in 0.2% MWCNT–GE composite after room temperature testing.

V. CONCLUSION

In the present work, the effect of multi walled carbon nanotubes addition on tensile and natural frequency characteristics of glass epoxy composites were studied. The dispersion of carbon nanotubes in epoxy and FRP composites was investigated and found uniform dispersion, before performing the tests. The tensile test was carried out by INSRON 1195 at 1mm/min loading rate. Addition of 0.2% MWCNT to the GE resulted in enhancement of both modulus and strength by 17.5% and 27.6% respectively when tested at room temperature due to MWCNTs are mostly isolated from each other and uniformly distributed throughout the matrix of 0.2% MWCNT–GE composite The natural frequency values for the first four modes of vibration were investigated experimentally and analytically with different end conditions such as cantilever and simply supported. The obtained values very close between the experiments and predictions through ANSYS software. The natural frequency values were higher for simply support boundary condition. In particular the high natural frequency values were obtained in fourth mode at simply supported boundary condition case as compared to other boundary conditions and other modes of FRP nano composites. The magnitude of natural frequency value was higher for 0.6%CNT+GE composite i.e.251.04 Hz. The data present in this study will be useful to CNT+GE composites are recommended for structural applications due to their tensile and vibration isolation at room temperature.

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