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Research Article

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Experimental Stress and Vibration Analysis of Hybrid Composite Laminated Cracked Beam

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Abstract

In this paper, an analysis of the fundamental mode of free vibration for hybrid laminated cracked composite beams was done. Hand layup is used to make the beams. Glass and carbon are used as fibers, and epoxy and resin are used as matrix materials. The properties of a material are found on the Universal Testing Machine. The experimental stress and modal analysis of carbon and glass fiber reinforced cracked hybrid laminated beam has been carried out for fixed-fixed and fixed-free beams. The [0°-90°-0°-90°] lamination scheme and [C-G-G-C], [G-C-C-G] composition have been used. The Lab VIEW software was used to perform the experiment. The strain gauges are used to perform stress analysis, and an accelerometer is used for modal analysis. The natural frequencies for all the cases have been determined. A finite element modal has been developed using ANSYS. The experimental data are compared to the ANSYS-obtained numerical results. For the compositions [C-G-G-C] and [G-C-C-G], the natural frequency drops as the number of cracks rises. Additionally, it has been found that both the laminated compositions [C-G-G-C] and [G-C-C-G] experience an increase in stress, strain, and deflection when the number of cracks increases. Maximum stress occurs at the fixed end if there is no crack; if a crack is present, it is located close to the fixed end, and as the number of cracks rises, the site of maximum stress shifts.

Keywords

Natural frequency, Transverse crack, Hybrid composite beam

Introduction

In this 21st century, fiber-reinforced composite materials are widely used for various kinds of applications in aeronautical, marine, automobile, manufacturing, and packaging industries. They are used because of their excellent mechanical properties, low density, and ease of manufacturing of any shape and size, with minimal to extensive size components. As composite materials' utilization increases daily, it is necessary to investigate the pros and cons of those materials.

Beams and elements that look like beams are the main structural parts of many structures. They are often found in fast machines, airplanes, and light structures. Crack is a common form of structural deterioration that can lead to the catastrophic collapse of the structure. A crack in a composite structure can make it less stiff and strong, which can change how it behaves both when it is still and when it is moving. As the use of laminated composite beams grows, we need to learn more about how they vibrate and what their properties are. Determining the dynamic characteristics of fractured hybrid composite laminated beams is critical not only during the design phase, but also for the performance of the structure. Local variations in the stiffness of structural elements are induced by fractures, which therefore affect their dynamic properties. In the present investigation, an effort was made to analyze the literature on composite beams with fractures in the context of the current work, with examination limited to the following areas: Nikpur and Dimarogonas [1] demonstrated the local compliance matrix for unidirectional composites. They have demonstrated that the degree of anisotropy in composites increases the strength of interlocking deflection modes. Kirugulige and Tippur [2] found the element stiffness matrix of a cracked beam by adding up the stress intensity factors. They then found the cracked beam's finite element modal. This modal is applied to a cantilever beam with a crack along the edge, and the eigen frequencies are determined for various crack lengths and positions. Finally, a straightforward way for locating the crack is provided. Based on the relationship between the crack and the eigen pair (eigenvalue and eigenvector) of the beam, this method can be used to complicated constructions with multiple cracks if the stress intensity factors of the cracks are known. Ostachowicz and Krawczuk [3, 4] came up with a way to figure out how two open cracks change the frequencies of a cantilever beam's natural flexural vibrations. There were two types of cracks that were looked at: double-sided cracks, which happen when there are cyclic loads, and single-sided cracks, which usually happen when there are fluctuating loads. It was also thought that the cracks happen in the opening mode, which is the first mode of fracture. There was an algorithm and a numerical illustration. Experiments conducted by Manivasagam and Chandrasekaran [5] examined how damage in the form of cracks affects the fundamental frequency of multilayer composite materials. The composite element model was used by Lu and Law [6] to study the dynamic condition assessment of a cracked beam. In this paper, the author uses Lab VIEW to compare carbon-glass hybrid composite beams with and without cracks in terms of their natural frequency, stress-strain, and deflection. Also, the results of the Finite Element package are compared to these.

Table 1: Mechanical properties of constituents of fiber used for test specimen.

Material	Elastic modulus E11 (GPa)	Shear modulus G12 (GPa)	Poisson ratio v12	Density (g/m³)
Carbon fiber	47.85	2.083	0.29	1325
Glass fiber	13.604	3.024	0.28	1685
Epoxy resin	4.1	1.576	0.3	1143.09

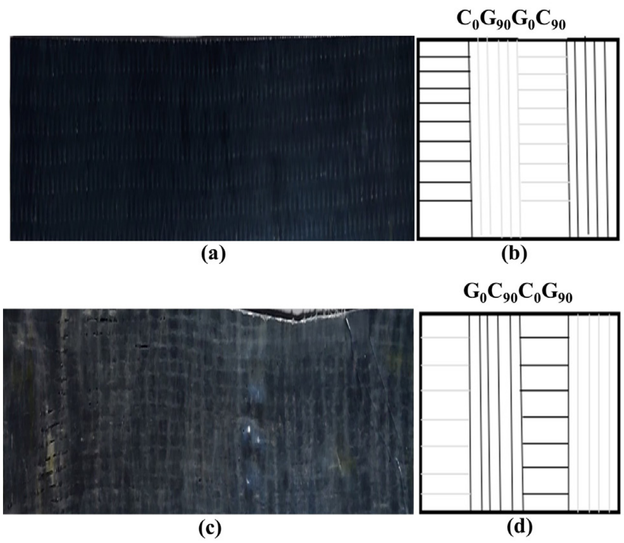

Figure 1: (a) Top view of [C-G-G-C] laminated hybrid composite beam with [0°-90°-0°-90°] stacking sequence. **(b)** Side view of [C-G-G-C] laminated hybrid composite beam with [0°-90°-0°-90°] stacking sequence. **(c)** Top view of [G-C-C-G] laminated hybrid composite beam with [0°-90°-0°-90°] stacking sequence. **(d)** Side view of [G-C-C-G] laminated hybrid composite beam with [0°-90°-0°-90°] stacking sequence. C_0 - Carbon layer with 0° orientation, G_0 - Glass layer with 0° orientation, C_{90} - Carbon layer with 90° orientation, and G_{90} - Glass layer with 90° orientation.

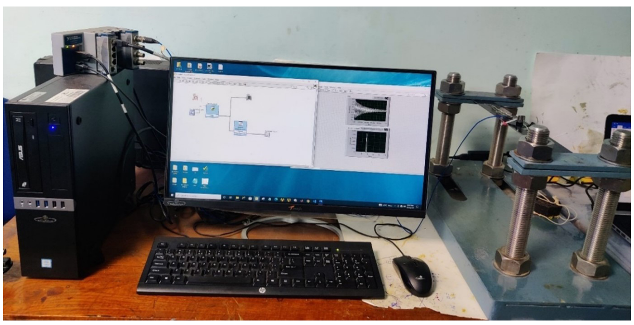

Figure 2: Experimental setup.

Methodology and Material Preparation

Hand Lay-up is the most popular and least expensive form of open molding since it requires the fewest tools. Hands put fiber reinforcements in a mold, and a brush is used to

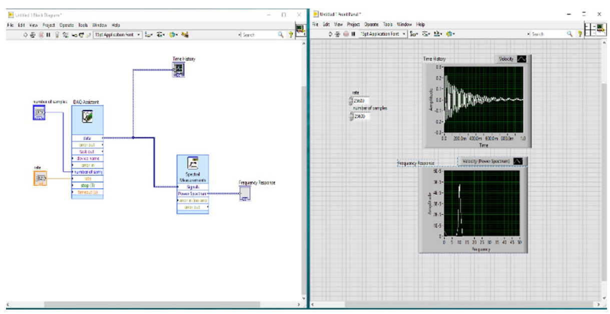

Figure 3: Experimental plots of Time-History and Frequency-response in LabVIEW interface.

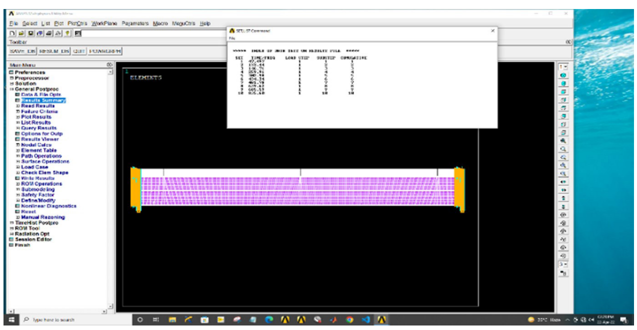

Figure 4: Natural Frequency for [C-G-G-C] hybrid composite beam with three cracks under Fixed-Fixed boundary condition.

Table 2: Natural frequency of glass carbon hybrid composite laminated beam [C-G-G-C] without any crack and with all 3 cracks under different boundary condition.

Number of cracks	Boundarycondition	Non-dimensional frequency (Lab VIEW)	Non-dimensional frequency (ANSYS)	Percentage of error
Zero crack	Fixed free	7	7.67	9.57
	Fixed-fixed	41	48.84	19.12
Single crack	Fixed free	7	7.63	9.00
	Fixed-fixed	43	41.33	-3.88
Double crack	Fixed free	7	7.37	5.29
	Fixed-fixed	48	51.37	7.02
Triple crack	Fixed free	7	7.32	4.57
	Fixed-fixed	52	47.47	-8.71

Table 3: Strain of glass -carbon composite laminated beam [G-C-C-G] without any crack and with all 3 cracks under different boundary condition.

Number of Cracks	Boundary condition	Strain (LabVIEW) (10^{-3})		Strain (Ansys) (10^{-3})		Percentage of error	
		upper	lower	upper	lower	upper	lower
Zero crack	F-F	1.12	-1.18	1.09	-1.26	2.93	6.78
	C-C	0.22	-0.21	0.20	-0.18	7.52	14.69
single crack	F-F	4.52	-4.12	4.13	-3.93	8.36	4.63
	C-C	0.38	-0.40	0.35	-0.37	8.01	6.48
Double crack	F-F	6.01	-4.23	3.55	-4.53	40.86	6.89
	C-C	0.61	-0.46	0.62	-0.50	2.62	8.81
Triple crack	F-F	3.62	-8.29	3.50	-4.76	3.25	42.04
	C-C	0.81	-0.52	0.66	-0.50	18.04	3.728

Note: F-F is Fixed-free boundary condition, C-C is clamped-clamped boundary condition.

Table 4: Deflection and stress of carbon-glass hybrid composite laminated beam of sequence of [0°-90°-0°-90°] and composition [C-G-G-C] without any crack and with all 3 cracks under different boundary condition.

Number of cracks	Boundarycondition	Maximum deflection (ANSYS) 10^{-4} meter	Maximum stress (ANSYS) (MPa)	
			upper	lower
Zero crack	Fixed free	-5.410	7.59	-22.7
	Fixed-fixed	-0.0034	3.97	-2.83
Single crack	Fixed free	-5.028	80.3	-83.8
	Fixed-fixed	-0.0031	6.47	-7.29
Double crack	Fixed free	-5.330	53.4	-73.5
	Fixed-fixed	-0.0032	11.4	-7.44
Triple crack	Fixed free	-6.030	88.3	-57.9
	Fixed-fixed	-0.0035	8.96	-13.0

add resin. Polymer resin is used to make the material for the matrix. With a K-6 hardener, Lapox-12 is added. (10:1 in terms of weight). The right amount of resin was weighed (such that the weight of the fibers to the weight of the resin was 40:60). Hardener was added to this measured amount of resin so that the weight of the hardener was 10% of the weight of the resin as a whole. To make sure the mixture was mixed well, it was stirred. Hardener has to be used because, without it, resin doesn't cure properly. After mixing the two chemicals together, it was left for a while so that any bubbles that formed while stirring could go away. Hardener is added to make it easier for the composite laminate to harden as it cures.

Experimental setup

In this research work, the LabVIEW interface was used to measure strain and vibration. During the static analysis of

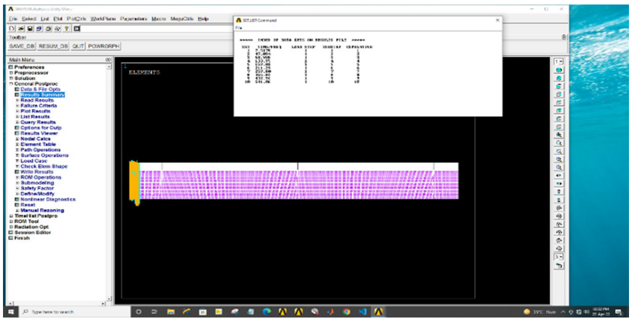

Figure 5: Natural Frequency for [G-C-C-G] hybrid composite beam with three cracks under Fixed-Free boundary condition.

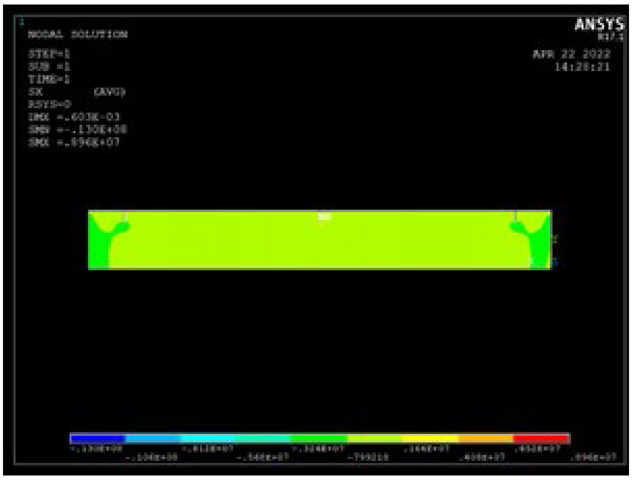

Figure 6: Strain at lower fiber for [C-G-G-C] beam with triple crack under Fixed-Fixed boundary condition.

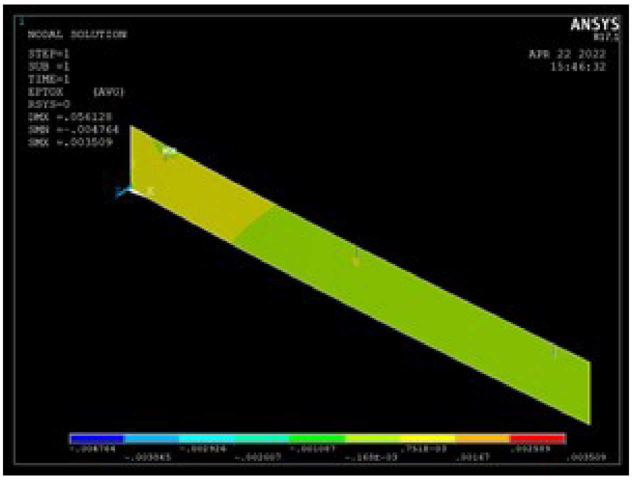

Figure 7: Strain at Upper fiber for [G-C-C-G] beam with triple crack under Fixed-Free boundary condition.

the composite beam, the longitudinal strain was measured at the clamped support of the beam for both clamped-clamped and clamped-free end conditions by applying a point load at the midpoint and at the free end, respectively. A NI cDAQ-9174 four-slot USB chassis to connect the hardware with LabVIEW software to analyze sensor data. A NI 9237 bridge module that can be used with compact DAQ. It has four RJ50 jacks that let you connect directly to most torque or load cells. It also lets you make your own cable solutions with a few tools. The NI 9237 module needs two NI 9945 Quarter bridge completion accessories to add a quarter bridge. Two RJ50 cables have a 10-Pin Modular Plug to a 10-Pin Modular Plug on each end. For each sample, two 350-Ohm foil strain gauges were used to put on both the top and bottom fibers. For the required point load, a pan was kept with a certain amount of weight (500 gm). ANSYS 17.1 APDL interface was used to carry out static and modal analysis to determine the strain and natural frequency value numerically.

Results and Discussion

Modal analysis of composite laminated beam

Using LabVIEW, the effect of a fracture on the static and modal characteristics of a glass-carbon hybrid composite beam with the sequence [0°-90°-0°-90°] and two compositions [C-G-G-C] and [G-C-C-G] is experimentally estimated and compared to ANSYS results. The length (L), height (H), and width (B) of the hybrid composite beam with composition [C-G-G-C] are assumed to be 395 mm, 2.174 mm, and 50 mm, while the same parameters for composition [G-C-C-G] are assumed to be 395 mm, 2.077 mm, and 50 mm. Because composites are made manually, their developed thicknesses vary slightly. Transverse Manually employing a hexa blade, three points on the beam develop cracks measuring 10mm1mm in width. The cracks are located concurrently at x = 30 mm, 197 mm, and 365 mm from one end of the beam.

The percentage difference between non-dimensional ANSYS and LabVIEW natural frequencies

$$e_{\varpi} = 100\left|\frac{\varpi_a - \varpi_l}{\varpi_l}\right| \qquad (1)$$

$\bar{\varpi}_a$ = Non-dimensional frequency from ANSYS

$\bar{\varpi}_l$ = Non-dimensional frequency from LabVIEW

Static analysis of laminated composite beam

The percentage difference between strains

$$(e_{\varepsilon}) = 100\left|\frac{\varepsilon_l - \varepsilon_a}{\varepsilon_l}\right| \qquad (2)$$

ε_a = Strain from ANSYS

ε_l = Strain from LabVIEW

Conclusions

Using the Hand Lay-up technique, a glass carbon hybrid composite with stacking sequence [0°-90°-0°-90°] and two compositions [C-G-G-C] and [G-C-C-G] has been created. The experimental static and modal analysis of composite laminated beams with and without transverse fracture under two boundary conditions, i.e., fixed-fixed and fixed-free, were performed using LabVIEW software. These experimental results were compared to those generated by the ANSYS programme. The subsequent conclusions are:

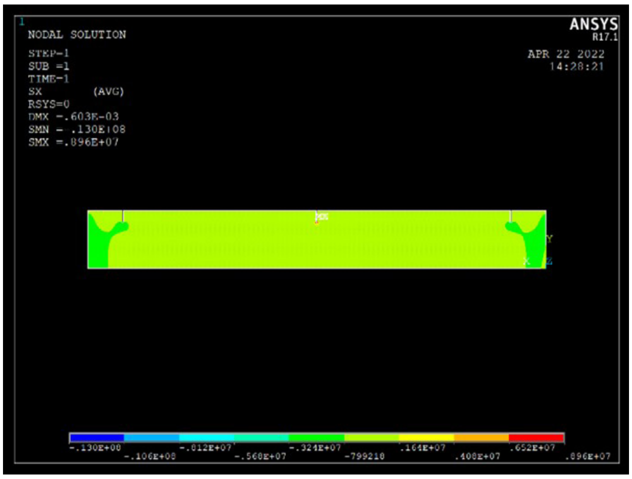

Figure 8: Stress distribution on lower fiber for [C-G-G-C] hybrid composite beam with three cracks under Fixed-Fixed boundary condition.

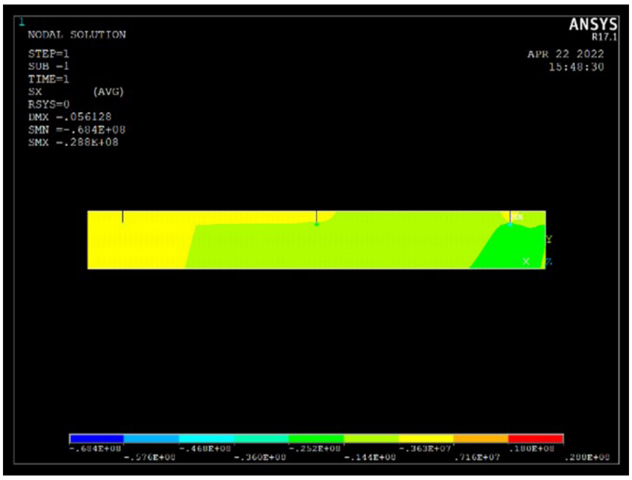

Figure 9: Stress distribution on lower fiber for [G-C-C-G] hybrid composite beam with three cracks under Fixed-Free boundary condition.

- Under fixed-fixed boundary conditions, the natural frequency of a [C-G-G-C] or [G-C-C-G] hybrid composite is higher than when the boundary conditions are fixed and free. Also, the natural frequency goes down as the number of cracks goes up in both fixed-fixed and fixed-free boundary conditions.
- The natural frequency of [C-G-G-C] and [G-C-C-G] hybrid composites without a crack in fixed-fixed and fixed-free boundary conditions is higher than with any number of cracks in the same boundary condition.
- The natural frequencies are significantly influenced by boundary conditions. The natural frequencies are higher when the support is clamped and clamped than when it is clamped and free.
- The impact of cracks is greater close to the fixed end than at the far end, which is free. When cracks are close to the fixed end, the middle of the beam, and the free end, they each have a greater impact on the first, second, and third natural frequencies.
- If there is no crack, the highest stress will be at the fixed end. If there is a crack, the highest stress will be near the crack, and if the number of cracks grows, the highest stress will move to a different place.
- In both [C-G-G-C] and [G-C-C-G], the frequency goes down as the number of cracks goes up.
- As the number of cracks increases, stress, strain, and deflection increase for both composition [C-G-G-C] and [G-C-C-G] of the hybrid composition beam.

Acknowledgements

None.

Conflict of Interest

None.

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