Vibration Behaviour of GFRP/CFRP/Graphene Oxide Nanofiller Laminates

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Abstract

This paper presents vibration behavior of GFRP/CFRP/Graphene Oxide (0.5 wt. %) laminates. Modal parameters such as damping ratio, mode shapes and frequency were experimentally determined using FFT analyser and data acquisition system. Unidirectional carbon fibres were used in the laminates in 0° orientation. Modal testing was performed with two fixations F-F-F-F and C-F-F-F. Vibration properties of the interlayer hybrid laminates were compared with those of GFRP laminates. Natural frequencies were higher for specimens with F-F-F-F fixations than that of C-F-F-F fixation. With C-F-F-F fixation, hybrid laminates S1 and T1 showed higher frequency than that of neat glass laminate G1. The S1 laminate with carbon fibre in the outermost layer showed highest frequencies amongst the three other laminates with carbon fibre in inner layers. The damping was found to be higher for hybrid laminates for the third mode.

Keywords: *GFRP/CFRP/GO Hybrid composites, natural frequency, mode shapes, damping ratio*

1.0 Introduction

Hybrid composites are researched because of their superior mechanical properties. Hybrid composites are classified as interlayer, intraply and tow-by-tow types. Interlayer hybrid composites consist of a matrix containing at least two types of fibres of low and high elongations [1, 2] and failure strains. Hybrid composites find aerospace, marine, automotive and other high-end applications in which the dynamic loads cause vibrations resulting in undesirable noise and reduced life of the component. Amplitudes of vibrations can be decreased by dissipation of energy through passive damping. Composites possess higher inherent damping than that of conventional engineering materials. Damping exhibited by conventional polymer composites may be inadequate for high-speed dynamic applications.

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At macro-mechanical level damping in composites can be increased by appropriate stacking sequence of fibre plies, interlayer and intra ply hybrid composites, viscoelastic plies, etc. Damping can also be increased by micromechanical means by changing orientation of fibres and aspect ratio of fibres, improving fiber-matrix interphase and dispersion of nanofiller in the matrix [3-5]. Modal testing is performed to determine natural frequency, damping ratio and mode shapes.

Glass fibres are used in polymer composites because of their high tensile strength and cost effectiveness. Carbon fibres are preferred because of high mechanical strength, modulus and low density [6, 7]. Composite laminates with balanced mechanical properties at optimal cost can designed by using combination of glass and carbon fibres [7-10]. Abu Taliba et al. [11] studied vibration behaviour of drive shaft by using both carbon and glass fibres. The authors observed the frequency decreased by 44.5% by varying direction of carbon fibres 0° to 90°. Nayak et al. [12] experimentally studied dynamic behaviour of hybrid composites fabricated by using glass and carbon fibres. In composites with carbon fibres 25% and glass fibres 75%, frequencies were minimum for $(G\text{-}C\text{-}G\text{-}G)_s$ stacking sequence and in laminates with 50% each of glass and carbon fibres, frequencies were minimum for $(C\text{-}G\text{-}C\text{-}G)_2$. Didik et al. [13] reported high damping ratio for in composites made of carbon and glass fibres at 45°/45° orientation. Murugan et al. [14] reported increase in damping ratio in composites with carbon and glass fibres. The laminates fabricated using carbon fibres in top layers and glass for inner layers displayed greater storage modulus, loss modulus and loss factor. Murugan et al. [15] reported that the stacking sequence influenced both mechanical and dynamic properties.

Nanofillers such as MWCNT, SWCNT, graphene, graphene oxide are evaluated for enhancing static properties of composites. Graphene oxide as nanofiller in polymer composites can enhance modulus, strength and toughness. Guan et al. [16] reported that addition of functionalized Graphene Oxide (GO) increased the mechanical properties such as elastic modulus, toughness and strength of epoxy. Addition of 0.5wt.% GO nanofiller increased tensile strength and toughness by 63 % and 119 % of epoxy. Galpaya et al. [17] reported that dispersion of 0.5 % GO in epoxy increased elastic modulus of epoxy by 35%. Liu et al. [18] reported that inclusion of GO in epoxy increased its storage modulus, flexural strength and flexural modulus. Pathak et al. [19] fabricated laminates with carbon fibres and GO nanofiller (0.3 wt. %) and reported increase of 66% bending strength and 70% flexural modulus. Nagabhushan et al. [20]

reported increase in damping ratio of GFRP due to the inclusion of GO nanofiller.

Rafie et al. [21] studied vibration behaviour of GFRP by incorporation of MWNT, GO and graphene nanoplatelets. Higher loading of nanofillers resulted in increase in damping ratio and decrease in natural frequency. Xiaoning et al [22] reported that inclusion of nanofillers is useful in increasing the frictional stick slip that enhances the damping behavior.

Review of literature [1-22] suggest that a few researchers worked on experimental determination of dynamic properties of hybrid composites with interlayer or intralayer configuration. The effect of addition of GO nanofiller in interlayer GFRP/CFRP is not comprehensively studied. This paper reports experimental study of vibration behavior of glass fibre / carbon fibre interlayer hybrid symmetric laminates embedded with 0.5 % wt. GO nanofiller for different stacking sequences of unidirectional carbon fibers. Influence of free and clamped boundary conditions was studied.

2.0 Experimental Details

2.1. Materials

Unidirectional glass fibres (UD glass fiber, 92145), unidirectional carbon fibres (UD carbon fibre (TENAX 796), epoxy (LY556 Araldite), hardener (HY951) and Graphene Oxide nanofiller were used for fabricating the specimens.

2.2. Fabrication of Laminates

Two types of laminates i.e. epoxy/UD glass and epoxy/UD glass/UD carbon/GO nanofiller (0.5 wt. %) were fabricated by using Hand lay-up method. Specimen details are presented in Table 1. Symmetric hybrid composite laminates were fabricated with different stacking sequence of carbon fibres as shown Fig.1. Epoxy and hardener were used in the ratio of 10:1. GO nanofiller was dispersed in epoxy by u ing ultrasonication. Hand lay-up followed by vacuum bagging was adopted for the fabrication of laminates.

2.3. Specimen Preparation

Specimens for modal testing were cut to size from the laminates using high-speed cutter. Specimen dimensions are 150 x 150 mm^2 for boundary F-F-F-F fixation and 170 x 150 mm^2 for C-F-F-F fixation (Fig. 1). For both F-F-F-F and C-F-F-F fixations, the effective area of the specimen for modal testing was maintained at 150 x150 mm^2. For C-F-F-F fixation, four 6 mm holes were drilled on the specimens. On each of composite specimens, grid points numbering 1- 49 were marked as shown in Fig. 2.

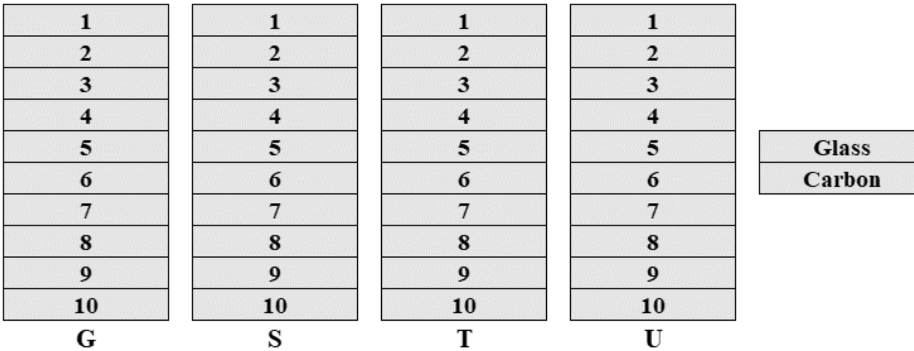

Fig. 1. Laminates with different stacking sequence

Table 1. Laminates Fabricated (fibres oriented at 0 degree)

Sl. No	Material	Laminate code	No of Layers	Stacking Sequence
1	GFRP	G1	10	$[G\text{-}G\text{-}G\text{-}G\text{-}G]_S$
2	Hybrid	S1	10	[C-G-G-G-G]s
3	Hybrid	T1	10	[G-G-C-G-G]s
4	Hybrid	U1	10	[G-G-G-G-C]s

Fig. 2. Specimens with 1- 49 grid points for C-F-F-F and F-F-F-F fixations

3.0 Modal Testing

The laminates were excited at the grid points (1-49) using a piezoelectric hammer and the response was recorded by an accelerometer. Piezoelectric hammer produces voltage by applying an impact force, which is converted to force. Accelerometer is connected to Data Acquisition System. A signal conditioning amplifier is used to convert the accelerometer characteristics compatible with the input electronics of the data acquisition system. The information received is channeled on to the data acquisition software, which processes the data and provide the frequency, damping values and mode shape. Each of the grid points were excited eight times using piezo-electric hammer and mean values were considered. For simulating free-free fixation (F-F-F-F) the specimens were suspended from a support frame as shown in Fig. 3a and for C-F-F-F fixation i.e. cantilever condition, the set-up is shown in Fig. 3b in which the test specimen is held in the fixture by using four threaded bolts.

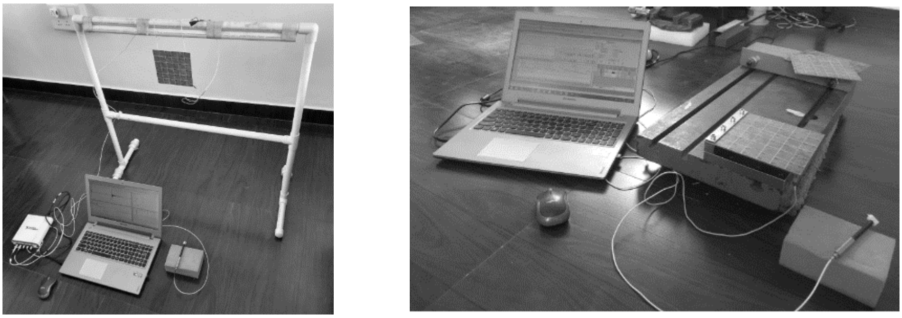

Fig. 3. a) Experimental setup for F-F-F-F fixation and **b)** Experimental setup for C-F-F-F boundary condition

4.0 Results and discussion

4.1. F-F-F-F boundary condition

Frequency and percentage damping obtained from the modal test for F-F-F-F fixation are shown in Table 2, Fig. 4.

Table 2. Modal test results for F-F-F-F fixation

Specimen	Modal Parameter	1st Mode	2nd Mode	3rd Mode
G1	Frequency, Hz	153	251	400
	% Damping	1.41	0.60	1.20
S1	Frequency, Hz	167	272	430
	% Damping	0.50	1.30	1.03
T1	Frequency, Hz	159	275	409
	% Damping	0.82	1.15	1.19
U1	Frequency, Hz	147	256	381
	% Damping	0.58	1.15	0.75

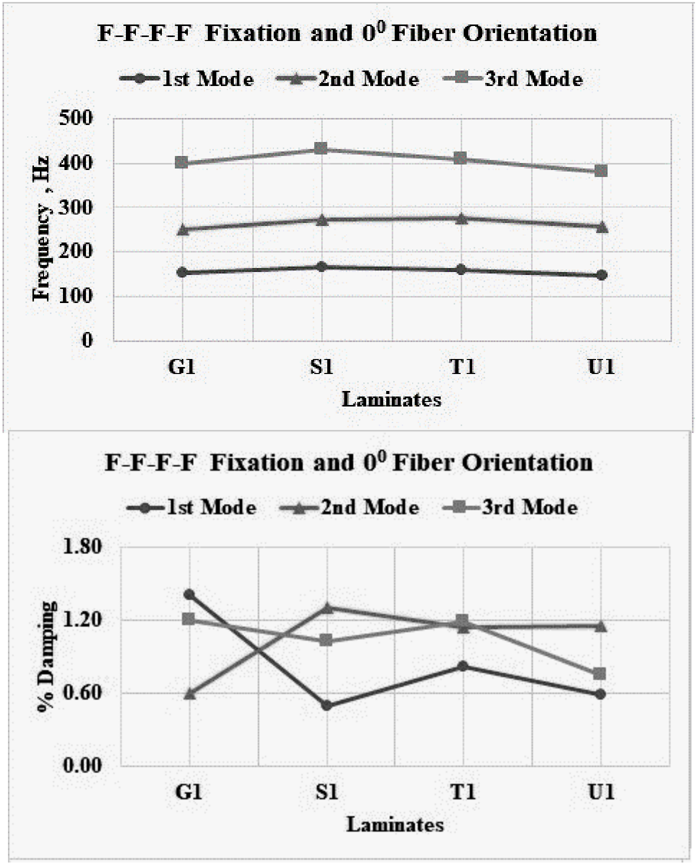

Fig. 4. a) Natural frequencies in F-F-F-F fixation and **b)** Damping (%) in F-F-F-F fixation

Fig. 4a shows that in F-F-F-F fixation, the frequency varied nominally with hybridization considering G1 as the reference specimen. S1 laminate showed 9.2 % increase in frequency for first mode, which is attributed to carbon fibres in the outermost layer. Such increase in T1 was 9.7%. In third mode, frequency of S1 increased by 7.5 %. Variation in frequency was similar for the three modes. S1 showed (Fig. 4b) decrease in damping of 64.4 % for first mode. T1 and U1 showed decrease in damping of 41.8 % and 58.5 % respectively for first mode. For second mode damping was higher in hybrid laminates. Laminate S1 showed increase in damping of 119.2 % whereas T1 showed increase in damping of 92.4 % and U1, 93.14 % compared to the reference laminate G1.

4.2 C-F-F-F boundary condition

Experimental frequency and % damping for C-F-F-F fixation are shown in Table 3, Fig. 5.

Table 3. Modal parameters for C-F-F-F

Specimen	Modal Parameter	1st Mode	2nd Mode	3rd Mode
G1	Frequency, Hz	64	102	297
	% Damping	0.35	1.48	1.01
S1	Frequency, Hz	96	133	314
	% Damping	0.32	0.35	1.23
T1	Frequency, Hz	73	120	315
	% Damping	0.92	0.31	1.80
U1	Frequency, Hz	64	103	279
	% Damping	0.41	0.66	3.20

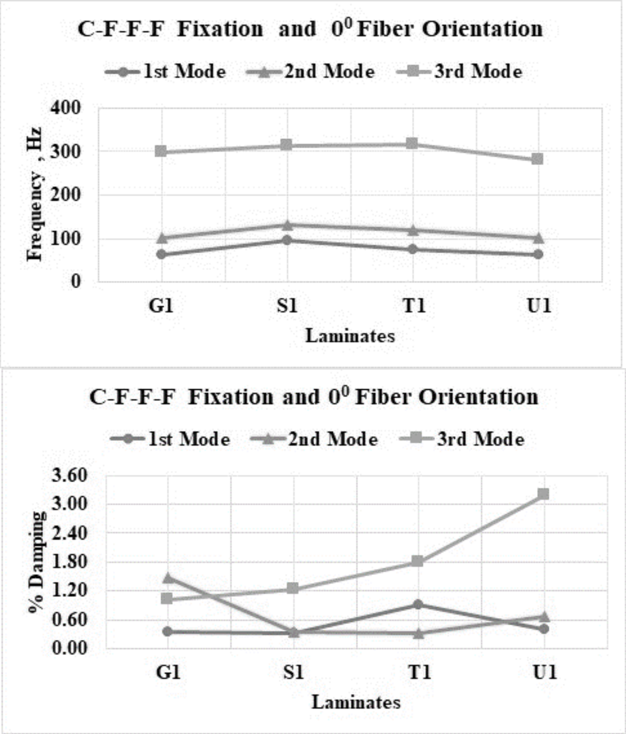

Fig. 5. a) Frequency for C-F-F-F fixation and **b)** Damping for C-F-F-F fixation

Variation in frequency in the four types of specimens for C-F-F-F is presented in Fig. 5a considering G1 as reference specimen. S1 displayed increase in frequency by 51 % for first mode, which is attributed to the carbon fibres in the outermost layer. In T1 frequency increased by 15.7%

for first mode. In mode 2, the frequency of S1 increased by 30 % and the same was 17.3% in T1. Frequency reduced in case of carbon fibres stacked towards the centre of the specimen. Variation in frequency was similar for the three modes. S1 showed decrease in damping of 8% for first mode (Fig. 5b). T1 and U1 showed increase in damping of 167.75% and 8.4% for first mode. For second mode, the damping was less for the hybrid laminates than that of the reference laminate G1. For third mode, S1 showed increase in damping of 21.6 %, T1 showed increase in damping of 78.4 % and U1 increase in damping of 216.5 % compared to that of G1. The damping exhibited by the hybrid laminates was highest for the third mode amongst the first three modes.

5.0 Conclusion

The vibration properties of GFRP/CFRP/GO nanofiller (0.5 wt. %) interlayer hybrid composite were investigated by modal testing considering the vibration behavior of glass/epoxy laminate as reference specimen. The following conclusions were arrived at based on the experimental observations:

- Natural frequencies were higher for specimens with F-F-F-F fixations than that of C-F-F-F fixation.
- Boundary condition used for holding the laminates significantly influenced the modal properties.
- With C-F-F-F fixation, hybrid laminates S1 and T1 showed higher frequency than that of neat glass laminate G1. The S1 laminate with carbon fibre in the outermost layer showed highest frequencies amongst the three other laminates with carbon fibre in inner layers. The damping was found to higher for hybrid laminates for the third mode.
- GFRP/CFRP/graphene oxide nanofiller showed improved damping behavior at higher modes.

Hybridization influenced natural frequencies and damping.

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