Experimental investigation on modal characteristics of plain woven glass/carbon hybrid composite beams with fixed-free end condition

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Experimental Investigation on Modal Characteristics of Plain Woven Glass/Carbon Hybrid Composite Beams with Fixed-Free End Condition

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Abstract. This paper presents an investigation on modal characteristics of plane woven glass/carbon hybrid composite beams with fixed-free end condition by experimentally. The composite beam specimens are extracted from composite laminates of 16 layers with different hybrid configurations fabricated using vacuum bagging technique. Experimentations have been performed to measure vibrational characteristics of beams. Based on the investigation, it has been revealed that hybridisation affects the vibration characteristics. First two natural frequencies of beam are increased by the use of higher stiffness fibres in the upper layer. The damping effect in the beam with carbon fibre as middle layer is found to be higher as compared to the dedicated plain woven glass composites.

INTRODUCTION

Use of plane woven composites in structural applications is escalating in recent decades due to their balanced mechanical properties, better stability due to yarn reinforcement in warp and weft direction, ease of handling, shape-ability along with and other attractive dynamic characteristics such as high damping and high stiffness. In the structural applications, dynamic characteristics are also equally important as the static properties as the structures are subjected to combined static and dynamic loading conditions.

Analysis of mechanical system subjected to dynamic loading is extremely important in the determination of the structural loads in the system as it can be the major contributing factor for failure. In composite materials, high strength is attributed to fibres and can be tailored by varying orientations angles. On the other hand, matrix as a binder contributes in load transfer and introduces damping in the structures[1]. In the design of the composite materials with desired dynamic properties, damping and storage modulus have major contribution. Stiffness is related storage modulus and energy dissipation of the whole structure is related to damping. A detail review on damping characteristics of synthetic fibre based composites reveals that damping effect is due to visco-elastic property of matrix material[2],[3]. Efforts have been made to increase damping effect of the materials focusing on resin toughness enhancement[4],[5] and hybridisation of resin [6].An investigation on the influence of nanoclay addition in unsaturated polyester resin and chemical modification of coconut sheath on free vibration characteristics such as natural frequency and modal damping. An enhancement in damping was observed with nanoclay addition[7].

Some key parameters that affect the performance of the composite material from reinforcement prospective include: length of fibre, fibre orientation, shape of fibre and fiber material[8],[9]. The damping behaviour of continuous carbon fibre (CFRP) and flax fibre reinforced polymer (FFRP) composites was studied by comparing angle-ply laminates [10]. Their results showed that flax and carbon fibre hybrids are high potential candidates for future light weight structures. An experimental investigation was carried out to study the influence of fibre orientation on damping in unidirectional glass fibre polymer composites. The results obtained indicated that specimens with small orientation of fibre angles of is preferable for high flexural modulus whereas for high damping value large angles of orientation should be preferred[11]. It is reported that, woven composites of satin type possess higher natural frequencies as compared to plain weave composites[12].In practice, numbers of glass layers required to obtain desired mechanical properties in structural applications will be more as compared to carbon fibres resulting in increased weight. When

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conventional composites made of one reinforcement fibre fail to provide all desired properties, composites with a combination of two or more types of reinforcements or matrix system will be a solution.
In general, hybrid composite structure is a combination of high modulus and low elongation fibre, and low modulus and high elongation fibre. The composite with the combination of two or more fabrics, it is possible to utilise the advantages of constituent fibres and modify their less desirable properties While, composite with high modulus and low elongation fibre (carbon) provides stiffness thus making the hybrid composite a high load bearing characteristic. On the other hand, composite with low modulus and high elongation fibre (glass) makes the hybrid composite more ductile and damage tolerant. However, with one or more types of fibres in hybrid composites having different internal structures and individual constituents respond differently when subjected to dynamic loading.
Past two decades, many efforts have been made by researchers to increase damping value in the composite structures using different methods. The aim of present work is to investigate the influence of inter-ply hybridisation and layer sequence on modal characteristics of composite beams with fixed-free condition by experimentally.

MATERIAL AND LAMINATE FABRICATION

Hybrid composite laminates were fabricated with 16 layers of different configurations. Plain woven glass fabric of S-type and plain woven carbon fabric of areal density 200gsm was used as reinforcement with matrix as epoxy resin LY556 premixed and homogenized with hardener HY951 in the ratio of 10:1 by volume. The laminates are fabricated using vacuum bagging technique after allowing to cure under room temperature and vacuum for 24 hour. The vacuum bagging setup developed for fabrication is as shown in the figure 1. The laminate was sealed in a vacuum bag then vacuum created with the help of vacuum pump. The hybrid glass/carbon, glass and carbon beams are extracted from the laminate using cutting machine. Figure 2 depicts the fabricated woven fabric beams of 16 layered glass (G1), carbon (C1), and three hybrid configurations. Three layup sequence were considered in fabricating hybrid laminates. In the GC1 arrangement, the two central layers of G1laminate were modified by carbon fabric layers. For the GG1, alternating layers of glass and carbon was used with glass as the top layer and in CC1 carbon was the top layer. All the specimens used in this investigation having average length of 250mm and average width of 25 mm as per ASTM-D3039M-14 standards.

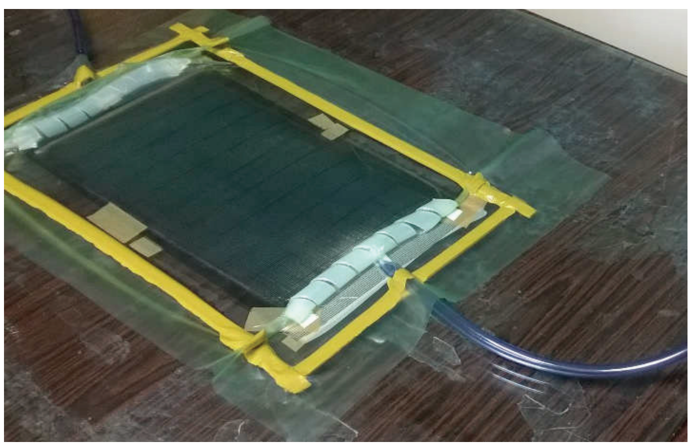

FIGURE 1. Vacuum bagging setup for composite laminate fabrication.

VIBRATION SETUP

The vibration setup as shown in figure 3 has been used to measure the first two natural frequencies and damping ratios of the beams. The beam is clamped at one end and other end is free. The NI LabVIEW software has been utilized for signal analysis and data acquisition. The accelerometer glued on to the beam is connected to the Data Acquisition System (DAQ). The excitation provided by the rolling impact hammer in the beam is acquired by the accelerometer in the form of electric signal. A signal conditioner transfers the characteristics of accelerometer compatible with the input electronics. The data received is streamed on to the LabVIEW software for processing. Data is gathered in frequency domain, and the magnitude of the frequency response function (FRF) is calculated from real and imaginary FRF values. The half-bandwidth method has been used for calculating the damping ratio.

FIGURE 2. Extracted composite beams: (i) 16 layer glass and (ii) 16 layer carbon, and hybrid are (iii) GC1, (iv) GG1 and (v) CC1.

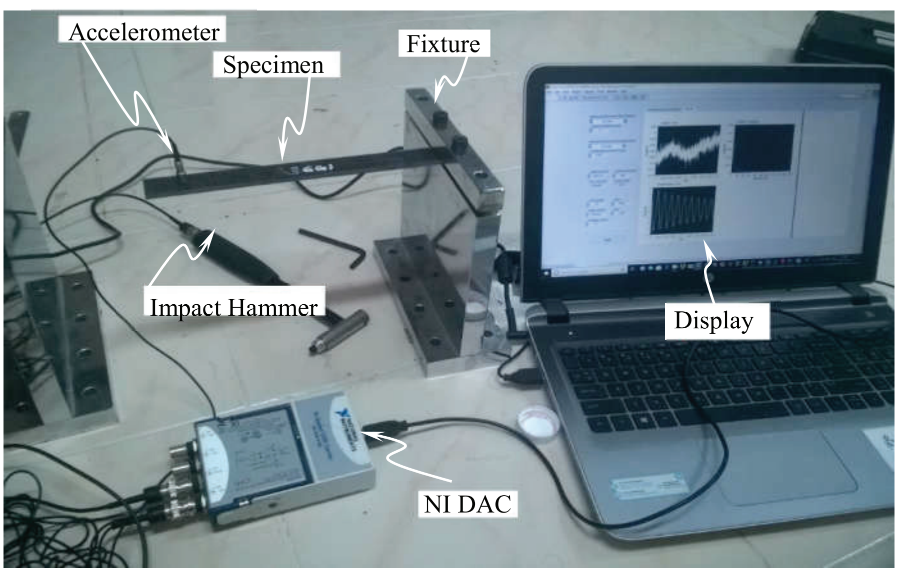

FIGURE 3. Vibration setup

RESULTS AND DISCUSSION

The vibrational analysis of different layup sequences of plain woven glass and carbon composite beams is analysed for extracting modal characteristics. In the present analysis, frequency response plots of composite beams of various layup sequence with fixed-free condition is considered for two different frequency ranges. The results of natural frequencies and damping ratio of different beam configurations are summarised in the table 1. The damping ratio in this investigation is calculated based on half band-width method.

Table 1 Measured natural frequencies and damping ratios of composite beams with fixed-free condition.

Vibration Mode No.		1st Mode		2nd Mode	
Layup sequence	**Symbol**	**Natural frequency (Hz)**	**Damping ratio**	**Natural frequency (Hz)**	**Damping ratio**
$[G_8]_s$	G1	30	0.156	205	0.036
$[C_8]_s$	C1	51	0.100	343	0.019
$[G_7C]_S$	GC1	28	0.190	256	0.090
$[G/C/G/C/G/C/G/C]_S$	GG1	46	0.095	294	0.056
$[C/G/C/G/C/G/C/G]_S$	CC1	45	0.088	327	0.020

Figure 4 (i) and (ii) depicts frequency responses of 16-layered glass and 16-layered carbon beams with fixed-free end conditions for frequency ranges of 1–100 Hz and 100–400 Hz, respectively. Among the two beams, the glass fabric beam, exhibit relatively low amplitude at successive natural levels as compared to carbon fabric beam. On the other hand, the influence of carbon and glass fibres on structural damping is confirmed by the trend of damping effects presented in Table 1.

Table 1 also present the measured first two natural frequencies and damping effects of composite beam configurations considered in the investigation. Frequency responses of glass and carbon and hybrid composite beams for a range of frequencies is shown in figure 5(i) and (ii).It is noticed that frequencies of all hybrid configurations: GC1, GG1, CC1 shows a natural higher than the beam with only glass fibres. This characteristic behaviour in the hybrid beams is attributed high modulus of carbon fiber which can be beneficial for weight saving aerospace applications. It is observed in Figure 5 (i) that natural frequency of all beams are more or less same in 1st mode. Further, in successive modes, natural frequency of beam, GC1, GG1 and CC1 has natural frequency values inclined towards pure carbon fabric beams. The carbon fabric beams found to be relatively at very high natural frequency level as compared with hybrid composite beams.

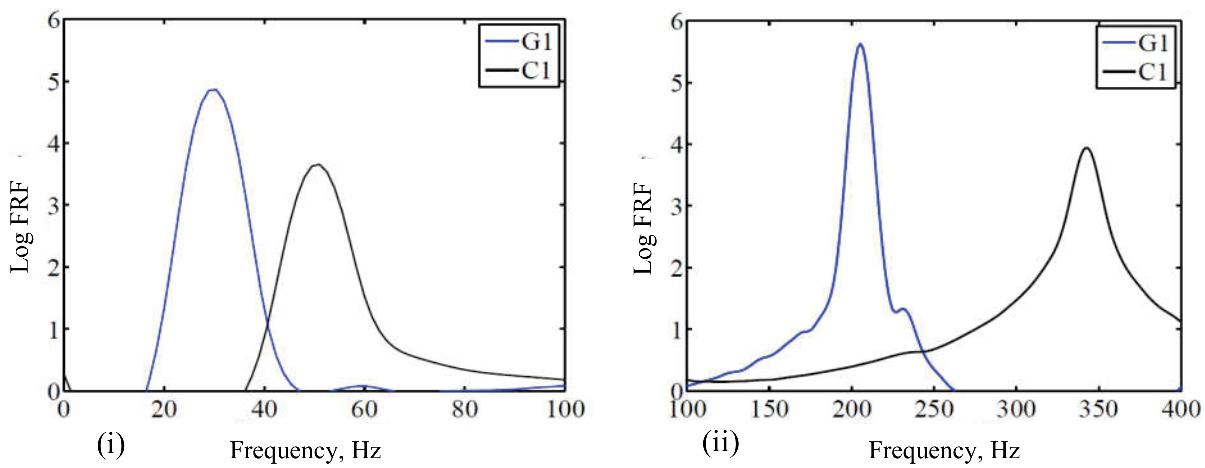

FIGURE 4. Frequency responses of glass and carbon composite beams: (i) 1st mode and (ii) 2nd mode.

Figure 6 depicts a comparison of natural frequencies of glass, carbon and three hybrid composite beam configurations considered in the study. It is observed that the hybrid composites forms a band between glass and carbon composite beams indicate that if carbon and glass layers are placed suitably then the benefits of carbon for high stiffness and glass for good damping characteristics can be utilised. Among the hybrid composite beams considered in the present study, GG1 with alternating layers of glass and carbon, GC1 with carbon in the central surface and CC1 with alternating layers of carbon and glass carbon on the top surface, it is observed in figure 6 that, CC1 has higher natural frequencies. The hybrid composite beam, GC1 is found to be having shift in natural frequencies towards higher frequency as compared to glass fibres indicating scope for load bearing characteristic with reduced weight and increased stiffness. On the other hand, from figure 7, it is observed that hybrid composite beam, GC1 has a linearly decreasing trend of damping ratio as compared to any other composite beams which is desirable character for damage tolerant and automotive structures. Thus, by placing carbon layers as sandwich in the centre of the glass layers not only reduces the weight of the structure but also contributes towards enhanced stiffness and stability of the structure.

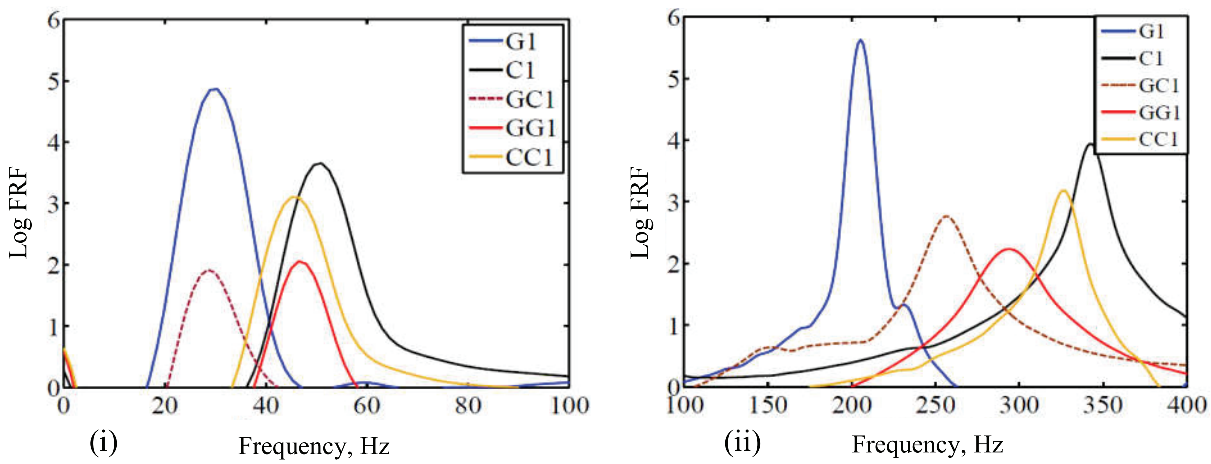

FIGURE 5. Frequency responses of glass and carbon and hybrid composite beams: (i) 1st mode and (ii) 2nd mode.

CONCLUSIONS

Paper presents an investigation on modal characteristics of plane woven glass/carbon hybrid composite beams with fixed-free end conditions by experimentally. The composite beam specimens were extracted from composite laminates of 16 layers with different hybrid configurations fabricated using vacuum bagging technique. Experimentations were carried out to measure first two natural frequencies and damping effect of beams. The investigation revealed that hybridisation affects the vibration characteristics. The natural frequencies of beams increased by the use of higher stiffness fibres in the upper layer. By using carbon layers with glass contributes towards increased natural frequency with reduced weight of the structure as compared to pure glass fabric structure. The damping effect in the beam with carbon fibre as middle layer was found to be higher as compared to the dedicated plain woven glass composites.

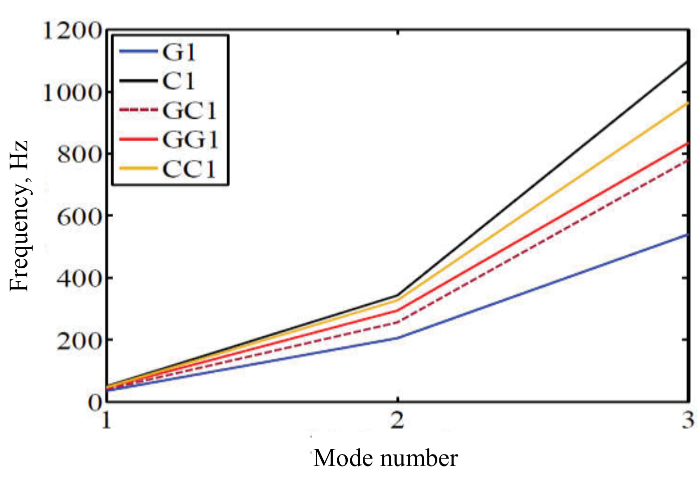

FIGURE 6. Frequency vs. Mode number plot of all beam

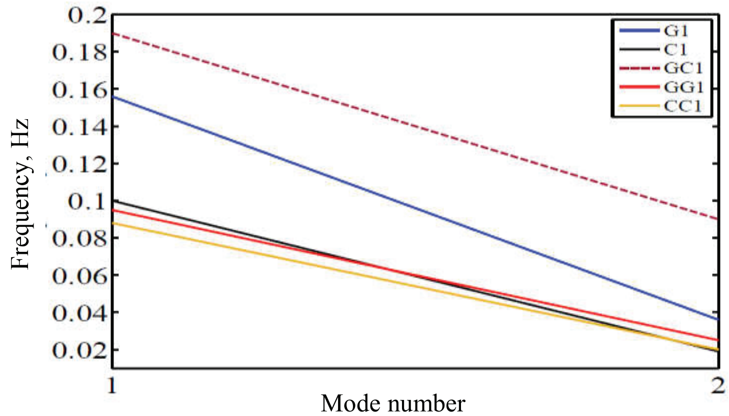

FIGURE 7. Damping ratio vs. mode number for all beam configurations.

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