PAGES: 12-19
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JOURNAL OF SCIENTIFIC RESEARCH AND TECHNOLOGY VOLUME-2 ISSUE-9 SEPTEMBER

# Impact of Graphene Reinforcement Upon Damping Properties of Epoxy/Glass Hybrid Composites

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## ABSTRACT

**The primary goal of this study was to examine how epoxy/glass fiber/graphene hybrid composites' inherent frequencies and mode shapes are affected by graphene reinforcement. Hybrid composite laminates were made using the hand layup method after graphene dispersions of 3, 4, and 5 weight percent were introduced into the epoxy resin using ultra-sonication. The experimental and numerical methods of determining the damping properties of the developed hybrid composite laminates were carried out utilizing a Model test rig and the ANSYS workbench, respectively. The addition of graphene to the hybrid composites enhanced their global stiffness, which in turn raised the natural frequencies of the first three modes by 8.05, 6.64, and 1.09%, respectively. The hybrid composites' reduced surface area for energy dissipation due to the graphene reinforcement resulted in a reduction of 35.29%, 56.63%, and 49.53% in the damping ratio of the first three modes, respectively. According to the results of the numerical validation, the first mode has a larger variance than the other two modes.**

**Keywords: Graphene Reinforcing, Damping Properties, Epoxy Glass Composites**

## I.INTRODUCTION

Hybrid polymer composites are a great choice because of their low density, high specific strength, and durability [1-4]. The design of FRPs structures is now plagued by vibration serviceability issues, since these materials are more critical than conventional ones. Structures using FRPs are subjected to strong vibrations, earthquakes, impacts, and collisions while they are in service. Additional structural criteria for FRPs include energy-strange-and vibration-damping industrial applications, as well as sound-absorbing properties [5].

There is little to no apparent strain energy absorption capability in FRP constructions. The use of hybrid reinforcement reinforced polymer composites, which retain the benefits of both types of reinforcements, may circumvent this problem. Adding filler elements to polymer composites may greatly improve their mechanical characteristics. To increase the strength of GFRP composites, popular filler materials including nano clay, carbon nanotubes, micro-glass bubbles, and so on are used [6-8].

Comparing hybrid fiber composites to composites reinforced with a single fiber reveals a significant difference in damping coefficient [9]. By incorporating nano filler into fiber laminates, the damping ratio is improved by about 20% [10]. Carbon black increases stiffness by increasing the bonding strength between the matrix and fiber via the incorporation of surface energy [11]. The mechanical and damping characteristics of hybrid composites were studied by a number of researchers [12–15] who focused on two or three fibers.

Previous research on hybridized two-fiber composites has shown its damping capability. Despite the extensive study on mechanical and tribological applications of hybrid composites based on nanofiller, the damping capabilities of these materials have received very less attention. Many hybrid composites rely on carbon-based nanofiller as a reinforcing material because of its superior mechanical, fatigue, and wear characteristics. Most often used nano-fillers are carbon nanotubes, graphene, fullerene, and carbon black because of their excellent performance and dimensional stability.

Since fullerenes and carbon fiber are too expensive, graphene might be used as a reinforcing filler. Despite a twenty percent improvement in the damping ratio, the dynamic behavior of GFRP filled with nanofillers reveals that the inherent frequencies and mode geometries of hybrid composites remain largely unchanged. Integral to the success of using composites in dynamic settings is a better understanding of their static and dynamic properties. In this study, we will use experimental and computational methods to determine how the amount of graphene in epoxy/glass/graphene hybrid composites affects their damping qualities.

## II. MATERIALS AND METHODOLOGY

In this research, a 10:1 ratio of aliphatic amines HY-951 to epoxy resins cured at room temperature was used to create nanocomposites of graphene and LY-556 epoxy. Graphene was distributed in epoxy with the use of twin-screw extrusion and ultra-sonication. The manufacturer's specs were used to calculate the amounts of resin, graphene, and hardener.

To make the graphene/epoxy specimens, a sun mica mold of 300 x 300 x 5 mm3 was used to shape the combination. Upon completion of curing, each specimen is then sliced into 240 × 240 mm, an oversize measurement that allows for a 20 mm margin of error on each side. Additionally, the damping capabilities of the laminates were not used until after they had cured for 24 hours at room temperature.

## III. EXPERIMENTATION

### *A.* Damping Test

On the surfaces of the specimens, straight lines were drawn in square grids with a spacing of 33 mm. This arrangement brought 41 nodes onto the specimens. As shown in Figure 1, the model test was carried out under Fixed-Free circumstances. In order to establish fixed boundary conditions, the specimen is laid out horizontally and its end is secured and tightened by the fixed bracket. In order to measure the plate's vibratory response, an accelerometer was attached to various nodes using petro wax. Plate reactivity to stimulation is captured by the accelerometer for a duration of one second subsequent to impact.

### *B.* Numerical Studies

The numerical analysis of the hybrid composites' damping properties was performed using the ANSYS Composites Pre (ACP) finite element program. When it comes to composite modeling, ACP provides excellent flexibility and produces effective laminate models. In addition, model analysis made use of the imported generated models. Each model has its first three natural frequencies determined. Additionally, for every mode form, the transverse displacement was calculated. After that, the formula for the central difference approximation was used to derive the curvature mode forms by replacing these transverse displacements. The predicted damage index was derived from the curvature mode shapes computed at each node. When feeding the data into ANSYS, Table 1 includes the characteristics of both epoxy/glass and epoxy/glass graphene. Lastly, the model analysis module was used to import the ACP solid model and determine the natural frequencies associated with the fiber orientation.

Table 1. Characteristics of GFRP and hybrid GFRP laminates uploaded in ANSYS

| Properties | GFRP laminate | Hybrid GFRP laminate |
|---|---|---|
| YM in X- direction (GPa) | 19 | 20.1 |
| YM in Y- direction (GPa) | 19 | 20.1 |
| YM in Z- direction (GPa) | 3.05 | 3.011 |
| Poisson's Ratio in XY direction | 0.044 | 0.0421 |
| Poisson's Ratio in YZ direction | 0.32 | 0.389 |
| Poisson's Ratio in ZX direction | 0.32 | 0.389 |
| Shear Modulus in XY direction (GPa) | 3.183 | 3.392 |
| Shear Modulus in YZ direction (GPa) | 1.51 | 1.521 |
| Shear Modulus in ZX direction (GPa) | 1.51 | 1.521 |

## IV. NUMERICAL VALIDATION

Numerical validation of the model parameters found by experimental model analysis is carried out in ANSYS Workbench using model analysis. Through numerical analysis, we were able to derive the first three modes' inherent frequencies and shape parameters. In what follows, we'll go into depth about the findings.

### A. Mesh Convergence Study

By using mesh convergence, the size of the quadrilateral shell element's mesh was chosen. The first model analysis was conducted using a 12mm element size, yielding extracted frequencies of 77.931, 131.97, and 405.91 Hz for the first three modes, respectively. Nevertheless, the investigation was wound down to a 3mm size since the extracted values were almost identical to the 4mm size. The first three modes are shown in Figures 2 and 3 at different mesh sizes.

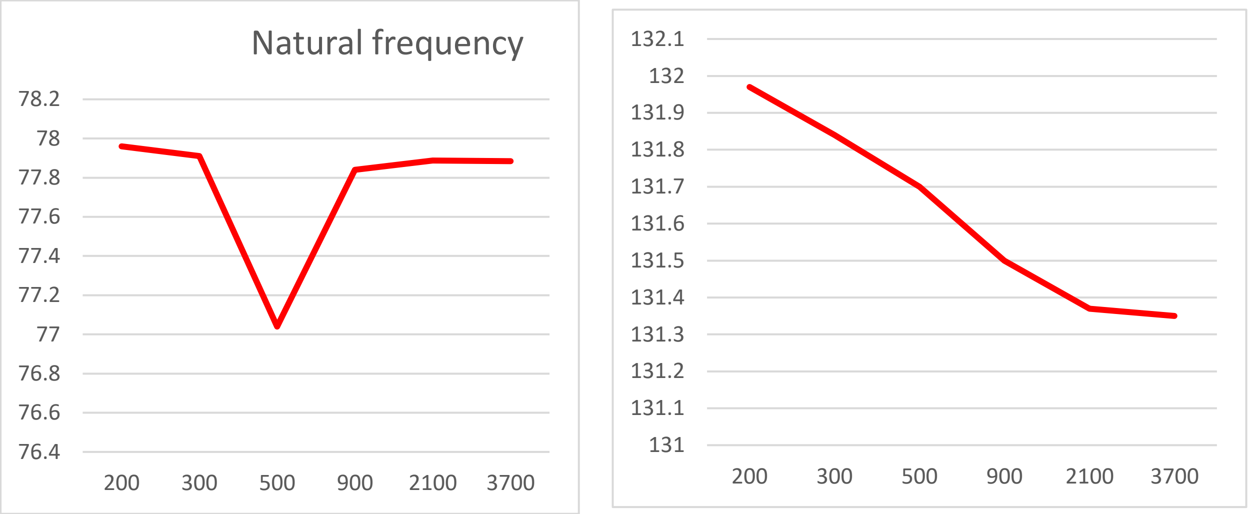


Fig. 1: Mesh Convergence study for (a) Mode 1 (b) Mode 2

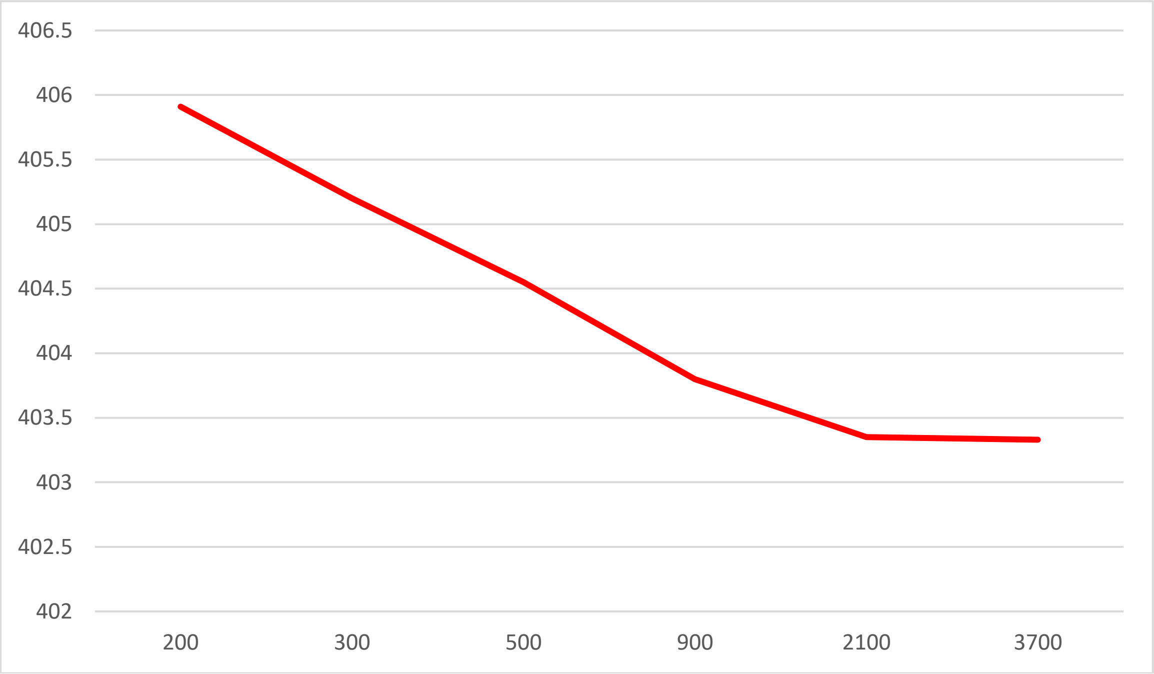


Fig. 2: Mesh Convergence study for (c) Mode 3

## V. RESULTS AND DISCUSSION

### *A.* Model Analysis of GFRP

In Figure 4, we can see the Frequency Response Function (FRF). Naturally occurring at 60.26, 131.5, and

445.23 Hz are the first three. The bending mode, with the greatest displacement at the edge opposing the clamped edge, is the mode shape for the first natural frequency. The second natural frequency has a twisting mode form, where the edges next to the clamped edge experience the most displacement. For the third natural frequency, the mode form is a hybrid of bending and twisting.

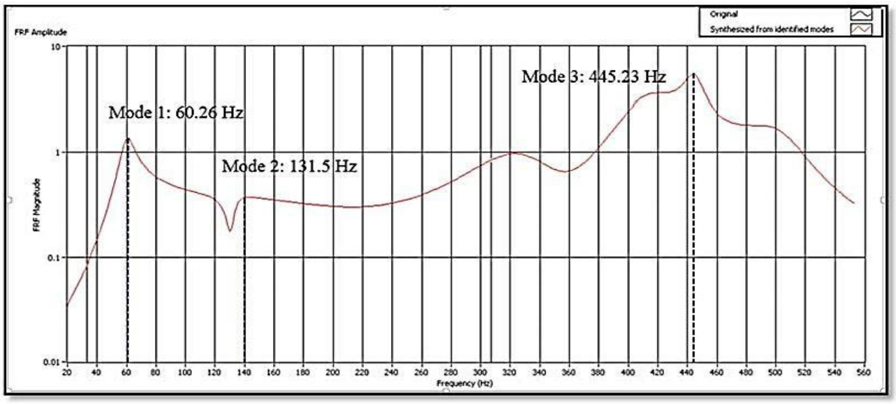


Fig. 3: Frequency response function for GFRP laminate

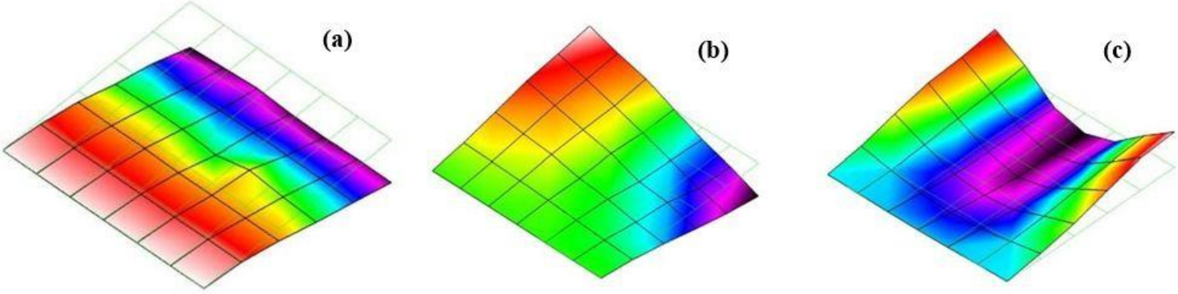


Fig.4: Mode shapes of GFRP laminate a) Mode 1: Bending b) Mode 2: Twisting c) Mode 3: Complex Mode

*B.* Model Analysis of Hybrid GFRP

In Figure 6, we can see the FRF. At 65.11, 140.23, and 450.09 Hz, you may find the first three of the natural frequencies. The initial natural frequency has a bending mode form, where the clamped edge is opposite the edge with the maximum displacement. The second natural frequency has a twisting mode form, where the edges next to the clamped edge experience the most displacement. For the third natural frequency, the mode form is a hybrid of bending and twisting.

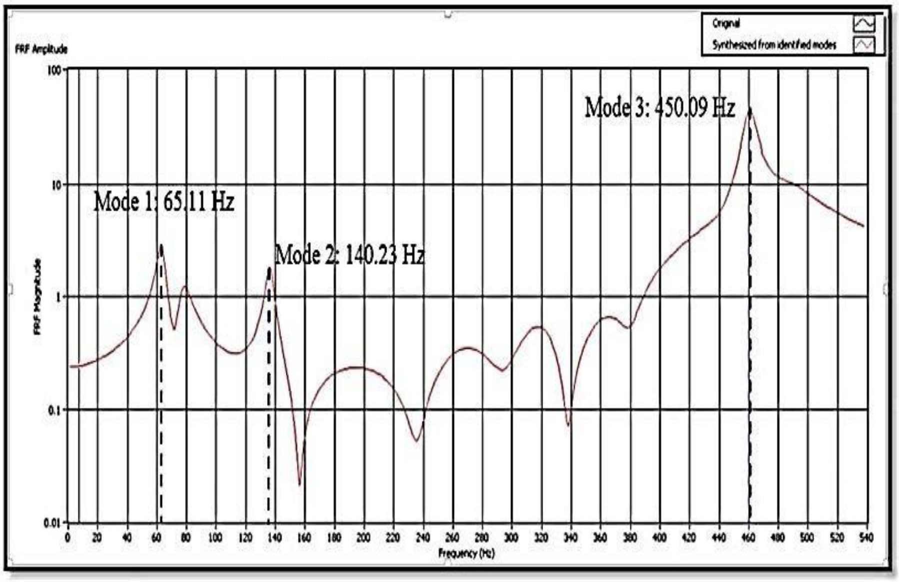


Fig. 5: Frequency response function for Hybrid GFRP laminate

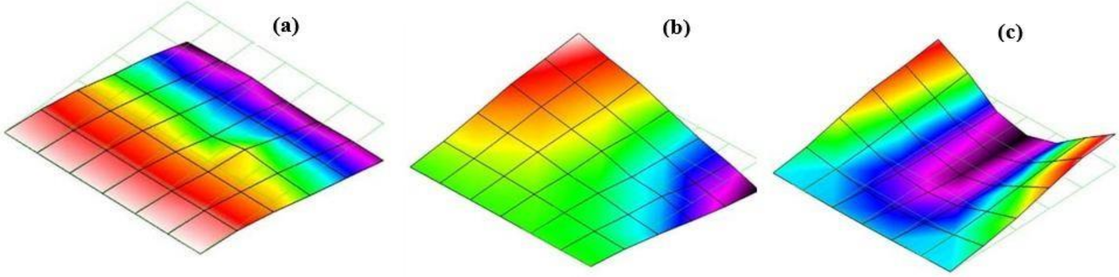


Fig. 6: Mode shapes of Hybrid laminate a) Mode 1: Bending b) Mode 2: Twisting c) Mode 3: Complex Mode

*C.* Dynamic Ehaviour Of Hybrid GFRP

*1)* Effect Of Filler On Natural Frequencies

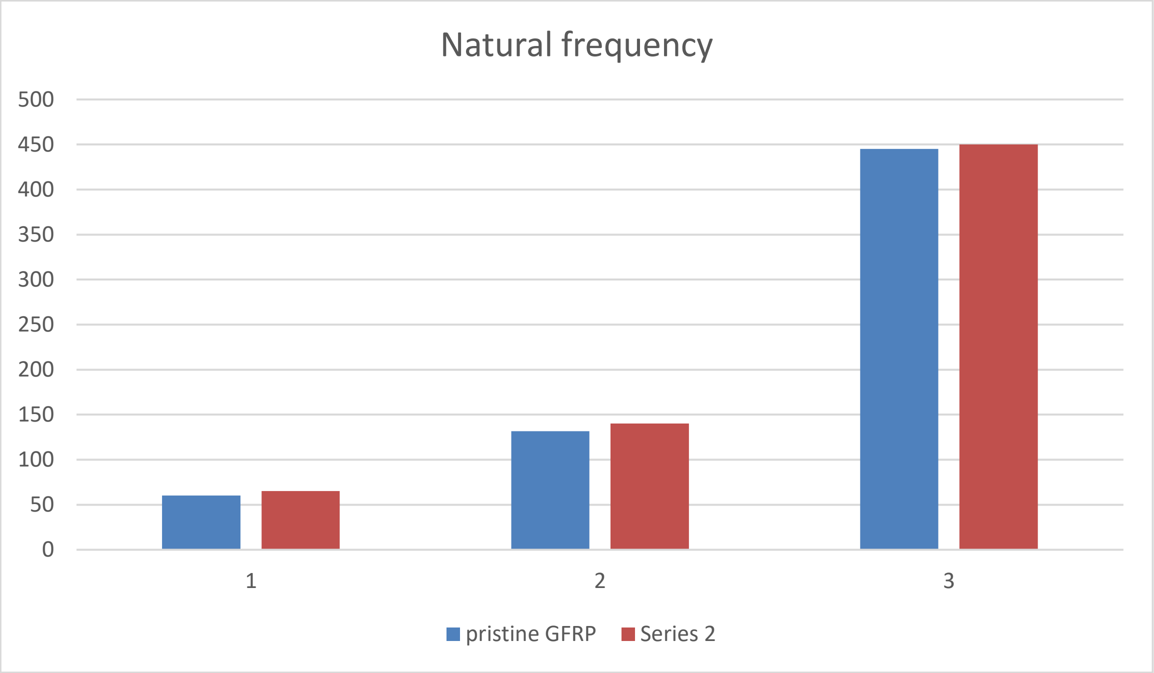


Fig. 7: Comparison of natural frequencies for Pristine and Hybrid GFRP specimens

Figure 7 shows that the hybrid laminate's inherent frequencies have been amplified as a result of the incorporation of carbon black, which accounts for 4% by weight. In comparison to the unaltered GFRP sample, the first three modes have grown by8.05,6.64, and 1.09%, respectively. With each successive mode, the percentage increase in natural frequencies diminishes, with the first mode showing the largest rise. The rise in natural frequencies is a result of the filler's effect on the laminate's global stiffness.

*2)* Effect Of Filler On Damping Ratios

Incorporating carbon black at a weight composition of 4% has reduced the damping ratios associated with the first three natural frequencies of the hybrid laminate, as seen in Figure 9. They have reduced by 35.29%, 56.63%, and 49.52%, in that order, when compared with perfect GFRP samples. Energy wasted at a given natural frequency is represented by the damping ratio, which grows as the surface area for dissipation between the plies rises. There is less surface area available for dissipating energy now that carbon black has been added.

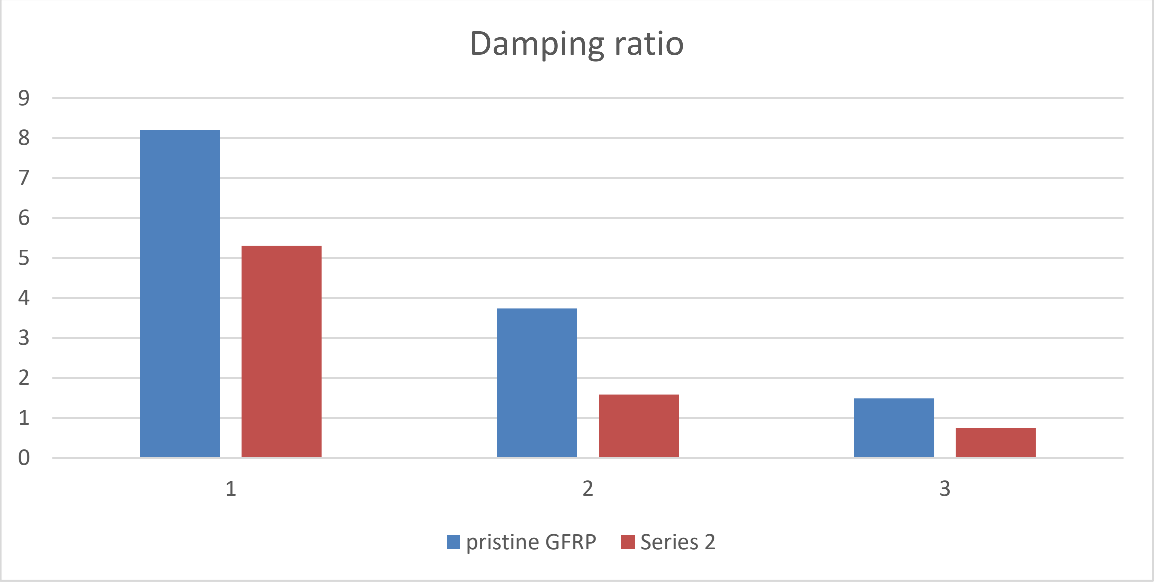
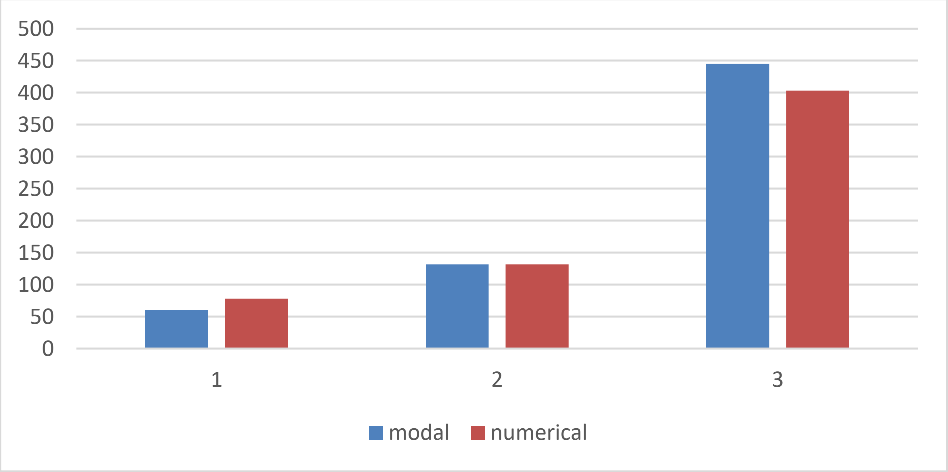


Fig. 8: Comparison of Damping Ratios for Composites and Hybrid GFRP specimens

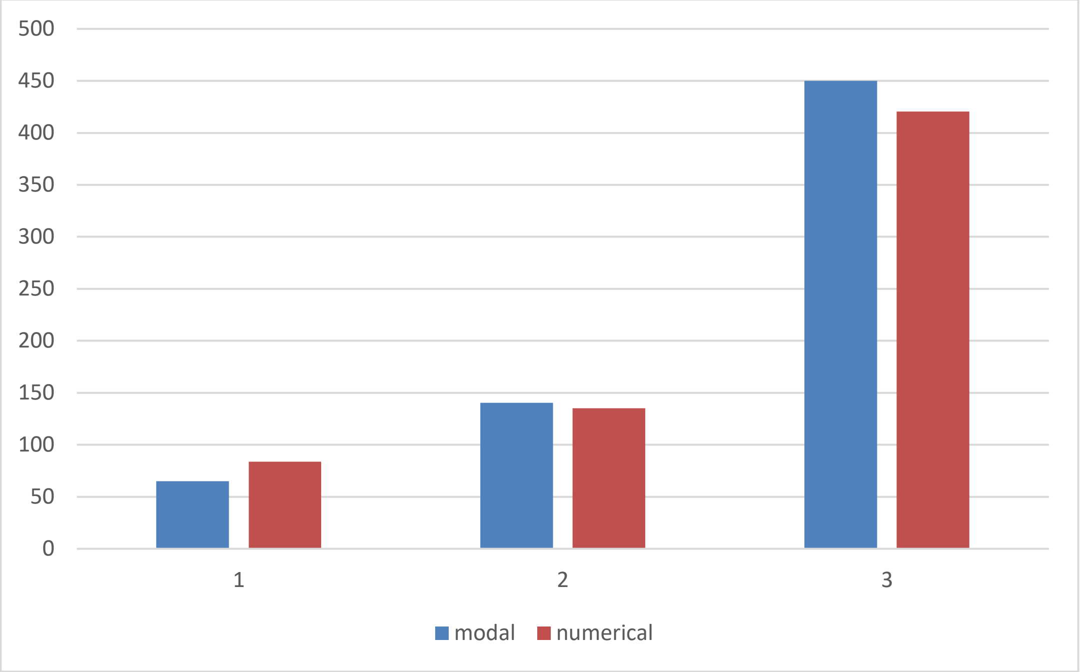
*3)* Comparison of Natural Frequencies

The retrieved values of natural frequencies exhibit a consistent pattern across all four laminates. For unaltered GFRP (number 29.24), hybrid GFRP (number 28.55), and damaged specimens D1 and D2, the initial natural frequency is higher than the experimental value by 34.57 and 48.29%, respectively. The experimental values for the second mode are higher for pristine GFRP (0.1), hybrid GFRP (3.6), and damaged specimens D1 and D2, respectively; nevertheless, the natural frequencies for these materials are lower by 4.08 and 5.2%.

Similarly, in the third mode, the natural frequencies for pure GFRP (9.51%), hybrid GFRP (6.55%), and damaged specimens D1 and D2 (0.42%) are lower than the experimental values. In the first mode, there is a significant fluctuation in natural frequencies compared to the second and third modes, according to the comparison of numerical and experimental values for all specimens. This is because, at this frequency, the structure shows signs of non-linearity. Because stiffness is considered constant in the numerical model, the analysis is based on the assumption that force and displacement are linearly related. But in various modes, composites show varying degrees of rigidity. If numerical analysis is to be more precise, the model parameters should be calculated using transient analysis, which takes this non-linearity into consideration.



(a)



(b)

Fig. 9 (a,b): Comparison of model and numerical natural frequencies for a) GFRP and b) Hybrid GFRP composites

## VI. CONCLUSIONS

The experimental and numerical investigation of the impact of graphene content on the damping capabilities of epoxy/glass/graphene hybrid composites. The results of the experiments led to the following conclusions:

1) Hybrid laminates have higher natural frequencies than Pristine GFRP laminates because the filler increases the global stiffness. Additionally, the damping ratios for the first three Hybrid laminate modes have been reduced. As a result, we can see that the first three modes experience less energy loss after adding the filler.
2) The model test clearly shows that the damaged specimens' inherent frequencies and damping ratios are different from the Hybrid laminates'. It demonstrates that damping ratios and natural frequencies may be used efficiently for damage detection. The damage's location and severity cannot be predicted by these two criteria, however.
3) In comparison to the second and third modes, there is a significant amount of fluctuation in the first natural frequency between the experimental and numerical findings for all specimens. The reason for this is because the stiffness is not linear at this mode. Additionally, it is assumed that the stiffness is linear at all modes in the numerical model analysis.

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