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Effect of Graphene Reinforcement on Damping Properties of Epoxy/Glass Hybrid Composites

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Abstract: The main objective of this work was to investigate the influence of graphene reinforcement on natural frequency and mode shapes of epoxy / glass fibre / graphene hybrid composites. The graphene of 3, 4 and 5 wt.% were dispersed in the epoxy resin by ultra-sonication, then the hybrid composite laminates were fabricated by hand layup technique Damping characteristics of the developed hybrid composite laminates were determined experimentally using Model test rig and numerical method using ANSYS workbench. The natural frequencies of the first three modes for the hybrid composites were increased by 8.05, 6.64 and 1.09% due to the presence of graphene leading to higher global stiffness. On the other hand, the damping ratio of the first three modes for the hybrid composites decreased by 35.29, 57.63 and 49.25%, respectively, because of the decrease in surface area available for energy dissipation caused by the graphene reinforcement. The numerical validation revealed that the deviation for the first mode is higher as compared to the other two modes
Keywords: Epoxy, Glass Fibre, Graphene Hybrid Composites, Natural frequency, Modes, Damping analysis

1. INTRODUCTION

Hybrid polymer composites are higher desirable aircraft structural components due to their high specific strength, low density and excellent durability [1-4]. Presently, vibration serviceability is the issue in the design of FRPs structure due to them being more crucial than that of traditional materials. During the service of FRPs, structures are exposed to impact, collision, earthquake, vibration with large excitation. Some other requirements for FRPs structure are sound absorption, energy strange and vibration damping industrial applications [5].

FRPs structures strain energy absorption capacity is not prominent. It can be overcome by hybrid reinforcement reinforced polymer composites, which retain the advantages of two reinforcements. The mechanical properties of polymer composites can be enhanced to a greater extent by adding filler materials. The prominent filler materials added to GFRP composites, such as nano clay, carbon nanotubes, micro-glass bubbles etc. to improve their strength [6-8].

The damping coefficient of hybrid fiber composites is considerably higher than that of single fibre-reinforced composites [9]. The addition of Nano filler into the fiber laminates enhances significantly around 20% of the damping ratio [10]. Carbon black incorporates surface energy that enhances the bonding strength between the matrix and fiber, which leads to higher stiffness [11]. Various researchers [12-15] investigated two or three fibres used for hybrid composites for improving mechanical and damping properties.

Elsewhere, many investigations on hybridized two fiber composites reported the damping capacity. Although much research work investigated nanofiller based hybrid composites for mechanical and tribological work, little / no research work focused on damping properties. Carbon-based Nanofiller are widely used reinforcement materials in hybrid composites due to their excellent mechanical, fatigue and wear properties. Carbon nanotubes, carbon blacks, graphene and fullerenes are the most used nano-fillers due to dimensional stability and high performance.

Carbon fiber and fullerenes are too costly; hence graphene is potential material for filler materials as reinforcement. Dynamic behaviour of Nano filler filled GFRP shows there is no considerable change in natural frequencies and mode shapes of hybrid composites, but the damping ratio was enhanced by 20%.

The use of composite structures in dynamic conditions needs a deeper understanding in both their static and dynamic characteristics. This research work aims to study the effect of graphene content on damping properties on epoxy /glass/graphene hybrid composites by experimentally followed by numerically.

II. MATERIALS AND METHODOLOGY

In the present study, the LY-556 epoxy was used as the matrix material for the fabrication of nanocomposites of graphene and aliphatic amines HY-951 has been used to cure epoxy resins at room temperature of the ratio 10:1. Graphene was dispersed in epoxy using ultra-sonication and twin-screw extrusion. The amount of resin, graphene and hardener were computed using the specifications of materials provided by the manufacturer.

Graphene /epoxy specimens were prepared by moulding the mixture of graphene and epoxy in a sun mica mould of 300 x 300 x 5 mm^3. After curing, all the specimens are cut into 240 x 240 mm, which is slightly larger than the required dimensions and involves a cutting allowance of 20 mm per side. Further, the laminates were allowed to cure for 24 hours under ambient conditions before putting to use of damping properties.

III. EXPERIMENTATION

A. *Damping Test*

Square grids were marked straight lines vertically and horizontally on the specimen surfaces of the distance between them was maintained 33 mm, which introduced 41 nodes on the surface of the specimen. The modal test was conducted using Fixed-Free conditions shown in Fig. 1. The specimen is placed horizontally and the end is clamped and tightened by the fixed bracket to provide fixed boundary conditions. An accelerometer was mounted using petro wax on different nodes to get the vibrational response of the plate. The accelerometer records the plate response to excitation up to one second after the impact.

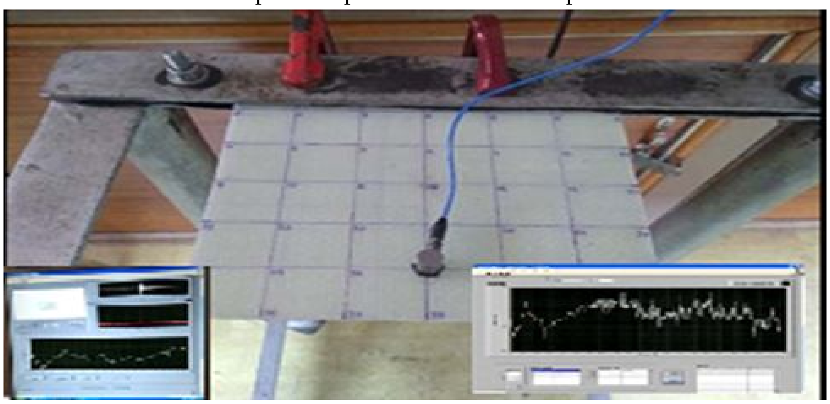


Fig 1. Modal test rig for modal analysis for hybrid composites

B. *Numerical Studies*

In this work, the Finite element tool- ANSYS Composites Pre (ACP) was used to compute the damping characteristics of the hybrid composites. ACP offers good flexibility in composite Modelling and results in efficient laminate models. Further, the developed models were imported for modal analysis. The first three natural frequencies were calculated for all the models. Further, the transverse displacement was extracted for each mode shape. Then, curvature mode shapes were calculated by substituting these transverse displacements in the central difference approximation formula. The damage index was estimated using the calculated curvature mode shapes at each node. Both epoxy/glass and epoxy/glass graphene properties are listed in Table 1, which was input into the ANSYS. Finally, the ACP solid model was imported into the modal analysis module to find the natural frequencies with fibre direction.

Table 1. Properties of GFRP and hybrid GFRP laminates uploaded in the ANSYS

Properties (Units)	GFRP laminate	Hybrid GFRP laminate
Young’s Modulus in X- direction (GPa)	18	20.8
Young’s Modulus in Y- direction (GPa)	18	20.8
Young’s Modulus in Z- direction (GPa)	3.065	3.058
Poisson’s Ratio in XY direction	0.033	0.0391
Poisson’s Ratio in YZ direction	0.34	0.392
Poisson’s Ratio in ZX direction	0.34	0.392
Shear Modulus in XY direction (GPa)	3.193	3.242
Shear Modulus in YZ direction (GPa)	1.49	1.494
Shear Modulus in ZX direction (GPa)	1.49	1.494

IV. NUMERICAL VALIDATION

The modal parameters determined by experimental modal analysis are validated numerically by modal analysis in ANSYS Workbench. The natural frequencies and mode shapes for the first three modes were extracted in numerical analysis. The results obtained are discussed in detail in the sections that follow.

A. *Mesh Convergence Study*

The mesh size for the quadrilateral shell element was selected through mesh convergence. The modal analysis was begun with a 12mm element size at which the extracted frequencies for the first three modes were 77.931, 131.97 and 405.91 Hz respectively. However, the study was concluded at 3mm size as the extracted values were almost the same as that of 4mm. Fig. 2 and Fig.3 shows the first three modes at various mesh sizes.

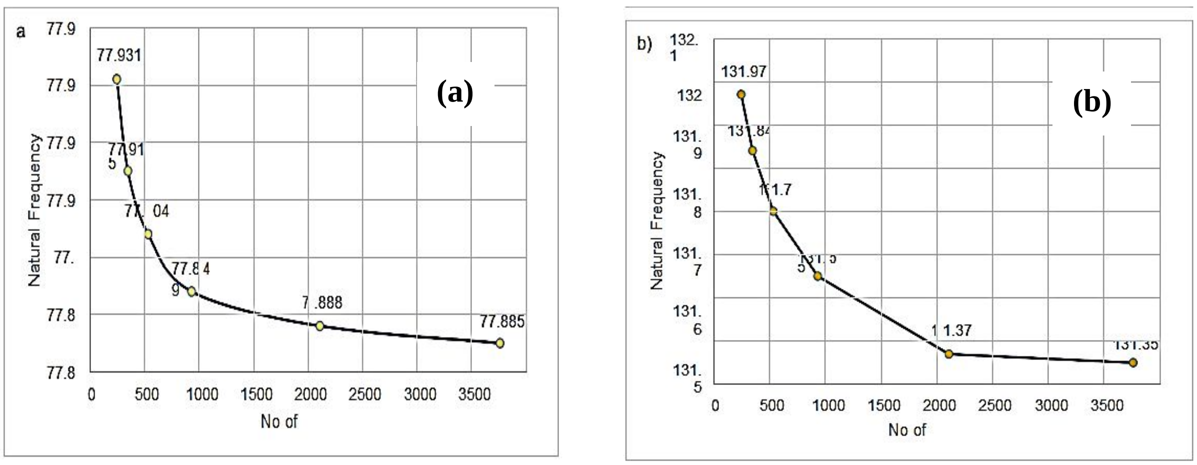


Fig. 2: Mesh Convergence study for (a) Mode 1 (b) Mode 2

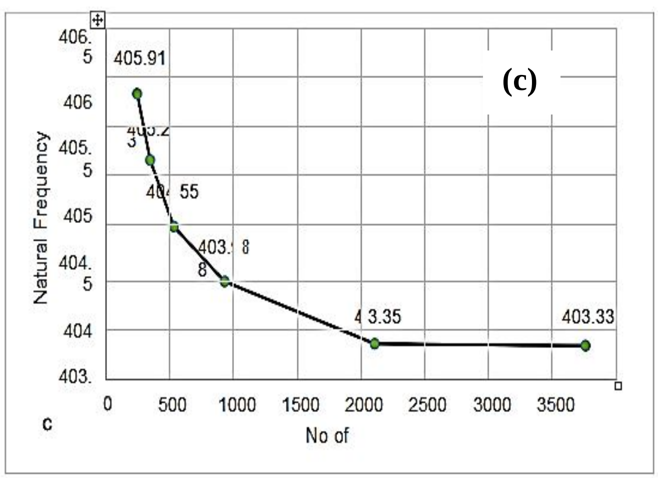


Fig. 3: Mesh Convergence study for (c) Mode 3

V. RESULTS AND DISCUSSION

A. *Model Analysis of GFRP*

The Frequency response function (FRF) is shown in Fig. 4. The first three natural frequencies are 60.26, 131.5 and 445.23 Hz. The mode shape for 1st natural frequency is bending mode with the highest displacement at the edge opposite to the clamped edge. The mode shape for the second natural frequency is a twisting mode with the maximum displacement at the edges adjacent to the clamped edge. Mode shape for third natural frequency is a combination of bending and twisting modes. The mode shapes for three natural frequencies are shown in Fig. 5.

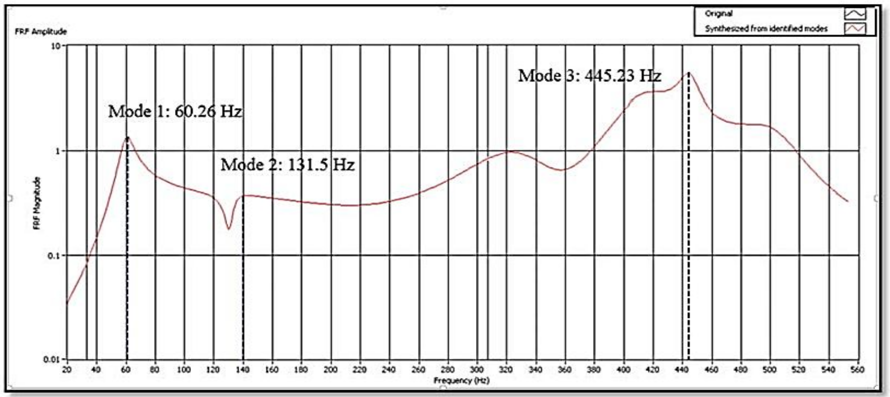


Fig. 4: Frequency response function for GFRP laminate

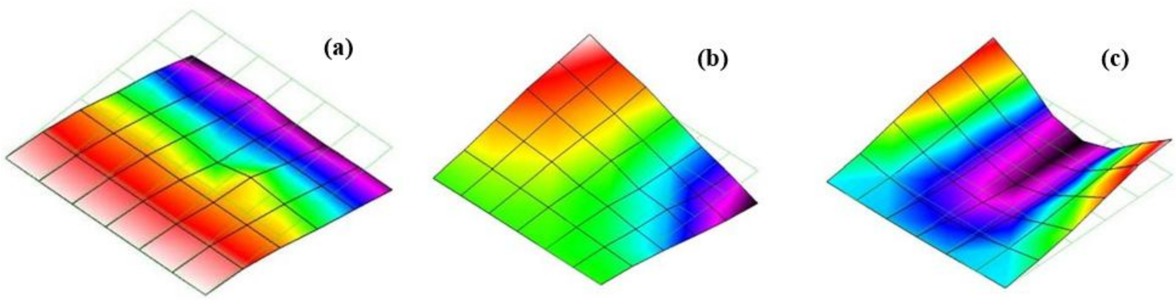


Fig.5: Mode shapes of GFRP laminate a) Mode 1: Bending b) Mode 2: Twisting c) Mode 3: Complex Mode

B. *Model Analysis of Hybrid GFRP*

The FRF is shown in Fig. 6. The first three natural frequencies are 65.11, 140.23 and 450.09 Hz. The mode shape for the first natural frequency is bending mode with the highest displacement at the edge opposite to the clamped edge. The mode shape for the second natural frequency is a twisting mode with the maximum displacement at the edges adjacent to the clamped edge. Mode shape for third natural frequency is a combination of bending and twisting modes. The mode shapes for three natural frequencies are shown in Fig. 7.

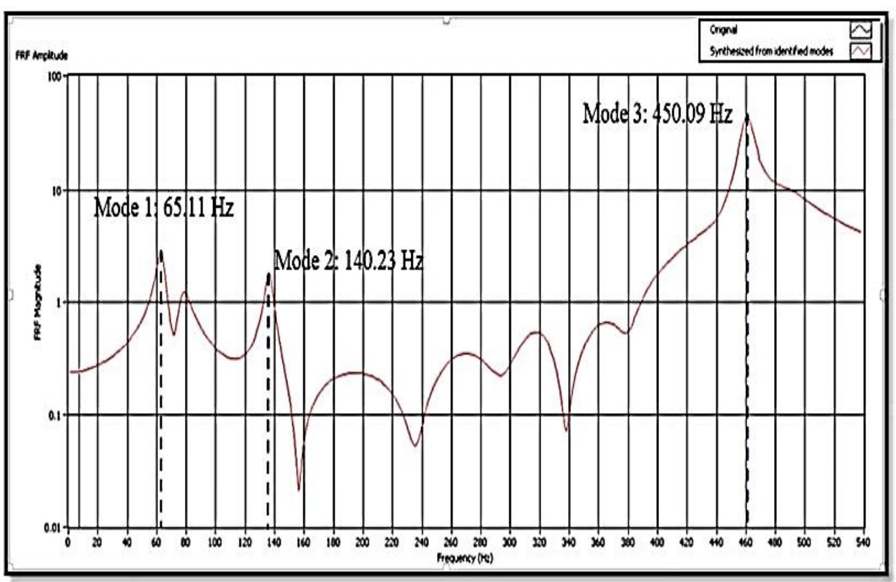


Fig. 6: Frequency response function for Hybrid GFRP laminate

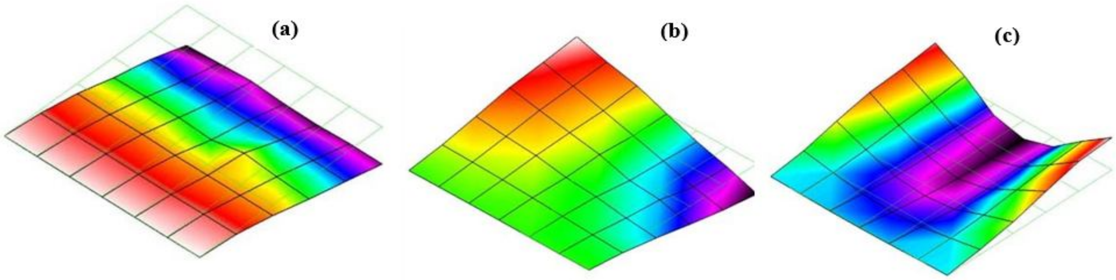


Fig. 7: Mode shapes of Hybrid laminate a) Mode 1: Bending b) Mode 2: Twisting c) Mode 3: Complex Mode

C. *Dynamic Ehaviour Of Hybrid GFRP*

1) *Effect Of Filler On Natural Frequencies*

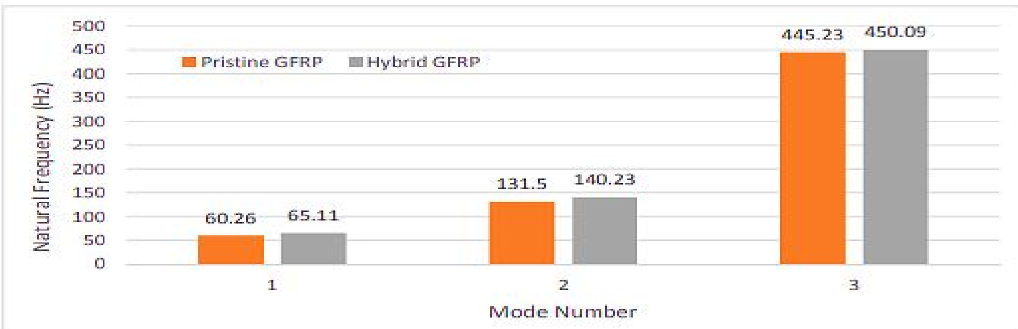


Fig. 8: Comparison of natural frequencies for Pristine and Hybrid GFRP specimens

The natural frequencies of the hybrid laminate have increased due to the addition of carbon black at a composition of 4% by weight as shown in Fig. 8. The first three modes have increased by 8.05, 6.64 and 1.09%, respectively, compared to the pristine GFRP specimen. The percentage increase in natural frequencies is highest for the first mode and further decreases with the second and third modes. The addition of filler has increased the global stiffness of the laminate, which is the reason for enhanced natural frequencies.

2) *Effect Of Filler On Damping Ratios*

The damping ratios corresponding to the first three natural frequencies of the hybrid laminate have decreased due to the addition of carbon black at a composition of 4% by weight as shown in Fig. 9. They have decreased by 35.29, 57.63 and 49.25%, respectively, compared with that of pristine GFRP specimens. Damping ratio signifies the amount of energy dissipated at a specific natural frequency and it increases with the large surface area for dissipation between the plies. The addition of carbon black has decreased the surface area available for energy dissipation.

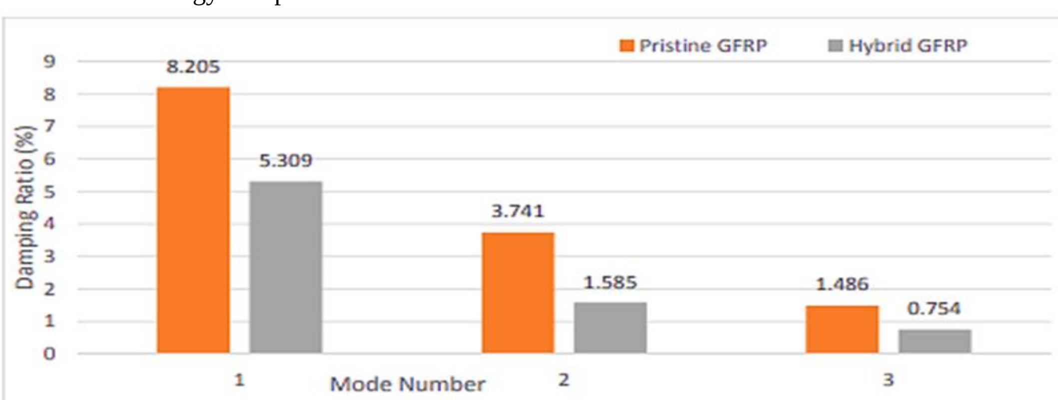
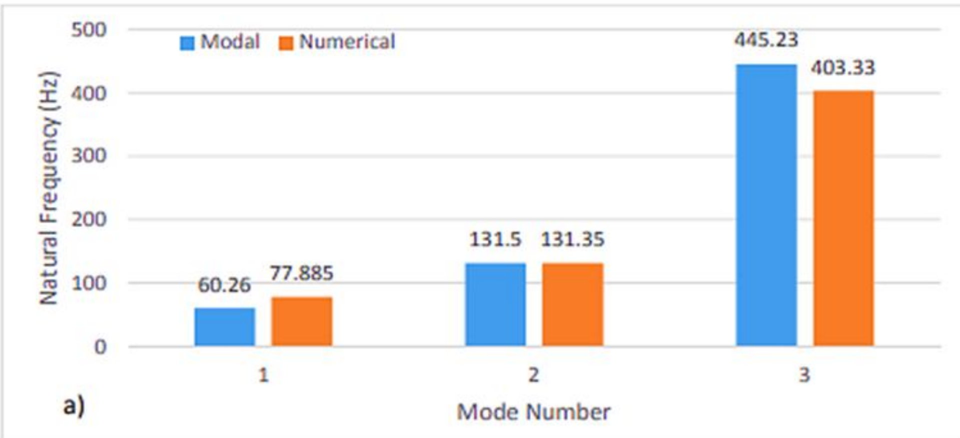


Fig. 9: Comparison of Damping Ratios for Composites and Hybrid GFRP specimens

3) Comparison of Natural Frequencies

The extracted values of natural frequencies follow the same trend for all the four laminates as shown in Fig. 10. The first natural frequency is greater than the experimental value by 29.24, 28.55, 34.57 and 48.29% for pristine GFRP, hybrid GFRP, and for damaged specimens D1 and D2 respectively. However, the natural frequencies for the second mode are less than the experimental values by 0.1, 3.6, 4.08 and 5.2% for pristine GFRP, hybrid GFRP and for damaged specimens D1 and D2 respectively.

A similar trend is observed for the third mode in which the natural frequencies are less than the experimental values by 9.41, 6.55, 6.95 and 0.42% for pristine GFRP, hybrid GFRP and for damaged specimens D1 and D2 respectively. The comparison of experimental and numerical values for the first three modes across all specimens shows that the variation of natural frequencies is considerable in the first mode as compared to the second and third modes. This is due to the non-linearity that the structure exhibits at this frequency. The numerical modal analysis assumes a linear relationship between the force and displacement, treating stiffness as constant. However, composites exhibit different stiffness at different modes. In order to improve the accuracy of numerical analysis, the modal parameters should be computed by transient analysis, in which this non-linearity is accounted for.



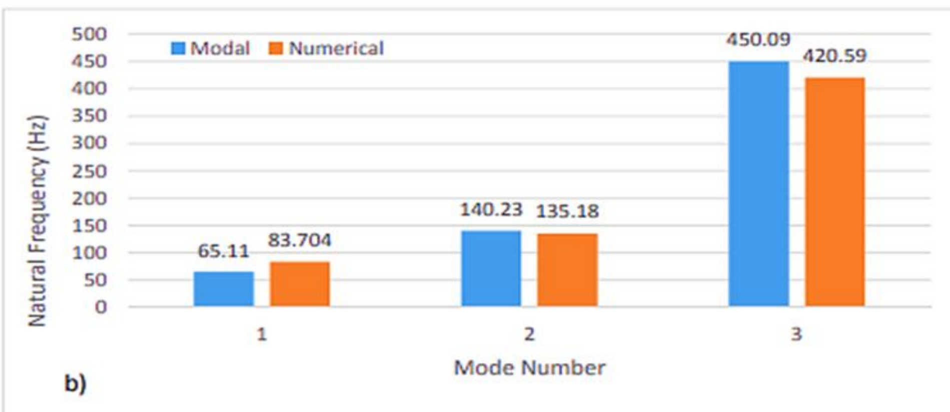


Fig. 10: Comparison of modal and numerical natural frequencies for a) GFRP and b) Hybrid GFRP composites

VI. CONCLUSIONS

The effect of graphene content on damping properties on epoxy /glass/graphene hybrid composites by experimentally followed by numerically. The following conclusions were drawn based on the experimental investigations:

1) The natural frequencies of the Hybrid laminate are greater than that of Pristine GFRP laminate as a result of an increase in global stiffness due to the addition of filler. Also, damping ratios have decreased for the first three modes of Hybrid laminate. It shows that the filler addition reduces the energy dissipation for the first three modes.

2) The mutation in the natural frequencies and damping ratios of the damaged specimens as compared to that of Hybrid laminates is evident from the modal test. It shows that damage detection can be effectively carried out using natural frequencies and damping ratios. However, these two parameters cannot predict the location of the damage and its severity.

3) The variation in first natural frequency between the experimental and numerical results for all the specimens is considerable compared to the second and third modes. It is due to the non-linearity of stiffness at this mode. Also, the numerical modal analysis assumes linearity of stiffness at all the modes.

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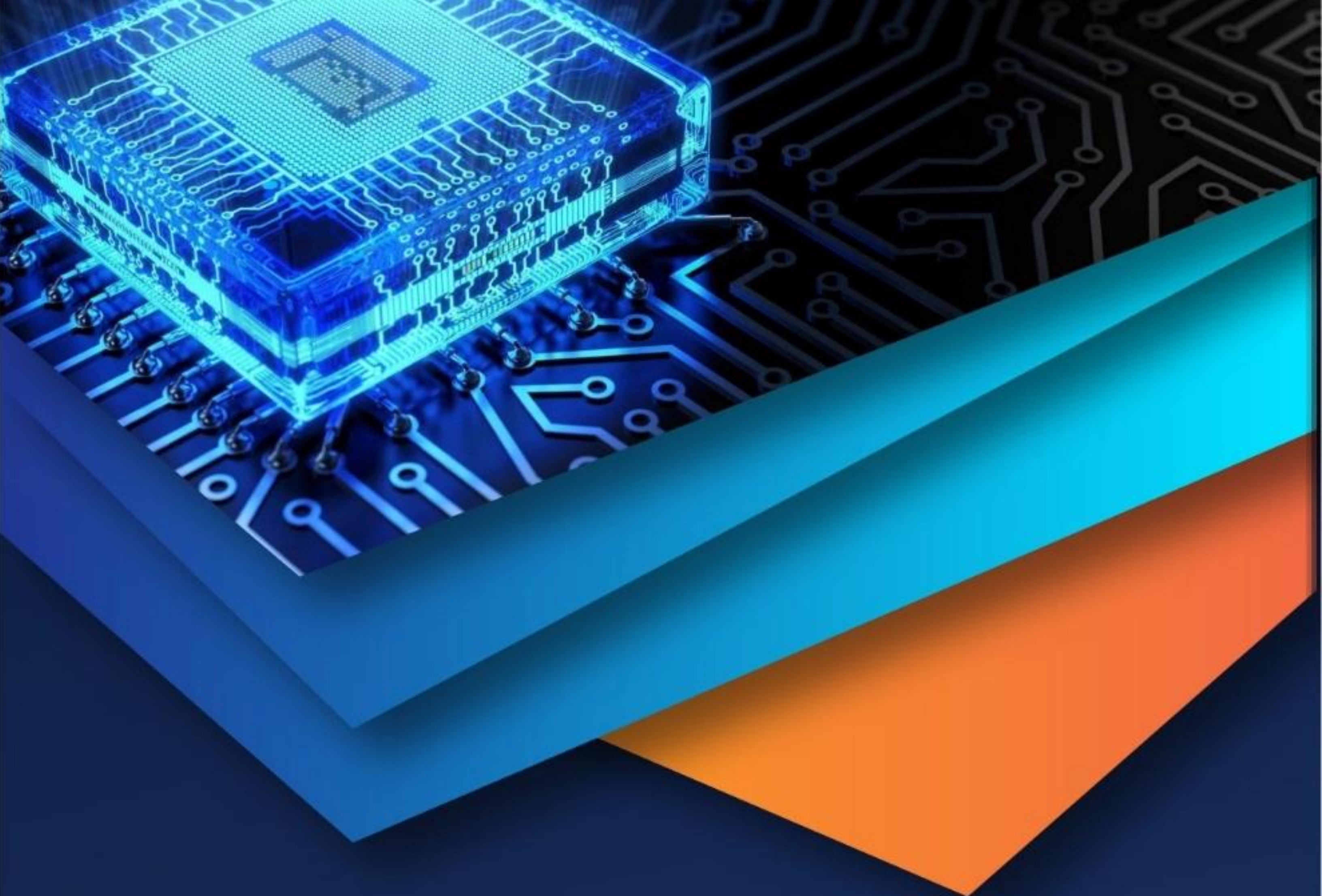

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