IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Vibration Damping In Advanced Fiber - Reinforced Composite: A Focused Review On Carbon Fiber Systems

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***Abstract**:* This review article presents a comprehensive examination of recent studies conducted to enhance the damping characteristics of carbon fibre-reinforced composites. Research indicates that adding multi-walled carbon nanotubes to the composite matrix enhances damping performance, primarily due to interfacial sliding between the nanotubes and the polymer. The integration of barium titanate-based piezoelectric nanowires improves energy absorption through combined mechanical and piezoelectric mechanisms.". Moreover, critical structural elements such as laminate thickness and fiber alignment significantly influence the damping performance of carbon fiber-reinforced composites. Investigations indicate that increased thickness enhances the overall stiffness and fundamental frequency, while fibre orientation affects vibration attenuation, with certain directions exhibiting superior damping capabilities. A through comprehension of these parameters is essential for enhancing the vibrational characteristics of CFRPs in real-world implementations.

Index Terms **- Interfacial skidding mechanism, piezoelectric nanowires, multiwalled carbon nano tubes, CFRC**

I. Introduction

Carbon fibre-reinforced composites are widely used in aerospace, automotive, and structural applications because of their high strength-to-weight ratio, corrosion resistance, and stiffness. However, their vibration and damping characteristics are critical for structural integrity, fatigue resistance and dynamic performance. This Dynamic Characteristics in CFRCs is influenced by various factor like orientation, matrix composition, interfacial properties, and manufacturing processes. The primary energy dissipation mechanisms include the viscoelastic behaviour of the polymer matrix, interfacial friction, and fibre-matrix interactions because of all these advantages of CFRC several experimental, analytical, and numerical modelling approaches have been employed in the past authors to evaluate CFRC damping behaviour, with hybrid composites incorporating materials like Kevlar and graphene showing

Carbon fibre is thin standard of carbon atoms which give them very high tensile strength also high stiffness they also have good thermal stability and corrosion resistant. The matrix is usually a thermosetting polymer like **epoxy**, **polyester**, or **vinyl ester** which binds the fibre together also protects the fibre from environmental damages the main role of matrix material is to provide in shaping the composite.

II. Literature Survey

Khan et al., [1] In this study, hybrid carbon fibre composite pyramidal truss sandwich panels with embedded viscoelastic layers were examined for their vibration and damping capabilities. Their dynamic behaviour was examined using both experimental and numerical techniques. Hot press moulding was used to create the hybrid sandwich panels, which included carbon fibre composite face sheets sandwiched between layers of viscoelastic material of various thicknesses. The findings showed that adding a viscoelastic layer preserved the structure's original frequencies while greatly increasing the damping loss factor.

Pheysey et al., [2] The study on the vibrational response and damping of short fibre unidirectional PEEK hybrid composites concludes that incorporating short fibres into unidirectional PEEK matrices significantly enhances the material's damping properties without substantially compromising stiffness. This improvement is attributed to the energy dissipation mechanisms introduced by the short fibres, which effectively mitigate vibrational amplitudes. These results demonstrate that such hybrid composites are strong candidates for applications requiring a balance of high stiffness and effective vibration damping.

Ula et al., [3] The investigation into the vibration characteristics of sandwich composite materials utilizing unidirectional and **twill carbon fibres** revealed that fibre orientation significantly influences the composite's dynamic behaviour. Specifically, specimens with unidirectional carbon fibre exhibited **higher natural frequencies** compared to those with **twill weaves**. Additionally, the damping properties, as indicated by loss factor values, were The results demonstrate that careful fiber alignment optimization is critical for enhancing damping characteristics of CFRP sandwich structures.

Guo et al., [4] In this study, the carbon fibre **microcrystalline** structure was modified by the **acid treatment** process, which significantly enhanced the **Seebeck coefficient** of CFRC. With the prolongation of the acid treatment time, the microporous content of the carbon fibre surface **increases significantly**. Moreover, the degree of disorder and defects on the surface of the carbon fibre rises dramatically. Which effectively enhances the scattering of carriers, resulting in an effective enhancement of the See beck coefficient of CFRC. The maximum Seebeck coefficient and maximum power factor of CFRC at 35 ◦ and 46.6 µ W m 1 K 2 C are about **1.24 × 10 4 µ V/ ◦ C**. The power factor increases by approximately five orders of magnitude compared to the untreated CFRC, achieving the highest ZT value to date of **1.57×10^{-2} at 35 ◦ C**. The results demonstrate that the microcrystalline structure of carbon fibre can be **modified to enhance the thermoelectric properties of CFRC effectively.**

Hoksbergen et al., [5] The primary goal of this research is to compare the vibration modal parameters of **magnesium AZ31B-O** and carbon fibre reinforced plastic plates. For every vibration mode these parameters consist of natural frequency, damping ratio, and mode shape. The plates are tested in the **free condition and also in a constrained condition** that simulated the boundary condition of a typical vibration test system. Based on the preliminary experimental investigation of magnesium and **CFRP plate** vibration characteristics, the conclusions of this research are given as **the damping** associated with the **CFRP materia**l is **substantially higher than that for the magnesium material.** In most cases the damping is at least 100% higher and typically is as high as 250–300% of the magnesium damping. This is a significant result and presents a major advantage of CFRP over magnesium.

Subramani & Ramamoorthy, [6] This study investigated how adding multi-walled carbon nanotubes (MWCNTs) affects the mechanical properties and vibration behaviour of laminated composite shell structures. Composite shells containing different Multi walled carbon nano tubes(MWCNT) (concentrations (0%, 0.5%, 1%, 1.5%, and 2% by weight) were fabricated using ultrasonic dispersion to ensure uniform nanotube distribution. Material characterization through TEM/SEM imaging confirmed the MWCNTs' homogeneous dispersion and strong interfacial bonding with the composite matrix. Mechanical testing revealed that 1% MWCNT reinforcement provided the optimal enhancement, yielding the highest Young's modulus and ultimate tensile strength. Vibration analysis under free boundary conditions showed a 20% increase in natural frequencies at this 1% MWCNT loading. Additionally, the damping performance improved progressively with higher MWCNT content, reaching maximum energy dissipation (33%) at 2% reinforcement. These results demonstrate that MWCNT incorporation significantly improves both the structural integrity and vibration damping characteristics of composite shell laminates, with 1% MWCNT content offering the best balance between stiffness and vibrational performance.

Zhou et al., [7] In this study, obtaining high damping performance of CFRP without scarifying its mechanical properties, a **3D GO-CNT carbonaceous nanostructur**e on CF surface using **EPD and ethanol pyrolysis** flame methods was designed and implemented. Microstructural characterization confirmed the formation of a hybrid architecture, whereby the 2D GO sheets were coated parallel to the fibre surface and the **1D CNTs** were perpendicularly grafted on the GO surface. Damping capacity tests and **MD simulations** demonstrated that the damping enhancement provided by the **GO-CNT nanostructure in CFRPs exceeded the combined contributions of GO and CNTs alone, showing a synergistic effect.** This was attributed to the rapid dissipation of mechanical energy through GO interlayer sliding and CNT/epoxy interfacial friction, combined with the additional **effect of CNT on increasing the stress transfer efficiency** at the CF/epoxy interphase. Moreover, optimal damping performance was achieved when all fabric layers were modified (η: 0.0459, +130.0%/ζ: 0.1276, +74.1%). Moreover, mechanical tests indicated that the reductions due to the GO interlayer sliding were offset by the grafted CNTs on GO surface. For GO-CNT modified Outermost layers in CFRP, the tensile strength, tensile modulus, and mode I interlaminar fracture toughness were 11.9%, 12.9%, and 34.8% higher, but the ILSS was 5.0% lower, than those of the Received CFRP.

Huang et al.,[8] Present work studied the free vibration of **carbon fibre/epoxy resin and carbon/carbon plain woven conical-cylindrical shell** under thermal environment with general boundary conditions. And the effects of the boundary conditions, geometry, total fibre volume fraction. The free vibration frequencies of circumferential modes 1–5 of the plain-woven reinforced resin-matrix composites conical-cylindrical shell under different V f , R 2 = 10 m, L/R 2 = 1, h/R 2 = 0.01, α = 30, L/L c = 1. temperature fields are studied comprehensively. The following conclusions can be obtained**. When the semi-vertex angel is relatively small, the stiffness of the conical shell becomes larger as the angle becomes larger, and the frequency of free vibration increases slowly.** As the semi-vertex angel increases, the stiffness decreases substantially because the conical shell is gradually degrading to a flat plate, resulting in a significant decrease in the frequency of free vibration.

Shao et al., [9] In this study, the low-frequency vibration-assisted riveting (**LV-SPR)** was first proposed and used in the assembly of **CFRP laminates and aluminium plates**. Analysing the riveting process, joint quality and microstructures, CFRP damage, and shear strength of the riveting joint revealed that low-frequency vibrations can significantly affect the deformation behaviour and CFRP damage in riveting joints. The LV-SPR achieved riveting of high-strength plates with a minimal force, thereby **reducing the power demand**s of the riveting equipment. In this experiment, using **acoustic softening**, stress superposition, and the dynamic friction effects of vibration, the riveting force of **LV-SPR was reduced by 68.2% with parameters of A = 0.2 mm and *f* = 10Hz**. Owing to low-frequency vibrations that alter the direction of friction via periodic loading and unloading, the friction force between the CFRP and rivet was reduced, leading to a **significant decrease in the CFRP damage.** Compared with T-SPR, the reduction of the CFRP damaged area in the LV-SPR joint reached 36.2% with vibration parameters of A = 0.2 mm and *f* = 10Hz.

Xu et al.,[10] This article experimentally explores the **nonlinear vibration characteristics of the C-C** under **partial bolt looseness** by utilizing **the virtual artificial spring technology.** Considering the displacement dependency at the bolt connection, the theoretical model of the nonlinear dynamic behaviour between substructure shells is established. Then, the energy equation at the bolt connection is formulated based on the determined main and auxiliary spring stiffness values, and the model is **solved based on the Rayleigh-Ritz method**. At the same time, the validity of the nonlinear theoretical model is supported by the data analysis. Moreover, the Analytical findings demonstrate that the nonlinear theoretical model is valid. Furthermore, by revealing the transition of sticky-sliding state at the bolt connection, the detailed description of the nonlinear dynamic behaviour at the bolt interface is provided. Finally, the effects of the number, degree and form of bolt looseness on the nonlinear vibration characteristics of the C-C are discussed based on the accurate nonlinear theoretical model. **The results are as follows** When the degree of bolt looseness certain, as the number of bolt looseness grows, the natural frequency of the C-C under various excitations is in a **decreasing trend**, while the response d**isplacement** is in an **increasing trend**. The maximum change values for both are **14.60Hz and 2.89*10 6 m** respectively. Moreover, the nonlinear behaviour becomes more apparent to some extent. The main reason for this is the rise in the number of bolts becoming loose, **resulting in a reduction of the equivalent stiffness** value at **the connection interface**.

Sargianis & Suhr, [11] From This study found that the core's shear stiffness (relative to its weight) has the biggest impact on wave behavior in sandwich composite beams at high frequencies **(above 1000 Hz**). Reducing this shear stiffness can improve wave response without losing bending strength—a key factor in many designs. By optimizing both shear stiffness and bending strength, the coincidence frequency (which affects sound performance) can be significantly increased. The research also highlights the need to use 'effective properties' when working with honeycomb cores in sandwich structures. Similarly, an increase in the core's mass will substantially decrease wave number amplitudes, further improving acoustic performance. In parallel, high structural damping can assist in decreasing wave number amplitudes, especially at frequencies over 2000 Hz. Not only will i**mproving the damping properties of a structure** boast improved fatigue life but also reduce the level of noise radiation by reducing wave number amplitudes.

Khan et al.,[12]In this study, the vibration damping properties of nanocomposites and CFRP hybrid composites containing CNT s were studied based on the free and forced vibrations tests. Therefore, the study yielded the following key findings The free vibration test revealed that the damping ratio of the CFRP-CNT hybrid composites rose with higher CNT content, supporting the earlier hypothesis of interfacial sliding between CNTs and the matrix. Although the CFRP composites had an inherently lower damping ratio than the neat epoxy, the former composites showed a high er rate of increase in damping ratio than the epoxy nanocomposites. The forced vibration test confirmed the beneficial effect of CNTs on improving the damping ratio of both nanocomposites and CFRP composites, in both the1st and 2nd vibration modes.

III. Conclusions

In this study, incorporating nanoparticles such as silicon dioxide (SiO_2) and multi-walled carbon nanotubes (MWCNTs), into CFRPs can enhance mechanical and vibration damping properties. Optimal improvements are noted at specific concentrations; for example, adding 1.5 wt% SiO_2 nanoparticles results in increased damping and mechanical strength. However, exceeding this concentration may lead to a decline in these properties. **The stiffness of the material rises with the inclusion of short carbon fibers, causing an increase in natural frequencies and a decrease in damping.** This stiffening effect is proportional to the fibre content, with a 267% increase in tensile modulu s observed at 30 wt% fibre reinforcement.

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