 ISSN: 2278-4632
Vol-13, Issue-12, No.04, December: 2023

FREE VIBRATION ANALYSIS OF COMPOSITE STRUCTURE WITH VISCOELASTIC CONSTRAINED LAYER-A REVIEW

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Abstract:

Sandwich composite structures has emerging advantages, addition of viscoelastic core layer improve its inherent damping property among two face sheets. It consists of three constituents i.e., face sheets, viscoelastic core and adhesive interface layers. In this study, damping response of composite structures has been reviewed. In the first stage, damping properties and analytical methods applicable to free vibrational analysis are described. Further, this paper represents the damping response involving micro-mechanical, macro-mechanical, and viscoelastic core material behavior approaches. Critical reviews of some significant works on various experimental studies on sandwich composite structures with viscoelastic cores for damping in fiber-reinforced composites and structures are presented. Additionally, an integrated strategy including methods for bettering damping and damping tailoring, having high mechanical properties, and being light in weight can give composite materials and structures better dynamic response. Some work on the application of various analytical/experimental investigations on damping response of composite structures with viscoelastic cores was done.

Key words: Dynamic response, Composite plate, Mode shapes.

1. INTRODUCTION

A vibrating structure's mechanical energy is converted into thermal energy, or heat, during damping. It reduces the amplitude of the structure's vibration. When using viscous damping, the damping force and speed are inversely related. It is a crucial factor in how dynamically composite structures behave. The life of an engineering structure is significantly influenced by vibration. Numerous major issues, including unwelcome noise, exhaustion, strains, and displacements, can be brought on by vibrations. Dampening layers made of viscoelastic materials are frequently employed to solve these issues. These are utilized for effective vibration control and noise reduction. Viscoelastic materials are highly effective at regulating and reducing vibration responses in lightweight composite constructions. A sandwich structure typically consists of a relatively thick core made of low-density materials sandwiched between relatively thin top and bottom face sheets of composite material.

2. ANALYTICAL PREDICTION OF DAMPING:

Forecasting the damping properties of composite constructions with viscoelastic cores involves a number of analytical models. Basically, elastic approaches and mechanics of materials have been used for elastic moduli solution, and the following techniques are used to further forecast the damping characteristics:

2.1 STRAIN ENERGY METHOD:

When an elastic material deforms under load, strain energy is stored within the solid. The strain energy is equal to the work performed on the material by external loads in the absence of energy losses caused by friction and damping.

ISSN: 2278-4632
Vol-13, Issue-12, No.04, December: 2023

The damping of each element and the percentage of the total strain energy in that element are related to the overall damping in the structure using this method. It claims that the loss factor may be calculated for any system of linear viscoelastic elements as the sum of the strain energy stored in each element divided by the loss factor for each element.

When these techniques are used on composites, the composite transforms into a system, and the nature of each constituent is determined by the macro- or micro-mechanical approach. Conor D. Johnson [1] and Rakesh Chandra et al. [2] discuss an integrated FEM modeling/strain energy approach for predicting loss factors, and comparisons are given between the results obtained by the MSE method implemented in NASTRAN software. The application of the finite element-MSE method is designed for integrally damped structures. Anisotropic stiffness layers in multi-damping layer, simply supported composite laminates were estimated using the finite-element-based modal strain energy (MSE) approach. According to Mohan D. Rao et al. [3], the MSE and closed-form approaches both entail approximations and assumptions.

2.2 FIRST AND HIGHER ORDER SHEAR DEFORMATION THEORY:

To ascertain the natural frequencies of composite sandwich plates, FSDT and HSDT have been applied. The dynamic behavior of composite sandwich plates is discussed by M. Meunier et al. [4] and the damping analysis of passive, active, and hybrid structures is assessed by Aurelio L. Arajo [5]. It has been found that both theories, which were initially developed for relatively thick laminated plates, produce accurate results when applied to the study of the dynamic behavior of composite sandwich plates.

A.L. Arajo [6] discussed the most recent advancements in frequency dependent passive damping of sandwich constructions with viscoelastic core optimization and parameter estimation. In this study, the displacement field of the viscoelastic core is represented by a higher order deformation theory (HSDT), while the displacement field of the neighboring laminated face layers is represented by a first order deformation theory (FSDT). M. Meunier investigates the dynamic behavior of a sandwich made of fiber-reinforced plastic with a PVC foam core [7].

2.3 DYNAMIC STIFFNESS METHOD:

With a limited number of degrees of freedom, the dynamic stiffness approach enables the modeling of an infinite number of natural modes. To frame constructions with damped or undamped structures, the approach has been expanded. Using an accurate dynamic stiffness model, J.R. Banerjee et al. [8] and S.M.R. Khalili et al. [9] investigated the free vibration characteristics of a three-layered sandwich beam with unequal thicknesses. According to A.R. Damanpack et al. [10], the dynamic stiffness approach is used to calculate the high-order free vibrations of sandwich beams. Numerical methods are used to calculate natural frequencies, and the well-known Wittrick-Williams algorithm was created by [8], [9], and [10].

2.4 REISSNER-MINDLIN’S THEORY:

The third element of the Kirchhoff hypothesis is eliminated in the Reissner Mindlin theory, also known as first order shear deformation theory (FSDT), because the transverse normal does not continue to be perpendicular to the mid-surface following deformation. Dynamic response in the time and frequency domains were computed by J.S. Moita [11] in his work, and good agreement with alternative solutions was obtained. The Reissener-Mindlin theory is used to model the core. M. Bilasse presents Mindlin's model, which incorporates shear deformation in the viscoelastic layer, and models the nonlinear geometrical impact using the Von Karman strain-displacement relationships [12].

2.5 GENERALISED DIFFERENTIAL QUADRATURE METHOD:

To solve the governing equations, the generalized differential quadrature method (GDQM) was used. The problem will be discretized and numerically solved using a finite number of grid points. The vibration analysis of three-layered, curved sandwich beams with elastic face layers and viscoelastic core was the topic of studies by Ozgur Demir et al [13] and A. Arikoglu [14]. The extended differential quadrature method is used to solve the equations in the frequency domain, and the impacts of different system parameters on the vibration and damping properties of composite structures with a viscoelastic core are investigated.

A finite element model was created using a traditional zig-zag model with shear deformation in the viscoelastic layer based on the works of K. Akoussan et al [15], Shao Hui Zhang [16], and Zhicheng Huang [17]. According to Jean-Marie Berthelot [18], the Ritz approach is used to first extract the natural frequencies and modes. Hamilton's concept is used to develop Aytac Arikoglu's [19] equation of motion, which governs the sandwich beam's free vibrations. The differential transform method is then used in the frequency domain to solve these equations. In the context of the modal analysis of frequency dependent orthotropic viscoelastic sandwich plates, Mohamed Hamdaoui et al. [20] explored the asymptotic numerical technique and contrasted it with a number of non-linear eigen solvers. Ali Ghorbanpour Arani et al. [21] also conducted research on the non-linear vibrational characterization of a sandwich plate made of a viscoelastic micro nano-composite that is integrated with a sensor and actuator. According to the findings of his study, the maximum frequency is produced by raising the volume percentage of carbon nanotubes (CNT) and taking surface effects into account. For the damping optimization of multilayer sandwich plates with a viscoelastic core sandwiched between elastic layers, including piezoelectric layers, J.S. Moita developed a straightforward and effective finite element model [22]. This model evaluates the free vibration response and corresponding modal loss factors. M. D'Ottavio [23] examined the application of the SGUF-Ritz formulation to the dynamic response of composite panels containing viscoelastic plies in the frequency domain. This extension represents a significant step towards the development of a numerical tool and is capable of analysing more realistic panel configurations, including viscoelastic layers for vibration or acoustic damping. Sandwich structures play a major role in many mechanical and aerospace applications.

To enhance the "Mead & Markus" theory, the current study adopts a higher order theory for composite sandwich beams with viscoelastic cores. H. Arvin et al. [24] made the assumption that there would be independent transverse displacement on two faces and linear changes throughout the depth of the beam core. Reddy higher order theory has been used to construct two new Reddy type elements with the assumed strain technique, according to A.K. Nayak et al. (25). The natural frequencies of sandwich plates, layered anisotropic composites, isotropic and orthotropic materials are calculated using this theory. M. Chehel Amirani et al. [26] concentrated on FG materials, and one of the well-liked mesh-less approaches, the element free Galerkin method, was used to extract the natural frequencies of sandwich beams with FG cores. Through the use of Ni Adam's theory, Jong Hee Yim et al. [27] carried out a quantitative analysis of the damping behavior of sandwiched laminated composites in 2003. They also demonstrate how laminated sandwich composites with embedded viscoelastic layers can greatly improve structural damping by modifying frequency and modal loss factors. It is demonstrated that the damping properties of the laminated sandwich composite beam may be effectively determined using the expanded Ni-Adams theory. The analysis of the structures using an updated Burgers model is presented in detail in this study [28], from the formulation of the finite elements to the solution method. The improved model is composed of several simultaneous classical Burgers components and a spring component that changes the viscoelastic fluid model into a viscoelastic solid model while also increasing accuracy. Chen Qian et al. [29] developed an analysis theory and a number of numerical algorithms for the dynamic behavior of composite constructions made of viscoelastic materials using an iteration method.

Recently, Komlan Akoussan et al. [30] conducted a sensitivity analysis of the damping characteristics of viscoelastic composite structures dependent on layer thicknesses. In fact, by increasing the thickness of the core, one can either enhance or reduce the stiffness of the structure, depending on the type of viscoelastic core used. By applying high damping viscoelastic materials coated on the surface structures, Tso-Liang Teng [31] researched surface treatment. The Ross-Kerwin-Ungar (RKU) model is used to study design parameters as well. Wei Sun et al. [32] analyze the viscoelastic core composite structure's frequency-dependent mechanical characteristics. The identification results were also incorporated into the analysis of the vibration response, and by contrasting the vibration responses produced from theoretical calculations with the experiment, the identification results' validity was confirmed.

For scenarios requiring vibration excitations across a wide frequency range, the work [33] on vibration control of machines and structures employing viscoelastic materials in suitable configurations is highlighted. In theoretical and practical work on the analysis, optimization, and usage of visco-elastically damped structures, attempts have been made to forecast future trends. Characterized is a development of the sandwich beam with elastic sides and a viscoelastic core that moves axially. Krzysztof Marynowski explored the effects of the transport speed, the core thickness, and the internal damping of the core material on the dynamic behavior of the system under the critical and supercritical range of transport speed [34]. A sandwich structure with a viscoelastic core, which is frequently utilized in both passive and hybrid control systems, was the subject of research by W.P. Hernández et al. The mean of the modal parameters remained essentially constant across all cases, according to this analysis of uncertainty propagation, while the dispersion of the probability density function of the modal parameters varied widely between the examined cases. A new higher-order system was proposed by Farough Mohammadi et al. To study the damping properties of a sandwich cylindrical shell, Taylor's expansions of displacement fields in the core layer were created. Due to the possible displacement profile that this model was able to accomplish, particularly for thick limited viscoelastic core layer, the higher-order model was taken into consideration in the optimization issues. Jun Xu et al. [37] created fractional constitutive models to assess the damping properties of coated sandwich beams. By utilizing a layer-wise displacement assumption based on Carrera's Unified Formulation (CUF), M. Boscolo [38] proposed an analytical closed form solution for the free vibrational analysis of multi-layered plates. An analytical model based on finite element solutions was created by M. Bilasse et al. [39] to assess the linear and non-linear vibrational properties of viscoelastic sandwich beams. To construct the Galerkin's foundation, four numerical methods for computing eigen modes have been proposed: real eigen modes (RM), improved real eigen modes (IRM), approached complex eigen modes (ACM), and accurate complex eigen modes (ECM). In this study, Hakim Boudaoud et al. [40] introduced a new shell finite element for the analysis of the vibration of five-layered controlled composite structures. The formulation used in this article, which is based on the Discrete Kirchhoff Theory, has only been tested on a triangular plate element with three nodes.

3. EXPERIMENTAL PREDICTION OF DAMPING:

Glass fiber laminates with one viscoelastic interleaved in the central plane or two viscoelastic interleaved on both sides from the main plane are the subject of the experimental inquiry. According to Jean-Marie Berthelot's analysis of the experimental data, laminate damping is reduced when compared to laminates with interleaved layers [41].

3.1 FAST FOURIER TRANSFORM ANALYSER:

A mathematical procedure called FFT (Fast Fourier Transform) converts time-domain data into frequency-domain data. Vibration amplitude is produced by this fourier transform as a function of frequency. Using an FFT analyzer, several studies [42–47] concentrated on the damping properties of composite constructions with viscoelastic cores. Using an FFT analyzer, Swapnil Sanjay Chavan [48] carried out an experimental research on a manufactured composite plate. In order to determine the natural frequencies of composite plates, an experimental examination is conducted utilizing the modal analysis technique. A recent experimental analysis on three active-passive damping design configurations applied to a cantilever beam was given by Marcelo A. Trindade [49]. Two design configurations based on the extension mode of piezoelectric actuators coupled with viscoelastic restricted layer damping treatments are presented in this article [49], and one design configuration uses shear piezoelectric actuators embedded in a sandwich beam with a viscoelastic core.

The following is another experimental investigation of composite constructions having a viscoelastic core: By using the natural frequency and four-point bend test, Buket Okutan Baba et al. [50] attempted to ascertain the impact of debonding between face/core and its location (upper and lower) on the stiffness of composite sandwich beams. The findings of this work are intended to add to the experimental evidence on the behavior of flat and curved sandwich beams with and without viscoelastic cores during free vibration. Amir Shahdin et al.'s [51] goal was to create a glass-entanglement sandwich, and mechanical tests were done on the samples to evaluate how well they performed to normal sandwich specimens with foam and honeycomb as the sandwich's core components. When compared to honeycomb and foam sandwich materials, the findings of the compression and bending tests reveal that the entangled sandwich specimens have a comparatively low compressive and shear modulus..

A flexible mixed numerical-experimental identification method was put forth by Marco Matter et al. [52] for assessing the elastic and damping characteristics of multi-layered composite laminates. In order to assess the damping qualities of sandwich beams with carbon/epoxy as the skin sheets and a honey comb core filled with a magnetorheological elastomer (MRE), free and forced vibration tests were carried out under various magnetic field intensities. When a magnetic field is applied, it is possible to shift the natural frequency (lower the frequency), according to Felipe de Souza Eloy et al. [53]. An experimental examination of the elastic wave energy propagation and dissipation characteristics of sandwich constructions with a periodically perforated VDM core was done by X. Q. Zhou et al. [54]. The FEM and IASEM are also used for comparison purposes. A commercial viscoelastic material that can be inserted and cured between the layers of composite laminates was the focus of Marco Troncossi et al's [55] investigation into the damping qualities of such materials. The impact hammer testing and shaker excitation measurements comprised two distinct investigations. The material is proven as a method for minimizing the vibrations caused in composite panels by adding high damping materials based on the findings of laboratory research. On sandwich beams, an interfacial toughness test is performed. For sandwich beams, the interfacial improvement technique with chopped glass-fibre matting is effective. This technique has produced materials with increased toughness and robust interfacial load capacity, making the improved structure more damage tolerant. The results of the long-term fracture tests conducted by Wang Can et al. [56] demonstrate a significant increase in the crack opening displacement and nominal stress intensity components. Three layered damped sandwich composite plate underwent theoretical and practical testing by Y. P. Lu, J. W. Killian, and G. C. Everstine [57].

An analytical framework appropriate for the triangle-wave and trapezoidal loading patterns often employed in indentation studies was utilized to analyze indentation tests on viscoelastic materials. Sharp (pyramidal) indentation investigations revealed differences between rubbery and glassy polymers [58], with the glassy polymer reaction appearing to be dominated by plastic deformation. A study on the creep behavior of sandwich panels made of lightweight natural fiber-reinforced polymer composite with honeycomb core was carried out by Yicheng Du et al. According to the testing findings, compared to other sandwich-structure materials, the sandwich panels showed a comparatively high creep rate.

4. BOTH ANALYTICAL AND EXPERIMENTAL PREDICTION OF DAMPING:

In their study, A. Dyson Bruno et al. [60] used an FFT analyzer and Ansys software to test and analytically assess the damping properties of plates. Here, the base layer's length and thickness are held constant while the patch's length change, restricted layer size, and damping layer size are modified. For various locales, patches might range in size and quantity. The vibration behaviors of multiple viscoelastic-layered fiber metal laminated plates (MVFMLPs) under various external excitation levels were recently accurately predicted by Hui Li et al. [61]. In this paper, an analytical

ISSN: 2278-4632
Vol-13, Issue-12, No.04, December: 2023

model accounting for both material and geometric nonlinearities is developed, and vibration tests are conducted to validate the proposed model.

In 2020, a three-layer composite plate element with a viscoelastic material core and frequency-dependent vibration responses was created for finite element modeling. Finally, Zhicheng Huang et al [62] analyze and investigate experimentally the vibration properties of the viscoelastic sandwich plate. Furthermore, Mehdi Saeed Kiasat and Seyed Saed Rezvani [63] concentrated on the free vibration analytical solution of a composite sandwich plate made of woven carbon laminated faces and a viscoelastic foam core. Through the use of experimental data, the impacts of the fluid density, foam core behavior, core thickness, and plate dimension ratio on the natural frequencies are explored and analyzed. Using theoretical and experimental techniques, Srinivasa Prasad K S et al [64] observed the free and forced vibrational properties of a flax reinforced composite beam with viscoelastic core. Wu Zhen et al. [65] propose an alternative sinusoidal theory for analyzing the higher order frequencies of composite and sandwich plates with various boundary conditions. J.I.R. Blake et al.'s [66] goal was to use a material that was known to reduce noise and vibration across joints in maritime structures. A progressive damage model is used to quantitatively analyze the effects of the new material on the joint's structural response. For the purpose of accounting for the viscoelastic core's frequency dependent features, the Gulla-Hughes-McTavish technique (GHM) is applied. By using the GHM approach and experimental validation, the authors [67], [68], and [69] concentrated on the frequency dependent viscoelastic dynamics of multifunctional composite structures. Four types of integral finite elements, including sandwich beam, plate, and shell structures with viscoelastic materials as core layers, were created by Q. Chen and Y.W. Chan [70] and utilized to evaluate the dynamical properties of elastic viscoelastic composite structures. Compared to conventional elements, the dynamical analysis of the EVC (elastic & viscoelastic core) structure may be completed more quickly and precisely. A new one-dimensional theory of beams dampened by a thin viscoelastic layer was presented by M. Mace [71]. Under various boundary conditions, the findings are compared with well-known analytical models and experimental solutions. It is discovered that the proposed theory, which uses a thin viscoelastic layer to predict the dynamic response of beams, is both highly straightforward and effective. Min Hao and Mohan D. Rao examined an analytical formulation to forecast the stiffness and damping of three layered beams with two different viscoelastic materials close to one another [72].

5. VALIDATION:

Ansys/Abacus software is used to validate the experimental and analytical solutions. Free vibration and damping properties of laminated plates/beams under various boundary conditions are analyzed experimentally/analytically using the Ansys/Abacus softwares, according to some studies [73], [74], [75], [76], [77], [78], and [79]. Ansys software was used recently by Kurhe Nikhil M et al [80] to analyze the modal behavior of a hybrid laminated composite plate with a viscoelastic core.

CONCLUSION

We highlight a number of topics of research on the damping of composite structures with viscoelastic cores. The following findings on composite structures are made in light of the literature review:

1. A variety of analytical models are frequently employed for the analytical prediction of damping in laminates and composite materials with linear viscoelastic fiber reinforcement.
2. Studies were done to take into account transverse damping effect and shear damping effect, however the effects are limited. Research [56] was provided on evaluation of material damping together with fiber considering the influence of fiber matrix-interface (third phase).
3. Although extensive research has been done on only a few different experimental methodologies, there are many sources of damping in composite structures. For the extensional mode, damping has been fully defined; however, models for the transverse and shear modes still need to be developed.

4. Two-dimensional state of stress is the focus of the majority of the documented research on damping in composite materials. However, there aren't many damping theories or models for thick composite laminates that take into consideration all three interlaminar stresses.
5. A literature review reports some work on the application of an enhanced analytical damping approach to generate high damping using the interleaving technique and hybrid composites.
6. Composite materials and structures, however, can perform better dynamically when an integrated strategy combining approaches for improving damping and damping tailoring, good mechanical properties, and low weight is used. There has been some work done utilizing the Ansys/Abacus software to validate the experimental/analytical solutions.
7. Because thermoplastic composites have good dynamic properties, it is necessary to investigate how stress and vibration amplitude affect damping in both linear and non-linear composites.

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