IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

A Review Of Experimental And Numerical Studies On Damping Behavior Of Visco-Elastic Material Using Acoustic Black Hole Technique

[1]Sujay M, [2]Tharun S, [3]Rakesh Gowda S R, [4]Anil Kumar A
[123] UG Students, [4] Assistant Professor, Department of Mechanical Engineering,
K. S. Institute of Technology, Bengaluru, India

Abstract: This review paper presents a comprehensive examination of hybrid damping systems that integrate viscoelastic materials (VEMs), Acoustic Black Hole (ABH) techniques, and honeycomb sandwich panels to address the persistent challenge of vibration mitigation in engineering structures. By exploring the theoretical principles, experimental validations, and numerical models underlying these advanced damping mechanisms, the study elucidates how the synergistic combination of VEMs, with their frequency and temperature-dependent energy dissipation, ABH's innovative wave-trapping geometries, and the exceptional stiffness-to-weight benefits of honeycomb structures can significantly enhance vibration attenuation. Applications across aerospace, automotive, and industrial domains are discussed, highlighting the potential for improved structural performance and extended service life. The review also identifies critical research gaps, such as the challenges in manufacturing and temperature sensitivity, and proposes future directions including adaptive damping strategies and optimization through machine learning. Overall, this work aims to provide a foundational framework for the development of next-generation hybrid damping solutions in complex engineering systems

***Index Terms* - Viscoelastic Materials, Acoustic Black Hole, Honeycomb Sandwich Panels, Vibration Damping, Hybrid Systems**

I. Introduction

The Widespread Challenge of Vibrations in Engineering Systems, vibrations are an inherent consequence of dynamic loads in mechanical, aerospace, and civil structures. While some vibrations are being, excessive oscillations lead to structural fatigue, noise, and operational failures. For instance, in aircraft wings, unchecked vibrations accelerate material degradation and compromise fatigue life. In automotive systems, vibrations contribute to passenger discomfort and reduce component lifespan.In industrial machinery, resonant vibrations can cause catastrophic failures. Traditional solutions like stiffening or adding mass are often impractical due to weight and space constraints. This has spurred research into advanced damping techniques that dissipate vibrational energy efficiently without compromising structural performance.

a. Fundamentals of Damping Mechanisms

Damping refers to the process of energy dissipation in vibrating systems, converting mechanical energy into heat. Key damping mechanisms include:

Viscoelastic Damping:Energy loss occurs through molecular friction in polymers (e.g., rubber, polyurethane). Frequency and temperature-dependent: VEMs exhibit higher damping near their glass transition temperature and at specific frequency ranges.

Structural Damping :Energy absorption via interfacial slip in composite layers (e.g., honeycomb cores). Honeycomb sandwich panels enhance damping by distributing shear deformation across their cellular structure.

Air/Gas Damping:Attenuation through fluid-structure interaction (e.g., perforated honeycomb panels).
Viscoelastic Materials (VEMs):VEMs are widely used due to their high loss factors and tunable properties. However, their effectiveness depends on. Storage modulus and loss modulus vary with excitation frequency. VEMs stiffen at low temperatures and soften at high temperatures. Higher strain rates increase energy dissipation.
Advanced VEM Models: Prony Series: Captures frequency-dependent behavior via exponential decay functions. Accurately represent viscoelastic hysteresis. The ABH effect exploits tapered geometry to slow and trap bending waves, minimizing reflections.
Physics of ABH :Wave Velocity Reduction: Phase velocity and group velocity approach zero as thickness decreases Ideal vs. Real and Manufacturing truncations cause reflections, necessitating damping layers.
Enhancements for Practical ABH :Damping Layer Integration: Thin viscoelastic films (e.g., polymers) reduce reflection coefficients to 1–3%. Hybrid Designs: Combining ABH with honeycomb cores improves low-frequency performance.

II. Literature Survey

M.-A. Bouchera et.al [1] focused on find out how much the ribs (walls) inside different honeycomb cells move when forces are applied—either by pulling/pushing straight (axial loading) or by applying sideways forces (in-plane shear), as shown in Figure1The goal is to place damping materials (materials that absorb vibrations) where the cell ribs move the most. This way, the damping material will experience the biggest strains and work more effectively. The honeycomb structure can increase the strain felt by the damping insert. In this analysis, the stiffness (resistance to bending) of the damping insert is ignored, assuming the honeycomb cell structure is much stiffer. This is supported by previous research (Abd El-Sayed et al.). But this assumption doesn't hold if the insert is very stiff or large.
According to Gibson and Ashby [2], when a honeycomb is loaded axially, the cell walls bend like cantilever beams (beams fixed at one end). However, this bending-only model only works if the cell walls are thin and the angle between them (h) is not too small.

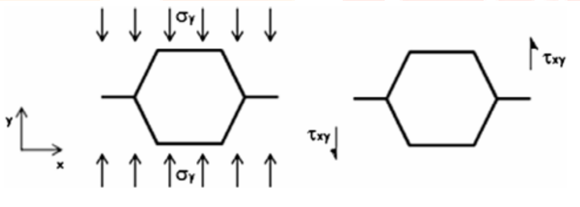

Fig. 1. Loading modes considered in the analytical model, In-plane axial loading (left) and In-plane simple shear loading (right).

Guilhem Michona et.al [2] Created A 2D computer model (using Finite Element or FE analysis) to study two types of honeycomb cells. A regular honeycomb cell with specific dimensions: side length a = 1 mm, height h = 1 mm, thickness-to-length ratio b = 0.02, and internal angle h = 30°.A re-entrant honeycomb cell (a shape that folds inward) with an internal angle h = 20°.These models were built using ANSYS 11.0 software, using 10 Beam4 elements (a type of element used to simulate thin beams) to represent the ribs (walls) of the cell. The ribs were modelled using aluminium material properties (with a Young's modulus of 70GPa and a Poisson's ratio of 0.3). The models were tested under 1% strain, both in axial (pulling/pushing) and shear (sideways) directions, using realistic boundary conditions to match the real-world scenarios and allow for a fair comparison with the analytical (math-based) model. During the simulation, the movement (displacement) of every point (node) in the model was recorded. The relative strain between each pair of nodes—like if a small ligament connected them—was calculated using Equation (7). This strain was based on the change in distance between two nodes before and after the deformation. Finally, after the simulation, they analysed the data to find which areas in the structure had the biggest relative displacements—meaning, the parts of the honeycomb where the most stretching or movement happened.
Sebastian Kocha et.al [3] Study on topological optimization using ANSYS 11.0 to improve the design of a 2D model of honeycomb unit cells. Two types of cells were studied: a regular honeycomb cell (with angle h = 30°) and a re-entrant cell (with h = 20°). Each unit cell was treated as a small, repeating part of a larger honeycomb structure, known as a Representative Volume Element (RVE). The goal of the optimization was to make the cell structure stiffer (i.e., reduce its *compliance*, which means it deforms less under load), while using 80% less viscoelastic material. At first, the entire honeycomb cell was filled with viscoelastic material. The idea was that, by carefully removing parts of the material, the remaining material would end up in areas that experience the most strain and energy. This would make the material more effective at absorbing vibrations, since it would carry more strain energy. To simulate real conditions, the models were tested with 1% strain in both axial (pulling) and shear (sideways) directions. The viscoelastic material used

had a Young's modulus of 0.1 MPa (very soft) and a Poisson's ratio of 0.35 (the maximum allowed by the software for this type of analysis). Symmetry boundary conditions were applied to mimic an endless honeycomb structure. Each model had around 1000 finite elements (called PLANE82 elements), and compliance was measured by how much the structure deformed under a given load.

X. Q. Zhoua et.al [4] compared the damping performance of a regular honeycomb cell by looking at two main values: the damping loss factor (g) and the loss modulus (E*). These values were analysed for different amounts of filling inside the empty spaces (voids) of the honeycomb. The honeycomb had the following dimensions: side length a = 1 mm, height h = 1 mm, thickness ratio b = 0.02, and angle h = 30°. The walls of the honeycomb were modelled using aluminium, with a Young's modulus of 70 MPa and a Poisson's ratio of 0.3. The filling material used inside the cells was a viscoelastic material, with properties: Young's modulus = 0.1 MPa, Poisson's ratio = 0.45, density = 1 g/cm³, and loss factor = 0.1. Based on earlier results, a partial filling design was used where a thin strip (ligament) of viscoelastic material was placed across the middle of the honeycomb cell. Figure 6 in the study shows two models: one where the honeycomb is completely filled with the viscoelastic material, and another where it is partially filled (30%) as shown in Figure 7. The models were tested under the same loading conditions as before—in-plane axial and shear loads. The damping characteristics of the honeycomb were calculated using a method called the modified modal strain energy method. The loss factor (g) was calculated using Equation based on the total strain energy of the structure the loss factor of the viscoelastic material (gv), and the strain energy in each part of the structure containing viscoelastic material (SEj visco).The analysis assumes that all damping comes from the viscoelastic material, which is reasonable because aluminium has almost no natural damping. Finally, the loss modulus (E*)—which indicates how much vibration energy is absorbed—was calculated as the product of the structure's loss factor (g) and its Young's modulus (E).

Seongmin Park et.al [5] Study on traditional vibration-damping materials (VDMs), like B-VDM and W-VDM, and methods like constrained layer damping (CLD) or active constrained layer damping (ACLD), are already widely used in engineering. However, there's a growing demand for materials with even better vibration control, especially with the rise of nanotechnology. To improve how VDMs absorb and reduce vibrations, researchers have started adding nanomaterials such as carbon nanotubes (CNTs), carbon nanofibers, nano springs, and nanoparticles into these materials. These nanomaterials improve VDM performance due to their strong mechanical properties and ability to absorb shocks and vibrations. They've been used in practical applications like seals, gears, bearings, and even human body prosthetics. Studies have shown that combining multi-walled carbon nanotubes (MW-CNTs) with VDMs leads to better stiffness, strength, and vibration performance than using single-walled nanotubes (SW-CNTs). The higher performance is because MW-CNTs have better tensile strength, stiffness, and heat conductivity. Some research found that when MW-CNTs are added to VDMs in increasing amounts (e.g., 3.3%, 7.7%, and 14.3%), the elasticity and strength of the composite improve, but the stretching ability (failure strain) decreases. Also, the glass transition temperature (Tg)—the temperature range where the material softens—increases, meaning the material can work at higher temperatures. Studies also found that the alignment of nanotubes matters. Aligned nanotubes improve stiffness much more than randomly arranged ones. While nanotubes aren't perfect for making the material stiffer, they're excellent for tuning the vibration-damping properties.

Zhiwei Wan et.al [6] they observed that the influence of material loss factors on vibration attenuation is analysed by comparing uniform damping layers and ABH (Acoustic Black Hole) damping layers. As the loss factor increases from 0.1 to 1, vibration peaks in the 10–8000 Hz range generally decay, except between 4000–6000 Hz, where higher damping does not always improve performance. Structural modal loss factors, which measure energy dissipation, reveal that uniform damping behaves like the steel beam's material below 4000 Hz but approaches the damping material's loss factor above 6000 Hz. Between 4000–6000 Hz, the loss factor is intermediate, explaining the inconsistent vibration reduction. For ABH damping, the structural loss factor mostly matches the damping material's, except around 4000 Hz, where it drops. Unlike uniform damping, ABH layers exhibit strong in-plane deformation ($\kappa \approx 0.25$) across most frequencies, enhancing energy dissipation. Below 4000 Hz, ABH outperforms uniform damping due to its wave-gathering effect, where even low damping (η = 0.1–1.0) suffices. Above 6000 Hz, increased damping further reduces resonance peaks. Thus, ABH's dominance below 4000 Hz and damping material's role above 6000 Hz highlight its superior vibration suppression, making excessive loss factors unnecessary in ABH designs.

Jingjing Wanga et.al [7] In this study they examine how the thickness (and mass) of damping layers affects vibration suppression, comparing uniform damping and ABH damping (ABHD) with a loss factor of 1.0. When ABHD thickness is halved (0.5m-ABHD), vibration levels are higher than uniform damping. However, increasing ABHD thickness to 0.75m (25% mass reduction) significantly improves vibration suppression between 100–4000 Hz, with further enhancement at full mass (m-ABHD). Reducing the loss factor to 0.6, even 0.5m-ABHD outperforms uniform damping below 1600 Hz, with resonance peak reductions up to 2.7 dB. A 2.5 mm thickness increase (0.75m-ABHD) extends effective suppression to 4000 Hz, with peak reductions up to 9.7 dB. At a loss factor of 0.1, 0.5m-ABHD suppresses vibrations across 100–4000 Hz (up to 7.5 dB reduction), while 0.75m-ABHD achieves up to 12.5 dB reduction. ABHD's efficiency stems from its wave-focusing effect, requiring less damping material than uniform layers—25–50% mass reduction for loss factors above/below 0.6. However, uniform damping remains superior above 6000 Hz due to better structural coupling. Thus, ABHD offers lightweight, high-performance vibration control, especially at lower frequencies.

Hozhabr Mozafari et.al [8] The analysis the wave-gathering capability of ABH damping (ABHD) by dividing the structure into three parts: the connection area (Part 1), base beam (Part 2), and variable-thickness ABHD region (Part 3). The MSV ratios (τU and τA) quantify wave transmission, showing that ABHD effectively concentrates energy despite impedance mismatch with the beam. When damping loss is minimal (η=0.001), τA exceeds τU at most resonance frequencies, confirming ABHD's inherent wave-focusing ability. Higher damping (η=1) reduces τA as energy dissipates before reaching the ABH center. In-plane vibrations exhibit stronger energy accumulation in ABHD than vertical displacements. Displacement maps of the 4th and 11th resonances demonstrate that increased damping enhances vibration suppression while maintaining coupling between layers. The results prove ABHD successfully concentrates and dissipates energy, with performance scaling with loss factor magnitude.

Liang Xu a et.al [9] The study of examination of the vibration reduction performance of constrained damping material (CDM) placed at different locations on an Acoustic Black Hole (ABH) structure. A unit load is applied at (0.168, 0.148) under free boundary conditions, with frequency responses analysed from 1–2000 Hz. Results show that CDM-Location3 outperforms CDM-Location2 and CDM-Location1 in the 0–1000 Hz range, as seen in modal loss factors and mean square velocity (MSV) . However, above 1000 Hz, MSV trends indicate that CDM placement significantly affects modal behaviour but cannot uniformly enhance vibration reduction across the entire frequency band. CDM improves low-frequency vibration suppression, a challenge in ABH applications, but compromises high-frequency performance. When applied to the ABH's center, CDM's high Young's modulus stiffens the structure, diminishing the ABH effect . Free damping material, in contrast, preserves the ABH's wave-focusing capability. Thus, optimizing CDM placement is crucial to balance low- and high-frequency suppression while maintaining lightweight design. Topology optimization is suggested to maximize CDM efficiency and reduce costs, ensuring effective vibration control across the studied frequency range.

X.Q. Zhou et.al [10] The investigation how the placement of granular material (sand) within a honeycomb structure affects vibration damping. Five distributions of 310 g sand were tested, keeping the total mass 5% lighter than the original structure while improving vibration resistance. Results showed that concentrating all material in one area (configurations b and c) performed worst, while uniform distribution (a) was most effective, reducing vibrations by 1.7 dB compared to the worst case. However, the sand's mass had a greater impact (7 dB reduction) than its placement. Further analysis revealed that vibration peaks occurred near the oil sensor ("circle") and the lower-right region ("peak"). Filling these high-amplitude zones individually (122 g at peak, 136 g at circle) reduced localized vibrations, with the circle filling providing better overall damping. Combining both zones with 251 g sand achieved the best results (137.7 dB sum level), outperforming other configurations with 19% less mass. The findings suggest that strategic partial filling—targeting high-vibration areas—can optimize damping while minimizing added weight.

III Conclusions

This review demonstrates that combining viscoelastic materials with advanced techniques such as the Acoustic Black Hole (ABH) effect and honeycomb sandwich panel architectures can lead to significant improvements in vibration damping across a range of engineering applications. By integrating hybrid damping systems that leverage the frequency- and temperature-dependent characteristics of viscoelastic materials, the wave-trapping abilities of ABH geometries, and the lightweight yet high stiffness properties of honeycomb structures, it is possible to achieve enhanced energy dissipation and extended service life in structures as diverse as aircraft components, automotive systems, and industrial machinery. The review also highlighted the promising role of nanomaterials—such as carbon nanotubes, nanofibers, and nano springs—in further tuning and optimizing the damping performance, while acknowledging the challenges associated with manufacturing complexities, temperature sensitivities, and optimal filler dispersion. Overall, this work lays a foundational framework for the development of next-generation hybrid damping solutions and points towards future research directions, including adaptive damping strategies and machine-learning-based optimization.

References

[1]. M.-A. Bouchera, C.W. Smitha , F. Scarpab , R. Rajase karanc, K.E. Evans , Effective topologies for vibration damping inserts in honeycomb structures,Composite Structures 106 (2013) 1–14.

[2]. Guilhem Michona, Ahmad Almajida , Gwen elle Aridon, Soft hollow particle damping identification in honeycomb structures, Journal of Sound and Vibration 332 (2013) 536–544.

[3]. Sebastian Kocha,n, Fabian Duvigneaua, Ryan Orszulikb, Ulrich Gabberta, Elmar Woschkea, Partial filling of a honeycomb structure by granular materials for vibration and noise reduction , Journal of Sound and Vibration 393 (2017) 30–40.

[4]. X.Q.Zhoua,D.Y.Yua,X.Y.Shaoa,S.Q.Zhanga,S.Wangb,Researchandapplicationsofviscoelasticvibrationdampingmaterials:Areview, CompositeStructures136(2016)460–480.

[5]. Seongmin Park, Wonju Jeon, Concave-shaped acoustic black holes with asymmetric arrangement for suppression and amplification of structural vibration, Journal of Sound and Vibration 600 (2025) 118885.

[6]. Zhiwei Wan , Xiang Zhu , Tianyun Li , Kexin Zhong , Huchuan Wan, Lightweight damping layer with acoustic black hole profile bonded to a beam for broadband vibration reduction, Composite Structures 341 (2024) 118235.

[7]. Jingjing Wanga, , Wei Huangb, Hongli Jia,∗, Jinhao Qiua, Topology optimization of constrained layer damping on acoustic black hole structures for vibration reduction, Applied Mathematical Modelling 140 (2025) 115904.

[8]. Hozhabr Mozafari & Sara Najafia , Vibration analysis of foam filled honeycomb sandwich panel – numerical study, Australian Journal of Mechanical Engineering, 13 Jun 2017, To link to this article: https://doi.org/10.1080/14484846.2017.1338325.

[9]. Liang Xu a , Jie Zhang , Jiang Li , Huaan Tian , Chaofan Zheng, Shaoyun Guo, Design of a lightweight broadband vibration reduction structure with embedded acoustic black holes in viscoelastic damping materials, Materials & Design 248 (2024) 113450.

[10]. X.Q. Zhou, D.Y. Yu , Elastic wave propagation energy dissipation characteristics analysis on the viscoelastic damping material structures embedded with acoustic black hole based on semi-analytical homogeneous asymptotic method, Applied Mathematical Modelling 70 (2019) 221–245