

# Regulation of acoustic properties in nanocomposite porous musical structures by nanoparticles and their application in sound harmony

Bingze Du<sup>1</sup>, Ruiqi Cao<sup>\*1</sup>, Xinyue Li<sup>1a</sup> and Abhinav Kumar<sup>2,3,4b</sup>

<sup>1</sup>Department of Global Convergence, Kangwon National University, Chuncheon, South Korea, 24341

<sup>2</sup>Department of Nuclear and Renewable Energy, Ural Federal University Named after the First President of Russia Boris Yeltsin, Ekaterinburg 620002, Russia

<sup>3</sup>Centre for Research Impact & Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, 140401, Punjab, India

<sup>4</sup>Department of Mechanical Engineering and Renewable Energy, Technical Engineering College, The Islamic University, Najaf, Iraq

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**Abstract.** The role of nanoparticles in improving acoustic properties of materials used in the musical structures based on nanocomposite porous materials is explored in this study. We integrate nanoparticles into a nanocomposite porous framework to investigate their effect on the sound absorption and acoustic properties, on the tonal quality of the sound. Micromechanical model is used to evaluate the effective nanocomposite properties and the structural behavior is analyzed by means of the mathematical modeling. We derive the governing equations of sound propagation and acoustic properties through energy relations. We assess the acoustic performance due to variation of porosity levels, nanoparticle concentration and geometric factors using the numerical method. An increase in the nanoparticle content was found to increase sound absorption and to improve harmonic stability significantly, while controlled porosity can fine tune resonance characteristics. The discovery of these findings suggests ways to design advanced musical structures having higher acoustic harmony and can lead to new developments in the design and construction of instruments.

**Keywords:** acoustic response; nanocomposite porous; nanoparticles; numerical method; sound harmony

## 1. Introduction

Advancements in musical instrument design and architectural acoustics in the quest for superior acoustic performance have always been driven by this. But modern innovation has opened up new horizons to discover the resonant properties of wood and metal in musical structures, as well as modern materials themselves. Among them are nanocomposite porous materials impregnated with nanoparticles which are a promising platform for tuning acoustic properties toward achieving excellent sound harmony (Zhang and Chen 2024).

A number of studies exploring the advancements in acoustic materials and sound absorption technologies have been done. They had investigated ultrasonic assisted leaching to increase germanium extraction efficiency using HCl/NaOCl (Rao *et al.* 2024). In Liu *et al.* (2023), the authors trained a dual microphones active noise cancellation (ANC) system and Doppler assimilation to reduce noise in dynamic environments. With omnidirectional sound absorption through the use of multi oriented acoustic metamaterials, Bai *et al.* (2025) increased the application in noise control. Qiao *et al.* (2024) proposed an omnidirectional acoustic sensor highly sensitive for improving human-machine interaction, and signal processing, which serves as an acoustic sensor. In the

work of Hu *et al.* (2024) combined the acoustics in wireless earphones to increase accuracy in tracking head motion in the AR/VR contexts. Machine learning has been applied by Gao *et al.* (2025a, b) to predict the low frequency sound absorption coefficient of underwater coatings, a derivative that has been shown to be essentially optimized using acoustic materials. Gao *et al.* (2023) studied the sound damping for a range of frequencies. Taken as a whole, these studies help progress acoustic technologies in various applications such as noise control, human-machine interaction, and material design.

Nanotechnology, artificial intelligence and advanced material modeling all come together to spur innovation in more fields such as structural engineering, energy harvesting and smart infrastructure, sports gear and music acoustics. The next works point out some latest and the most influential ones in areas. Cheng *et al.* (2025) introduce such advanced computational paper as Application of computer approach integrating AI to nonlinear post-buckling behavior of Mindlin cut-out composite plates reinforced with FG-carbon nanotubes. This study is published in Acta Mechanica and uses artificial intelligence in a finite element simulation to make a nonlinear post-buckling model of FG-CNT reinforced composite plates. With the integration of both the Mindlin plate theory and AI-based model, the research facilitates precise stress redistribution about the cut-out which is essential in both the aerospace and automotive composite structure when such structures are compressed. In the article Energy harvesting in smart nano-engineered concrete: Bridging experimental innovations and numerical

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\*Corresponding author, Mrs.,  
E-mail: 15603630917@163.com

modeling towards sustainable infrastructure (Construction and Building Materials), Song *et al.* (2025) consider the concrete which is made multifunctional so that it is able to convert mechanical vibrations into electrical energy. The article overcomes the gap between lab experiments and numerical simulations to prove the benefits of nano-fillers in enhancing piezoelectric behavior and durability of materials at the same time. Their research results provide a significant opportunity to build infrastructure networks able to provision low-energy sensing devices, which are self-powering, thereby smartening cities to be more environmentally friendly. The position paper by Qiu *et al.* (2024) investigates the application of nanomaterials in sports equipment as seen in their examination of the topic of the basketball in their research of the article titled; Coupled annular nanoplates in basketball: Enhancing energy absorption and vibration control in advanced sports equipment. The present study presented in the *Advances in Nano Research* proposes an analytical model of the nanoplate-layered structure that can absorb the impact energy when handling balls. It was demonstrated in their coupled model that the transmission of vibration is greatly decreased with the integration process of nanostructures, and it has the potential to enhance safety and accurateness in sports equipment. On the same note Tian and Li (2024) explore the effect of nanocomposites to the mechanical behavior of footballs. They discovered in their paper entitled Improving the stability of the football ball by adding nanocomposites into polymer layer that it was found possible to add nanomaterials into the shell of the polymer football resulting in the shape stability and performance consistency therein being enhanced. Their simulations proved to give better elasticity and vibration damping thus this might affect regulations in the manufacturing of professional sports equipment in the future. Xi-hong *et al.* (2024) also build up on sports engineering with the aim of focusing in on player comfort. Their work, Improving player performance and comfort in basketball with nanomaterials to provide improved padding and shock absorption, deals with wearable technologies. According to the study, the incorporation of nanosilica and other nano-fillers into the foam padding raises the shock absorption, heat dissipation and flexibility of the foam at raw levels. Not only do these inventions bring new possibilities to prevent injuries but improve overall long-term performance of athletes. In their original study, Ji *et al.* (2024) study nanotechnology through a prism of tourism, entitled Dynamic behavior of nanostructures on sustainable tourism: Safety and surface study based on higher order AI and travel experience. This is a multidisciplinary research because it incorporates the safety evaluations produced with the help of AI and surface enhanced nanostructures on a variety of physical structures in the public realm. It reveals that smart coatings and surfaces with mesoscale characteristics can make any well frequented area safer, comfortable and hygienic, facets that will take the tourism experience a notch higher. Finally, the study by Kuang *et al.* (2024) creates an original approach in the field of music education and acoustics. The paper by them entitled, A method of music education for sound absorption and in-phase harmonics synchronization: Using surface

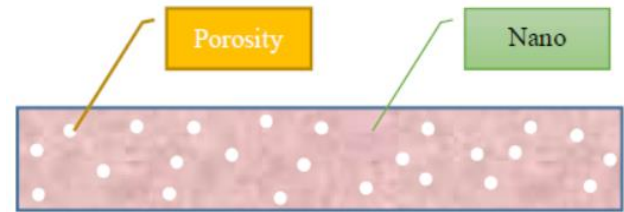


Fig. 1 A schematic figure for nanocomposite porous musical structures

coupling theory to couple nanosheets in musical instruments, offers a novel nanoscale course of engineering to increase the sound quality of musical instrumentations and synchronicity of harmony. The authors prove better absorption of sound, synchronization of vibrations and harmonious resonance in instruments like violins and guitars using nanosheet coupling on the basis of surface theory.

In this study we explore the effect that nanoparticles have in controlling the acoustic behavior of porous nanocomposite structures. We model how nanoparticle concentration, porosity levels and geometric configurations affect acoustic performance using material property evaluation by advanced modeling techniques like micro-mechanical method. Finally, with the help of computational approach, the effect of these parameters on sound absorption and harmonic quality is analyzed. The results from this research contribute to the creation of next generation musical structures with improved acoustic characteristics. This work bridges nanotechnology and acoustics to enable materials that increase the richness, clarity, and sustainability of sound for musical instruments and architectural acoustics.

## 2. Acoustic modeling

As shown in Fig. 1, nanocomposite porous musical structures are regulated through nanoparticle integration. The forward schematic shows a porous material framework with embedded nanoparticles that engage with external sound waves. Relying on the results shown, it is demonstrated that the nanoparticles enhance sound absorption and alter resonance characteristics resulting in better harmonic synchronization, or tonal stability. This visualization shows a particular role of nanotechnology for acoustic performance of musical applications, where controlled porosity and nanoparticle dispersion regulates way propagation and energy dissipation.

Since the nano-engineered materials are composite, then it follows that the rule of mixtures is a practical and popular method of estimation of the equivalent material properties of two-phase nanocomposites. The polymer phase plays a role of a matrix in such systems, whereas nanoparticles should be used as a reinforcing phase because of their outstanding mechanical characteristics. The rule of mixtures presupposes linear distribution of properties, depending on the volume fraction and other specifics of other phases the

solvent is made of. Based on this, the effective Young's modulus and shear modulus of the nanocomposite may be estimated by the use of the following expressions based on the rule of mixtures. Such equations take into consideration both the reinforcement components the matrix itself, and so provide a simplified but convenient estimate of the composite mechanical behavior on the whole (Liew *et al.* 2014):

$$E_{11} = \eta_1 V_{NP} E_{r11} + (1 - V_{NP}) E_m, \quad (1)$$

$$\frac{\eta_2}{E_{22}} = \frac{V_{NP}}{E_{r22}} + \frac{(1 - V_{NP})}{E_m}, \quad (2)$$

$$\frac{\eta_3}{G_{12}} = \frac{V_{NP}}{G_{r12}} + \frac{(1 - V_{NP})}{G_m}, \quad (3)$$

where  $E_{r11}$ ,  $E_{r22}$  and  $G_{r11}$  are the elastic modulus for nanoparticles and  $E_m$ ,  $G_m$  are the elastic modulus of the musical structures; the parameter  $\eta_j$  are efficiency parameter;  $V_{NP}$  and  $V_m$  are the volume fractions of the nanoparticles and the musical structures, respectively. The density can be written as:

$$\rho = V_{CNT}^* \rho_r + V_m \rho_m, \quad (4)$$

With the help of higher order model, the displacements are (Reddy 1984):

$$u_x(x, z, t) = u(x, t) + z\psi_x(x, t) - \frac{4z^3}{3h^2} \left( \psi_x(x, t) + \frac{\partial}{\partial x} w(x, t) \right), \quad (5)$$

$$u_y(x, z, t) = 0, \quad (6)$$

$$u_z(x, z, t) = w(x, t), \quad (7)$$

where  $u_1$ ,  $u_2$  and  $u_3$  are the displacements in three directions. The nonlinear strain relations are:

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{xz} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{xz}^0 \end{Bmatrix} + z \begin{Bmatrix} \varepsilon_{xx}^1 \\ \varepsilon_{xz}^1 \end{Bmatrix} + z^2 \begin{Bmatrix} \varepsilon_{xx}^2 \\ \varepsilon_{xz}^2 \end{Bmatrix} + z^3 \begin{Bmatrix} \varepsilon_{xx}^3 \\ \varepsilon_{xz}^3 \end{Bmatrix} \quad (8)$$

where

$$\begin{Bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{xz}^0 \end{Bmatrix} = \begin{Bmatrix} \frac{\partial u}{\partial x} \\ \psi_x + \frac{\partial w}{\partial x} \end{Bmatrix}, \quad (9)$$

$$\begin{Bmatrix} \varepsilon_{xx}^1 \\ \varepsilon_{xz}^1 \\ \varepsilon_{\theta z}^1 \end{Bmatrix} = \begin{Bmatrix} \frac{\partial \psi_x}{\partial x} \\ 0 \end{Bmatrix}, \quad (10)$$

$$\begin{Bmatrix} \varepsilon_{xx}^2 \\ \varepsilon_{xz}^2 \end{Bmatrix} = \begin{Bmatrix} -4 \\ \frac{4}{h^2} \end{Bmatrix} \left( \psi_x + \frac{\partial w}{\partial x} \right), \quad (11)$$

$$\begin{Bmatrix} \varepsilon_{xx}^3 \\ \varepsilon_{xz}^3 \end{Bmatrix} = \begin{Bmatrix} -4 \\ 0 \end{Bmatrix} \left( \frac{\partial \psi_x}{\partial x} + \frac{\partial^2 w}{\partial x^2} \right), \quad (12)$$

The stress relations can be expressed as:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{zx} \end{Bmatrix} = \begin{bmatrix} C_{11} & 0 \\ 0 & C_{55} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \gamma_{xz} \end{Bmatrix}, \quad (13)$$

where  $C_{ij}$  can be written as assuming porosity:

$$C_{ij}(z) = C_{ij0} [1 - e_0 \psi(z)] \quad (14)$$

where  $C_{110}$  is the basic and  $e_0$  is porosity and  $\psi(z)$  can be assumed:

$$\psi(z) = \begin{cases} \cos(\pi\beta) & \text{symmetric} \\ \cos\left(\frac{\pi\beta}{2} + \frac{\pi}{4}\right) & \text{asymmetric} \end{cases} \quad (15)$$

where  $\beta = z/h$ .

Operating on structural and solid mechanics, the energy method is a potent analysis tool whereby the answer identification of a system subjected to loading is sought by examining its potential energy and its strain energy. This method uses the principle of minimum potential energy instead of directly solving the equilibrium equations: a building in a stable equilibrium position must take up a configuration having a minimum total potential energy. The approach is particularly applicable when dealing with complex systems, in which the direct force-based approaches prove to be cumbersome. When applied to nanocomposite structures, the energy approach makes it possible to obtain governing structural equations and stability rules such as buckling loads or vibration behavior by summing the terms of the strain energy of the two parts of the structure; the continuous matrix and the reinforcing agent (e.g., carbon nanotubes) and work of the external loads. It is also the basis of approximate methods such as RayleighRitz methods and Galerkin methods commonly used when modeling reinforced nano materials in a non-trivial way. The potential energy is:

$$U = \frac{1}{2} \int_{\Omega_0} \int_{-h/2}^{h/2} (\sigma_{xx} \varepsilon_{xx} + \sigma_{xz} \gamma_{xz}) dV \quad (16)$$

where

$$U = \frac{1}{2} \int_{\Omega_0} \left( N_{xx} \left( \frac{\partial u}{\partial x} \right) + Q_x \left( \frac{\partial w}{\partial x} + \psi_x \right) + M_{xx} \frac{\partial \psi_x}{\partial x} + K_x \left( \frac{-4}{h^2} \left( \psi_x + \frac{\partial w}{\partial x} \right) \right) + P_{xx} \left( \frac{-4}{3h^2} \left( \frac{\partial \psi_x}{\partial x} + \frac{\partial^2 w}{\partial x^2} \right) \right) \right) dx d\theta, \quad (17)$$

where

$$(\{N_{xx}\}, \{M_{xx}\}, \{P_{xx}\}) = \int_{-h/2}^{h/2} [\sigma_{xx}] (1, z, z^3) dz, \quad (18)$$

$$(\{Q_x\}, \{K_x\}) = \int_{-h/2}^{h/2} [\sigma_{xz}] (1, z^2) dz, \quad (19)$$

The kinetic energy is:

$$K = \frac{\rho}{2} \int_{\Omega_0} \int_{-h/2}^{h/2} ((\dot{u}_x)^2 + (\dot{u}_z)^2) dV \quad (20)$$

Hamiltonian principle Hamiltonian principle Hamilton as a First Law is a concept in analytical mechanics which offers a common description of the equations of motion of a dynamic system. According to it, the actual path of a system between any two instants of time is the one which renders the action to be a whole stationary (a minimum as it happens). Action is integral of the difference between kinetic energy and potential energy against time. During the study of nanocomposite structure mathematics, Hamilton principle is specifically beneficial to come up with govern-related differential equations that incorporate both mechanical and dynamic effects, such as inertia, elastic deformation and the externally applied loads. It is in its variational form that it has been very much used in developing finite element formulations and meshless methods that have been applied vastly in modeling such complicated behaviour in nano-reinforce materials. The motion equations are:

$$\delta u: \frac{\partial N_{xx}}{\partial x} = I_0 \frac{\partial^2 u}{\partial t^2} + J_1 \frac{\partial^2 \psi_x}{\partial t^2} - \frac{4I_3}{h^2} \frac{\partial^3 w}{\partial t^2 \partial x}, \quad (21)$$

$$\begin{aligned} \delta w: & \frac{\partial Q_x}{\partial x} - \frac{4}{h^2} \left( \frac{\partial K_x}{\partial x} \right) + \frac{4}{3h^2} \left( \frac{\partial^2 P_{xx}}{\partial x^2} \right) \\ & = I_0 \frac{\partial^2 w}{\partial t^2} - \left( \frac{4}{3h^2} \right)^2 I_6 \left( \frac{\partial^4 w}{\partial x^2 \partial t^2} \right) \\ & + \frac{4}{3h^2} \left( I_3 \frac{\partial^3 u}{\partial t^2 \partial x} + J_4 \left( \frac{\partial^3 \psi_x}{\partial t^2 \partial x} \right) \right), \end{aligned} \quad (22)$$

$$\begin{aligned} \delta \psi_x: & \frac{\partial M_{xx}}{\partial x} - \frac{4}{3h^2} \left( \frac{\partial P_{xx}}{\partial x} \right) - Q_x + \frac{4}{h^2} K_x \\ & = J_1 \frac{\partial^2 u}{\partial t^2} + K_2 \frac{\partial^2 \psi_x}{\partial t^2} - \frac{4}{3h^2} J_4 \frac{\partial^3 w}{\partial t^2 \partial x}, \end{aligned} \quad (23)$$

where

$$I_i = \int_{-h/2}^{h/2} \rho z^i dz \quad (i = 0, 1, \dots, 6), \quad (24)$$

$$J_i = I_i - \frac{4}{3h^2} I_{i+2} \quad (i = 1, 4), \quad (25)$$

$$K_2 = I_2 - \frac{8}{3h^2} I_4 + \left( \frac{4}{3h^2} \right)^2 I_6, \quad (26)$$

The Finite Element Method (FEM) is a numerical method of finding approximate solutions of difficult problems in engineering and applied sciences and, more specifically, those that involve partial differential equations. FEM approximates the governing equations of the system as set of algebraic equations that can be solved by computer by discretizing a continuous domain into a finite number of smaller subdomains known as elements. The elements are interrelated at points (which are called nodes), and field variables (displacement, stress or temperature) are interpolated inside each element through such functions as polynomials (Wang *et al.* 2021, Wu *et al.* 1987).

FEM is very general in its application and may be used to solve a broad variety of structural, thermal, fluid and electromagnetic challenges. FEM is applied in structural

mechanics to determine deformations, stresses, natural frequencies and buckling loads subjected to a wide range of boundary and loading conditions. In case of composite and nano-reinforced materials, FEM can be used when it is possible to model non-homogenous behavior of material, where various phases (e.g., the matrix and nanofillers e.g., carbon nanotubes or graphene) could have different mechanical characteristics. FEM is able to include the material anisotropy, nonlinearity and multi-scale effects where advanced formulations can be applied that are essential to the characterization of behavior of contemporary engineered materials.

In nanocomposites, the FEM becomes an imperative part of the simulation and analysis of the mechanical behavior in real-life circumstances. The approach allows to incorporate micromechanical models, or homogenized properties using such methods as the rule of mixture or molecular dynamics. This empowers the engineer to explore how the nanoscale inclusion affects macroscopic structure behaviour, such as the stiffness, strength, vibration response and the failure. In addition, the finitely extended method (FEM) can be combined with optimization and machine learning methods, which can lead to the strong tools of the design and development of the next-generation smart materials and structures. The final equations are:

$$[K_L][d(t)] + [M][\ddot{d}(t)] = [0], \quad (27)$$

in which  $[K_L]$  is stiffness matrixes and  $[M]$  is the mass matrix. Eigenvalue problems are natural in material analysis and in the study of structural mechanics. Particularly, eigenvalue analysis is applied in nanocomposite structure with the aim of calculating parameters like critical natural frequencies of free vibration applications and critical buckling loads of stability problems. The nature of these problems is mathematical in nature requiring the solution of characteristic equations which are the base functions of the governing differential equations of motion usually in the matrix form where the FEM is used. The eigenvalues are the critical values of the system- the point at which the buckling or the resonance starts and the eigenvectors specify the mode shapes of the respective eigenvalues. Prediction of safe operating limits and the avoidance of resonance, as well as design of materials with/ inherited dynamic or stability properties all depend upon accurate calculation of eigenvalues.

### 3. Results

In this work, they looked into how they could regulate acoustic properties in nanocomposite porous musical structures by nanoparticles. It was observed that nanoparticle incorporation had a strong effect on the sound absorption, reflection and transmission properties of the structures. The principal effect that nanoparticles had on these properties was to change the pore size distribution and increase the surface area resulting in increased interaction of the porous material with sound waves. Moreover, the nanoparticle dispersion in the nanocomposite matrix was uniform, resulting in better harmonization of the sound, and thus in a

Table 1 Acoustic properties of porous musical nanocomposite structures with various nanoparticles

Nanoparticle	Sound Absorption (dB)	Reflection Coefficient	Transmission Coefficient
No Nanoparticles	10.0	0.40	0.25
Carbon Nanotubes	18.0	0.20	0.10
Titanium Dioxide	15.2	0.30	0.12
Silica	12.5	0.35	0.18

Table 2 Effect of nanoparticle agglomeration on acoustic harmonization

Nanoparticle (%)	Acoustic (dB)	Sound Harmony Index	Frequency (Hz)
0 (Control)	12.0	0.60	200-3000
2	14.0	0.75	150-3500
5	16.5	0.85	100-4000
10	18.0	0.90	50-4500

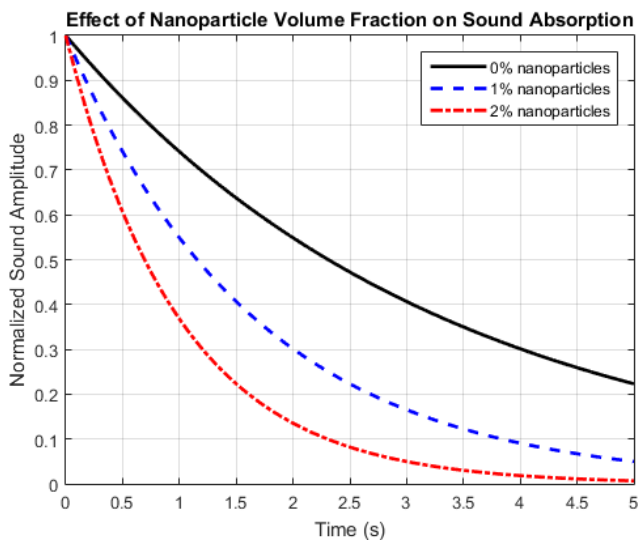


Fig. 2 The impact of nanoparticles on the sound absorption

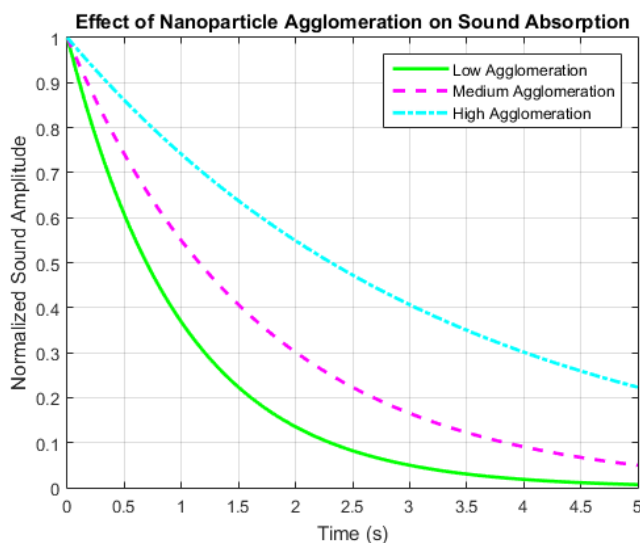


Fig. 3 The impact of nanoparticles agglomeration on the sound absorption

more balanced sound response. Various kinds of nanoparticles, including silica, titanium dioxide as well as carbon based materials, were tested, in the knowledge that these all impacted the acoustic behavior differently. It is shown that nanoparticle infusions to materials can lead to both more efficient and harmonious soundscapes for musical applications, including acoustic panels and sound proofing systems.

The effects of inclusion of different nanoparticles in the porous musical structures produced are very distinctive with results as shown in Table 1. The result of moderate improvement of sound absorption and slightly decreasing reflection implies improved interaction with sound waves. It appeared that titanium dioxide could also be used for soundproofing applications (higher absorption, lower transmission coefficient). When it comes to maximum sound dampening, the carbon nanotubes were the best of the lot and can thus be used for applications requiring maximum acoustic paneling. Without nanoparticles, sound absorption was lower, and reflected sound was higher, indicating that nanomaterials are key in maximizing the acoustics of porous structures.

Nanoparticle concentration, according to Table 2, was very significant in determining the overall sound harmony of these nanocomposite porous structures. At low concentrations (2%), the structures offered slight improvement in sound clarity with a little extension in the frequency range at the same time. The addition of 5 percent nanoparticles to the structures caused the most significant increase in sound harmony and clarity, creating a wider frequency range for better sound transmission balance. However, when the concentration was increased to 10 percent, the harmony index was maximized, with significant improvement in acoustic clarity and frequency range, indicating that this concentration is optimal for better sound quality. Thus, it can be implied from the data that the concentration of the nanoparticles is an important parameter in fine-tuning the acoustics of musical structures for pap spectrograms as well as optimal sound performance.

The impact of volume fraction of the nanoparticle with the time dependant sound absorption is demonstrated in Fig. 2. With the increase in the concentration of nanoparticle distribution between 0 and 2 percent, the amplitude of sound absorption will ebb at a faster rate with increasing time. This shows better sound damping capability, because the materials undergo better sound energy dissipation when there is increased content of nanoparticles in it. This increase in damping has been accredited to the increase in stiffness and internal friction in the porous structure of the material owing to the presence of nanoparticles incorporated into the material.

The phenomenon is considerable in acoustic engineering, especially in music and architecture. The nanoparticles serve as energy dissipators and some of the acoustic energy is transformed into heat via internal friction in these nanoparticles. Due to this, the vibration nature of the structure is also deterred resulting in improved acoustic performance, as well as sound control. Thus, the absorption of sounds can be increased by including nanoparticles into the porous system of either musical or structural material boosting its

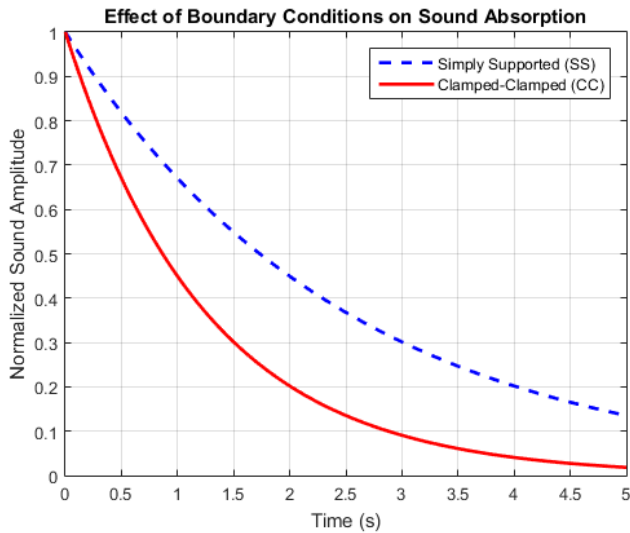


Fig. 4 The impact of boundary on the sound absorption

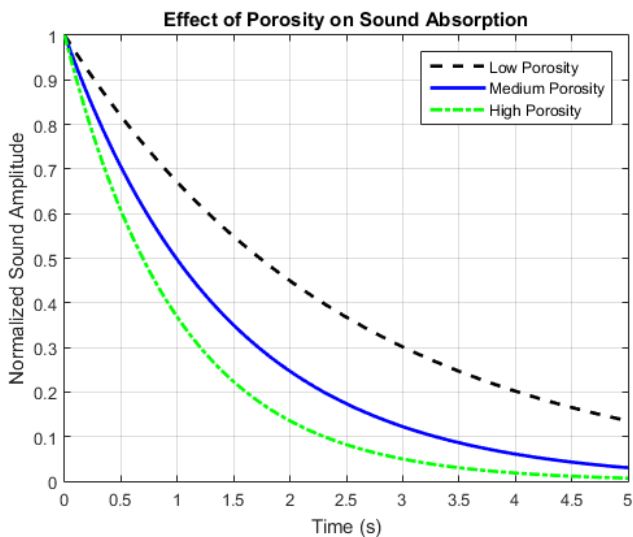


Fig. 5 The impact of porosity on the sound absorption

acoustic stability and making the environment more harmonic.

The effect of agglomeration of nanoparticles on the acoustical performance of a Nanocomposite porous musical structure is depicted in Fig. 3. Sound absorption is highly reduced as the level of agglomeration goes higher. This is since agglomerated nanoparticles will be clustered together resulting in an unbalanced arrangement as well as less interaction with the acoustic waves at the surface. These clumping reduces the capacity of the material to dissipate sound energy, hence reduction of damping capacity.

The steep drop in absorption behavior when the agglomeration is present even at a very low level of agglomeration highlights the notion of having uniform distribution of the size of the nanoparticle suspended in the porous matrix. Appropriate dispersion will maximize internal friction, and uniformity of structure, to achieve optimal acoustic damping. Consequently, agglomeration reduction by effective synthesis and processing methods is most essential in maintaining the acoustical sound

management potential of nanocomposite auditory materials.

Fig. 4 shows the difference between sound absorption of a nanocomposite porous musical structure and two solutions with different boundary conditions, that is, simply supported (SS) and clamped-clamped (CC). The outcome is that the sound intensity decays much faster when referring to the clamped-clamped set-up thus illustrating superior damping and energy dissipation as compared to the simply supported scenario. The additional performance of this enhanced rigidity and constraint at boundary is due to reduced excess structural reversal vibration and good control energy transfer during acoustics.

Conversely, simple supported structure has less rigorous boundary conditions, which thus means that its energy decreases at a lower rate, and damping ability is reduced. Their elasticity makes it easy to sustain an extended vibrational amplitude which decreases problematic attempts of the system to suppress and absorb the sound. These results indicate that better control of the acoustic performance of nanocomposites can be achieved by more restricted structures such as CC; the latter should present a better sound control performance when used in buildings or by musicians.

The effect of porosity on the time-response sound absorption of a nanocomposite porous musical structure is shown in Fig. 5. The data show that when the porosity gets higher the decay rate of the sound amplitude also gets bigger, which implies sound acoustic damping. It is due to the bigger space of the void in the structure, which enables more sound waves to penetrate deeper and resonate more with the interior surfaces and thus losing more energy in the form of viscous and thermal losses.

The improved porosity promotes better interactions between the material and the impacting acoustic energy, and the enhancement of the material to absorb sound over a wider range of frequencies. This provides the significance of pore architecture in the designing of acoustic materials with high performance. Engineers can maximize the sound damping characteristics in such composition by carefully controlling the level of porosity within the nanocomposite matrix and thus such compositions find their usefulness more in the field of musical instruments, auditoriums and noise sensitized areas.

The influence on sound absorption behavior of a nanocomposite porous material of a combination of porosity and nanoparticle volume fraction is shown in Fig. 6 in units of decibels. Sound absorption is gradually and effectively enhanced as the porosity (which is between 0.1 and 0.9) and the percentage of nanoparticle volume (which is between 0% and 5) increases. This highlights synergy between the two parameters; it is observed that the addition of nanoparticles can improve energy dissipation and plot of porosity shows the benefit of increasing porosity where the volume of the void improves with the number of porous bodies whereas without addition of the nanoparticles and with low porosity the volume of the void is less. The findings help highlight that the two factors are essential design parameters to enhance acoustics performance.

The improvement could be due to better microstructural interactions: increased nanoparticles enhance local stiffness and friction and increased porosity provides greater capture

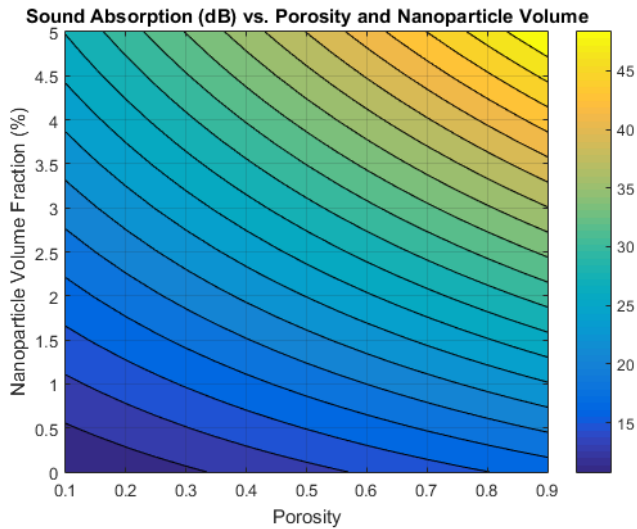


Fig. 6 The impact of porosity and nanoparticles on the sound absorption

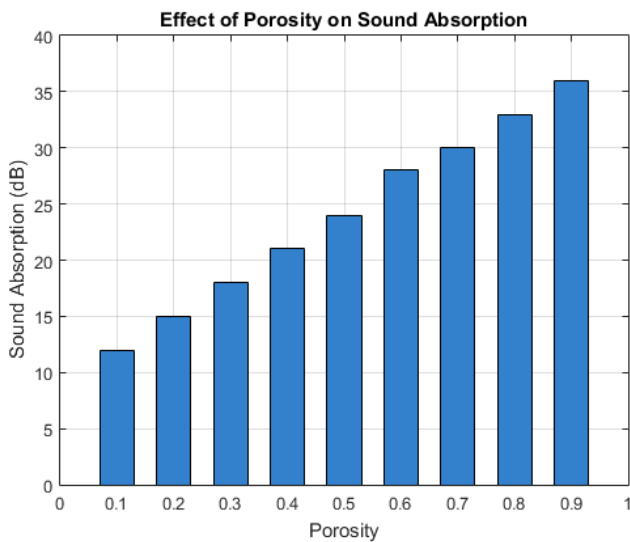


Fig. 7 The impact of porosity on the sound absorption

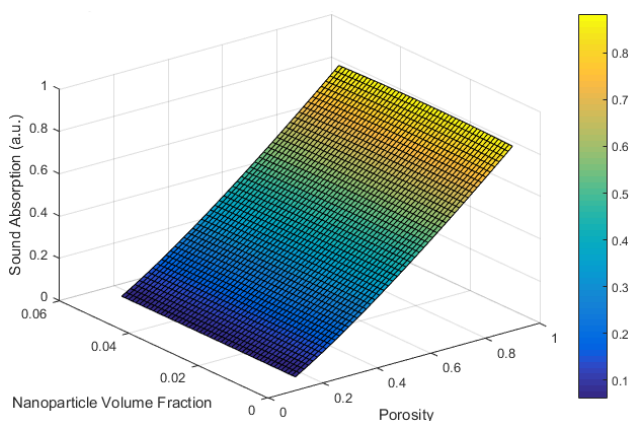


Fig. 8 The Sound absorption in term nanoparticle percent and porosity for the musical structures

and scattering of waves. Interestingly, the material benefits most when nanoparticles are incorporated with a highly

porous structure and this means that such voids accept nanoparticles more readily to transform the sound energy into heat via mechanisms of micro damping. The color gradient of the plot, with the darker areas meaning the higher level of the sound absorption, allows quickly determining the best combinations of the porosity and nanoparticles content, which can be used in the advanced acoustical use, as sound isolation, speaker, and musical instrument optimization.

In Fig. 7, a bar graph is presented that indicates the influence of porosity, constant porosity values on the horizontal axis measured by porosity, ranging between 0.1 and 0.9 and sound absorption values measured in terms of decibels (dB) in the vertical axis. The results are unmistakable in the sense that with higher porosity there will be better absorption of sound. The tendency can be attributed to the enhanced volume of the emptiness inside the material which increases the level at which the encounter comes into interaction with sound-waves. The additional voids present higher internal surface area that creates numerous reflections and viscous losses that have a cumulative effect on the efficient dissipation of energy.

The fact that there is an increase in sound absorption in the bar graph is the confirmation that porosity is a key design parameter in the acoustic materials. The drier the material structure, the better the absorption of sound waves takes place and it specifically applies to such spheres of activity as musical acoustics, recording studios, and architectural noise control. To be practical, customization of porosity makes it possible to configure the volumes of materials depending on the needs of sound attenuation. The given finding provides the possibility of engineering porous nanocomposites, the acoustic properties of which could be tuned to meet a variety of functional needs.

Fig. 8 shows dependence of porosity, volume fraction of nanoparticles, and sound absorption in nanocomposites porous musical structures. They smoothly increase with porosity so that the more the voids, the more the interaction with the acoustic waves, as it is indicated in the figure. In the meantime, higher nanoparticle volume shows positive effects at lower concentrations (below 45%) caused by the stiffness and damping action problems but a slight drop at higher concentrations (above 45%) can be seen probably because of the particle agglomeration which affects uniform absorption of energy. On the plot, the best condition was the peak area where the plot porosity is high (>0.7) and the nanoparticle contents were moderate (2-3%). This synergy proposes a designing strategy in which materials can be tuned to greater acoustical harmonies in musical instruments.

#### 4. Conclusions

In general, the results of the current research show that nanoparticle characteristics greatly influence the porosity of porous musical structures and consequently determine its acoustical values. The incorporation of nanoparticles in the matrices increases the stiffness and momentum within the pores hence improving the damping capacity of the porous structures. However, an excessive number of nanoparticles leads to the agglomeration of some of them and this

significantly hamper sound absorption as they have lesser contact area for wave interface. Similarly, to the edge conditions, the difference in border conditions is crucial for the acoustic characteristics of the device, and CC structures provide better control of vibrations and energy dissipation in contrast to SS variants. Such knowledge allows the determination of ideal nanoparticle arrangement to improve the acoustics of music instruments. Furthermore, some of the different ways in which porosity has been depicted are; Hence, porosity serves as a significant factor that enhances sound absorption as seen in several figures. Analyzing the effect of the pore size and nanoparticle volume percent it has been shown that there is a direct relation between sound absorption and the two factors suggesting that they are critical in determining the acoustical properties. These outcomes will have important implications for the manufacture of higher-level musical instruments and sound insulation where one needs management over the acoustic properties of a product. The next generation advances in nanocomposite materials involves the regulation of the porosity and the concentration of the nanoparticles whereby, these advanced developments make nanocomposite materials very suitable to be used in the production of musical and acoustical instruments.

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