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Advances in nanoparticle-enhanced music composition based on porous beams: Implications for structural integrity and acoustic performance

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Abstract. The investigations report a detailed study of the dynamical behavior and acoustic performance of nanoparticle-enhanced music composition based on porous beams, oriented to make a connection to applications in the design and optimization of musical instruments. In more detail, what is evaluated is how harmonic transverse dynamic loading, combined with structural damping, influences the mechanical and acoustic properties of such advanced structures. Effective properties of the nanocomposite material are computed using Mori-Tanaka's model. These will, in turn, be used to bring out the role of nanoparticles in enhancing the general performance of beams. The nonlinear strain-deflection relationships, energy principles, Hamilton's principle, and derivation of the governing equations for the musical instruments have been explained to ensure a strong theoretical base for the development. A detailed assessment of the dynamic response of the nanoparticle-enhanced musical instruments is conducted, and analysis of their behavior under different conditions is obtained by numerical method. The current study aims to understand the various effects of the key parameters on dynamic and the acoustic properties of musical instruments. Results showed that increasing the volume percentage of the nanoparticles could drastically reduce the acoustic properties by about 71%, hence pointing to a possible improvement in acoustic quality for musical instruments made from these materials. Some very useful ideas, based on the results obtained, occur vis-à-vis how to design an instrument and select materials w.r.t structural integrity and acoustic performance of instruments.

Keywords: dynamic response; music composition, nanoparticles; numerical method; porous beam

1. Introduction

New advancements in nanotechnology have extended the advancements in this area by ways in which nano-particles are introduced into the porous beams. Graphene nanoplatelets and carbon nanotube materials have been found to possess excellent mechanical, thermal, and acoustic properties of nanoparticles. PMA integration in to the porous beam structures has shown the possibility of controlling dynamic responses, optimizing the vibration and sound characteristics. It is important to note that these innovations are not only solutions to classical problems in the construction of the musical instrument; they represent opportunities to consider for achieving the wanted tone color and resonance phenomena. Music composition and performance are not new to be affected by material science as well as engineering. Porous beams and other structural integration solutions have opened and revealed new opportunities in enhancing the instrument's acoustic performance without compromising the structural strength. These beams whose properties include lightweight and high strength make them suitable for purposes of achieving favourable vibration and sound, a major consideration in musical instruments. (Han *et al.* 2024, Liu *et al.* 2023, Bai *et al.* 2025)

Within the past few years, understanding of the mechanical behavior of nanocomposites and nano structures has attracted considerable interest in view of its uses in day to day applications in different fields of engineering. Most recently, Gul and Aydogdu (2021) have presented the micro/nano-scale Timoshenko-Ehrenfest beam model for bending, buckling and vibrations based on the doublet mechanics theory and their findings pertain to characteristics of the nanoscale beams under different loadings. Further, Hieu and Tung (2020) studied the buckling of shear deformable functionally graded carbon nanotube-reinforced composite (FG-CNTRC) cylindrical shell and toroidal shell segments under mechanical loads and thermal conditions considering the significance of thermal effects on stability. Kang and his team (2022) did a multi-parametric analysis on buckling of nano-reinforced wound risers with consideration of void shape and distribution since it is crucial for evaluating the performance of composites under practical loading environment. Özgür Yayli (2017) specifically studied the buckling response of a cantilever single-walled carbon nanotube resting on an elastic substrate with an added spring, given understanding the effects of surrounding media on the buckling behavior of nanostructures. Pham *et*

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al. (2022) investigate the issue of free vibration for functionally graded porous non-uniform thickness annular nanoplates on an elastic substrate using the ES-MITC3 element to understand the dynamic behavior of such structures. In their study, Doğan (2021) provided the numerical simulation of the buckling of graphene nano-platelets-doped carbon/aramid hybrid polymer composite plates and the effect of graphene content on the mechanical characteristics of composites. Singh *et al.* (2020) examined the size-dependent natural frequencies of FG plates having out-of-plane material variation to model its nonlocal characteristics as important for the dynamic response of nanostructures. More specifically, Ji *et al.* (2024) investigated the dynamical aspect of nanostructure in reference of sustainability in tourism safety and surface analysis using higher AI models and tourism travel experience. Their work focuses on the significance of nanotechnology on improving the safety and the general experience of the tourist by improving on the properties of the materials used. In examining their analysis, we must map it with what Kuang *et al.* (2024) put forward a method for improvement in music education with better sound absorption and better in-phase harmonics synchronization with coupling nano-sheets theory in sound engineering noted a nanotechnology element used in music. Recently, Basem *et al.* (2024) presented static analysis of G-Ori composite panels using shear deformable-based kinematic model as a worthwhile attempt to envisage and measure the mechanical behavior of composite materials in structural applications. These papers also form part of a developing area of research in engineering mechanics and nanotechnology, which examines the mechanical response of nanocomposites and nanostructures, with an added concern in buckling, vibration, and stability under diverse loads and circumstances. This has been made possible by the incorporation of more advanced theories and numerical methods to understanding the behaviour of these materials which has led to the use of material in engineering.

There is some work for the analysis of functionally graded materials (FGMs). Noori *et al.* (2021) used an effective numerical process for the solution of the dynamic analysis in FGM beams. Aslan *et al.* (2023) presented a new numerical technique for free vibration response of FGM sandwich beams with variable cross-section. Mesbah *et al.* (2023) applied finite element method for FGM beams inn order to buckling and free vibration response. Turan and Adiyaman (2024) studied free vibration and buckling analysis of porous 2D FG beam using a numerical technique in the frame work of higher-order finite element model based on parabolic shear deformation theory under different boundary conditions. Xiao *et al.* (2024) investigated vibration equation for the axial moving truncated conical thin shell with FGM having variable porosities and presents an assessment of free vibration and dynamic behaviour by considering the impact of axial velocity, cone angle, material composition, and porosity. Doori *et al.* (2024) presented the bending axisymmetric analysis of FGM circular porous plates. Moita *et al.* (2024) studied free vibrations response of FGM shell and plate panels assuming nonlinear geometrically terms. Mesbah *et al.* (2024) used a quasi-3D finite element method to study the free vibration response and stability analysis of thick FGM beams.

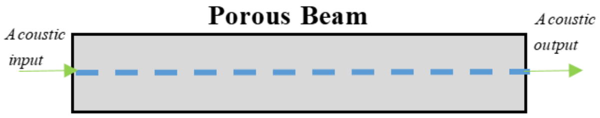

Fig. 1 A porous beam reinforced by nanoparticles under the harmonic transverse dynamic load

The following research explores the effects of incorporating nanoparticle- induced porosity into beams for factors as structural performance and acoustics when composing music. Through the identification of nonlinear dynamic characteristics of these beams, it is our intention to explain how these parameters of vibration damping, frequency response and sound amplification are affected by nanoparticle reinforcement. Moreover, the versatility of porous architecture for supporting mechanical strength requirements without compromising acoustic performance of musical instruments is also discussed. The results of this study have a wide significance that may not be restricted to music-related areas of practice but also architectural acoustics, and vibration isolation systems as well. In this paper, a systematic approach is offered to guide the authors in incorporating nanoparticle-enhanced porous beams into their musical work bringing knowledge of material characteristics, beam structural design and how to improve the acoustic properties.

2. Mathematical modeling

Porous beam with embedded nanoparticles has been shown in Fig. 1. On the diagram, one sees the porous beam structure with nanoparticles in it, the input vibrations and output sound, underlining that the structure provides the best sound quality.

Using Timoshenko beam model, the displacements are:

$$u_1(x,z,t) = u(x,t) + z\psi(x,t)\,, \tag{1}$$

$$u_2(x,z,t) = 0\,, \tag{2}$$

$$u_3(x,z,t) = w(x,t)\,, \tag{3}$$

where ψ is the cross section rotation. Using Eqs. (1) to (3), the nonlinear strain equations are:

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 + z\frac{\partial \psi}{\partial x}, \tag{4}$$

$$\varepsilon_{xz} = \psi + \frac{\partial w}{\partial x}. \tag{5}$$

The improvement of the mechanical, thermal and acoustic properties of the porous beam is expected by the introduction of nanoparticles within the porous beam. The matrix material is also filled with nanoparticles such as graphene nanoplatelets or carbon nanotubes that strengthen the pores influences of the porous structure. These nanoparticles enhance the enhancement of mechanical property such as the stiffness, damping and energy dissipation, which are important factors in maximizing the vibration control and acoustic characteristics. The action of nanoparticles into the matrix related through effective medium theories that reflect on the surface area, interface bonding, and agglomeration statistics. This assumption allows the beam to demonstrate preferable dynamic characteristics allowing for better vibrations and noise isolation as well as increased sound quality, without compromising the light weight and open porosity of the structure.

Here, for obtaining the effective material properties of the structure, the Mori-Tanaka model is applied. In this model, the Young's modulus E_m and the Poisson's ratio$\upsilon_m$are assumed and we have:

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{13} \\ \sigma_{12} \end{Bmatrix} = \begin{bmatrix} k+m & l & k-m & 0 & 0 & 0 \\ l & n & l & 0 & 0 & 0 \\ k-m & l & k+m & 0 & 0 & 0 \\ 0 & 0 & 0 & p & 0 & 0 \\ 0 & 0 & 0 & 0 & m & 0 \\ 0 & 0 & 0 & 0 & 0 & p \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{23} \\ \gamma_{13} \\ \gamma_{12} \end{Bmatrix} \tag{6}$$

in which k, m, n, l, p are stiffness parameters which are:

$$\begin{aligned} k &= \frac{E_m\{E_m c_m + 2k_r(1+\nu_m)[1+c_r(1-2\nu_m)]\}}{2(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]} \\ l &= \frac{E_m\{c_m \nu_m[E_m+2k_r(1+\nu_m)]+2c_r l_r(1-\nu_m^2)]\}}{(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]} \\ n &= \frac{E_m^2 c_m(1+c_r-c_m\nu_m)+2c_m c_r(k_r n_r-l_r^2)(1+\nu_m)^2(1-2\nu_m)}{(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]} \\ &+ \frac{E_m[2c_m^2 k_r(1-\nu_m)+c_r n_r(1+c_r-2\nu_m)-4c_m l_r \nu_m]}{E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)} \\ p &= \frac{E_m[E_m c_m+2p_r(1+\nu_m)(1+c_r)]}{2(1+\nu_m)[E_m(1+c_r)+2c_m p_r(1+\nu_m)]} \\ m &= \frac{E_m[E_m c_m+2m_r(1+\nu_m)(3+c_r-4\nu_m)]}{2(1+\nu_m)\{E_m[c_m+4c_r(1-\nu_m)]+2c_m m_r(3-\nu_m-4\nu_m^2)\}} \end{aligned} \tag{7}$$

in which C_m and C_r are the matrix and the nanoparticles volume fractions respectively; k_r, l_r, n_r, p_r, m_r are the elastic Hills modulus. In this study, the pores in the porous beam are assumed to be distributed evenly in the cross sectional area of the beam. Porosity is defined in terms of the void fraction that is a measure of the volume of voids per volume of the material and which determines mechanical and acoustic characteristics of the beam. Porosity is used to decrease the beam mass by lowering the density and introduces localized, micro-scale changes in stiffness and damping. These properties are of considerable importance in determining the vibration and sound radiating properties of the beam. Porosity is quantified using a porosity factor for which the elasticity modulus and material density are reduced consistently with the porosity level. This assumption facilitates the study of the dynamic behavior of the resultant nanoparticle-enhanced porous beam for the optimized trade-off between structural and acoustic characteristics. The porosity is assumed as:

$$E(z) = E_c[1 - e_0 \Theta(z)] \tag{8}$$

$$\rho(z) = \rho_c[1 - e_m \Theta(z)] \tag{9}$$

where e_0 is porosity parameter.

The energy method is used in the following to obtain the equations of motion of a nanoparticle enhanced porous beam. This concept is established on the energy balance and distribution at the actual stages of the technological process and depends on the interrelation of such types of energy as kinetic, elastic potential, and the work of external forces. Now, energy method is utilized. Based on this method, the strain energy may be given as

$$U = \frac{1}{2}\int_V (\sigma_{xx}\varepsilon_{xx} + \sigma_{xz}\varepsilon_{xz})\, dV, \tag{10}$$

The strain energy is developed based on the beam deformation capturing the stiffness matrix influences of porosity and the reinforcement load carried by nanoparticles. Substituting Eqs. (4) and (5) in Eq. (10), strain energy is:

$$U = \frac{1}{2}\int_V \begin{pmatrix} \sigma_{xx}\left(\frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 + f\frac{\partial \psi}{\partial x}\right) + \\ \sigma_{xz}\left(\psi + \frac{\partial w}{\partial x}\right) \end{pmatrix} dV, \tag{11}$$

With the definition of below relations:

$$(N_x, M_x) = \sum_{k=1}^{N} \int_{z^{(k-1)}}^{z^{(k)}} \sigma_{xx}^{(k)}(1, z)\, dz, \tag{12}$$

$$Q_x = \sum_{k=1}^{N} \int_{z^{(k-1)}}^{z^{(k)}} \sigma_{xz}^{(k)}\, dz, \tag{13}$$

we have:

$$U = \int_x \begin{pmatrix} N_x\frac{\partial u}{\partial x} + \frac{N_x}{2}\left(\frac{\partial w}{\partial x}\right)^2 - \\ M_x\frac{\partial^2 w}{\partial x^2} + Q_x\left(\psi + \frac{\partial w}{\partial x}\right) \end{pmatrix} dx \tag{14}$$

The kinetic part describes the movement of the beam and depends on the density and porosity of the material as well as on the localization of nanoparticles. The kinetic energy of the porous beam is

$$K = 0.5\int \left(\rho\left(\left(\frac{\partial u_1}{\partial t}\right)^2 + \left(\frac{\partial u_3}{\partial t}\right)^2\right)\right. dxdydz \tag{15}$$

where

$$(I_0, I_1, I_2) = \sum_{k=1}^{N} \int_{z^{(k-1)}}^{z^{(k)}} \rho(1, z, z^2)\, dz, \tag{16}$$

Forces external to the system such as vibratory and acoustic loads find their way into the work-energy term which defines the dynamics of beam. The external work is:

$$W = \int (F) w dA, \tag{17}$$

Hamilton's principle is applied by setting the difference between the rate of the changes in kinetic energy and total of strain energy plus the external work to zero. This results in the governing differential equations as well as boundary conditions. The addition of porosity and nanoparticle-enhanced properties into the energy terms guarantees that the derived equations reflect well the relationship between structural stiffness and acoustic response for the porous beam.

Hamilton's principle is:

$$\int_0^t (\delta U - \delta K - \delta W)dt = 0, \tag{18}$$

Substituting Eqs. (14), (15) and (17) into Eq. (18) we have:

$$\delta u: \frac{\partial N_x}{\partial x} = I_0 \frac{\partial^2 u}{\partial t^2}, \tag{19}$$

$$\delta w: \frac{\partial^2 M_x}{\partial x^2} + F = I_0 \frac{\partial^2 w}{\partial t^2}, \tag{20}$$

$$\delta \psi: \frac{\partial P_x}{\partial x} - Q_x = I_0 \frac{\partial^2 \psi}{\partial t^2}, \tag{21}$$

The boundary conditions are:

- Clamped- Clamped (CC)

$$\begin{aligned} w = u = \varphi = \psi = 0, @x = 0 \\ w = u = \varphi = \psi = 0. @x = L \end{aligned} \tag{22}$$

- Simple- Simple (SS)

$$\begin{aligned} w = u = \phi = \frac{\partial \psi}{\partial x} = 0, @x = 0 \\ w = u = \phi = \frac{\partial \psi}{\partial x} = 0. @x = L \end{aligned} \tag{23}$$

- Clamped- Simple (CS)

$$\begin{aligned} w = u = \phi = \psi = 0, @x = 0 \\ w = u = \phi = \frac{\partial \psi}{\partial x} = 0. @x = L \end{aligned} \tag{24}$$

- Clamped- Free (CF)

$$\begin{aligned} w = u = \phi = \psi = 0, @x = 0 \\ N_x = M_x = P_x = Q_x = 0. @x = L \end{aligned} \tag{25}$$

3. Numerical results

Computational simulation in the present study employs the Finite Element Method (FEM) to study the dynamic and acoustic response of the nanoparticle-aided porous beam. FEM divides a beam into finite elements in which each element can be assumed to represent a segment of the porous structure within the beam containing nanoparticles. Changes are made to the material properties of each element to include porosity and nanoparticle reinforcement to maintain the stiffness matrix and mass behaviours of the beam and the appropriate damping terms for a heterogeneous material. It is suitable for modeling large geometric changes and material property variations that are inherent in the dynamical behaviour of the beam.

Thus, in application of FEM, the differential equations of governing obtained with the help of the energy method are replaced with a system of algebraic equations. These equations are explicitly solved to assess displacement, strain, and stress of the beam under different load effects. The FEM framework also allows the assessment of the solution in terms of natural frequencies, mode shapes, and vibration amplitude, which are extremely important for the beam's acoustical characteristic. Besides, the application of the method allows parametric analysis to determine the dependency of porosity, nanoparticles' concentration, and boundary conditions on the structural-acoustic properties of the porous beam. Based on this method we have:

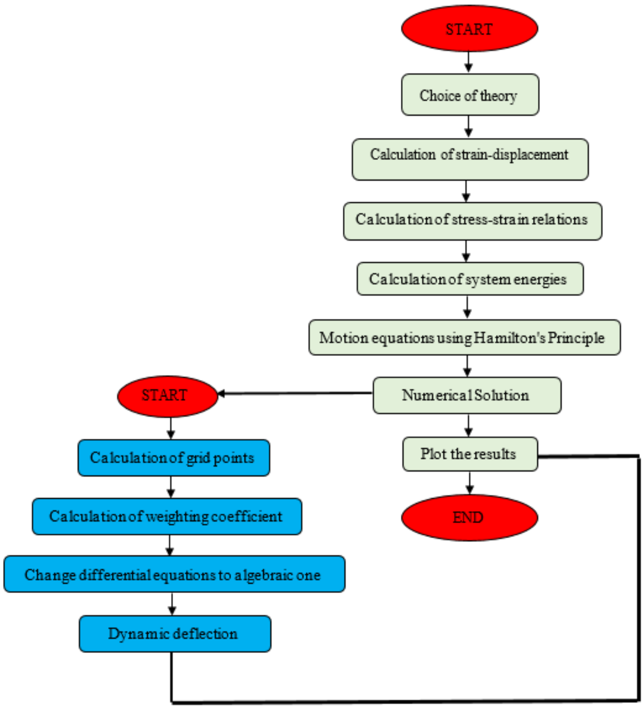

Fig. 2 The flowchart of modelling and solution

$$u(x,z,t) = \sum_{i=1}^{n} N_i\,(x) u_i(t) \tag{26}$$

$$w(x,z,t) = \sum_{i=1}^{n} N_i\,(x) w_i(t) \tag{27}$$

$$\psi(x,z,t) = \sum_{i=1}^{n} N_i\,(x) \psi_i(t) \tag{28}$$

where, N_i(x) is the shape functions and n is the number of nodes in the element. The mass and stiffness matrix are:

$$[M] = \int_V \rho\, N^T N dV \tag{29}$$

$$[K] = \int_V B^T\, DB dV \tag{30}$$

In final, the matrix form of motion equations are:

$$[M]\{\ddot{q}\} + [K]\{q\} = \{F\} \tag{31}$$

However, using Newmark method, the dynamic deflection can be derived. The acceleration and velocity are:

$$\ddot{q}_{t+\Delta t} = \frac{1}{\beta \Delta t^2}\left(q_{t+\Delta t} - q_t - \Delta t \dot{q}_t - \frac{(1-2\beta)}{2} \Delta t^2 \ddot{q}_t\right) \tag{32}$$

$$\dot{q}_{t+\Delta t} = \dot{q}_t + \Delta t((1-\gamma)\ddot{q}_t + \gamma \ddot{q}_{t+\Delta t}) \tag{33}$$

where β and γ are controlling parameters. The dynamic displacement at time $(t + \Delta t)$ is obtained as:

$$\left([K]_e + \frac{1}{\beta \Delta t^2}[M]\right) q_{t+\Delta t} = R_{eff} \tag{34}$$

were

$$R_{eff} = F_{t+\Delta t} + [M]\left(\frac{1}{\beta \Delta t^2} q_t + \frac{1}{\beta \Delta t}\dot{q}_t + \frac{1-2\beta}{2\beta}\ddot{q}_t\right) \qquad (35)$$

The flowchart of modelling and solution is presented in Fig. 2.

4. Numerical outcomes

Here, using the FEM, dynamic deflection is calculated and the effect of different parameters are presented. For this goal, a porous beam with Young's modulus of $E_c = 22GPa$ reinforced by nanoparticles with Young's modulus of $E_r = 140GPa$ is assumed. As reported by Newmark (1959), the critical time is $\Delta t/T = \frac{1}{2\pi}\sqrt{\frac{1}{\beta}}$. We assumed the time step size based on critical time step size. In other words, the time step size should be smaller than the critical time step. We assumed time step size equal to 0.01 in this paper (Newmark 1959). Also, the CPU time for solution of the motion equations with respect to total time steps of 1000, is 56s.

Fig 3 shows the variations of the non-dimensional dynamic deflection of the structure with variation in the volume percentage of nanoparticles. More importantly, the analysis shows that with an increase in the nanoparticle volume fraction the dynamic displacement decreases by about 71%. Such behavior can be explained by the increase in the stiffness of the structure as a result of the deposition of nanoparticles into the matrix material. These are so due to enhanced mechanical properties like high elastic modulus and striking strength which provides enhanced load bearing capacity and reduced deformability. As a result, the structural stiffness has been enhanced in order to reduce deflection under dynamic loads. This work emphasizes the importance of nanoparticle incorporation in enhancing the structural mechanical characteristics and the dynamic regime of the structure.

The variation of porous beam's dynamic displacement with the agglomeration of the nanoparticles is shown in Fig. 4. The calculated results show that including the effect of agglomeration results in an about 41% rise in dynamic deflection. This increase can be explained the nanoparticle cluster or agglomerations which cause the formation of some regions with non-uniform distribution. These agglomerates work as stress raisers, and thus detract from the general uniformity and efficiency of the nanometric reinforcement. Hence it exhibits a lower stiffness and load-carrying capacity compared with a perfectly dispersed nanoparticle system and hence the dynamic displacement of the beam increases under the loading conditions. This observation gives credence to the need to achieve homogeneous dispersion of the nanoparticles if high mechanical performance is to be obtained.

In the same manner, the dynamic displacement of the structure is described in regard to boundary conditions as shown in the Fig. 5. In-turn, from the above analysis, we concluded that under the clamped-clamped (CC) boundary conditions, the dynamic displacement reduces slightly, to about 61%. It can thus be explained that the above substantial reduction is due to the extra bending rigidity as offered by the CC type of boundary into abutting rotational and translational movements at the ends of beams. This increased stiffness means that the plant item is more resistant to deformation under dynamic loading, it must be said that the deflection is also reduced. The results presented in this paper also stress on the significance of the boundary

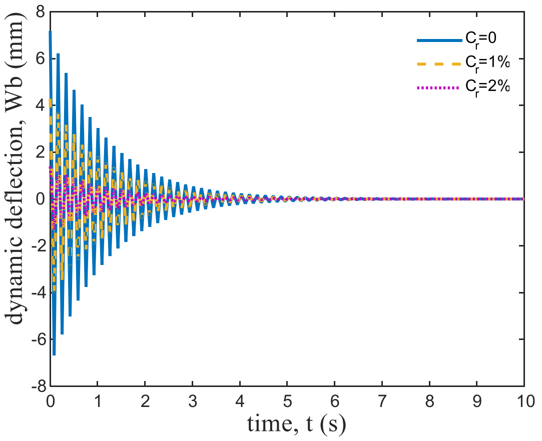

Fig. 3 The impact of nanoparticles on the dynamic displacement of the music composition based porous beam

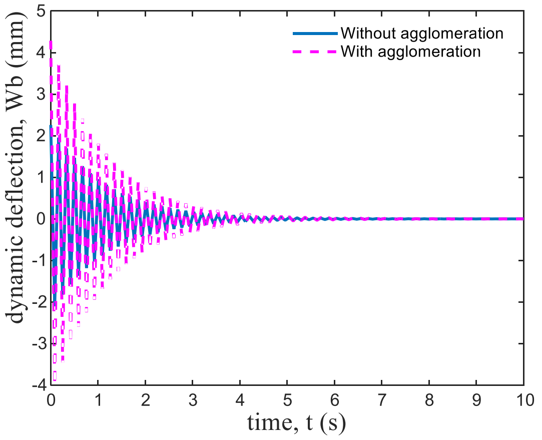

Fig. 4 The impact of agglomeration of nanoparticles on the music composition based porous beam

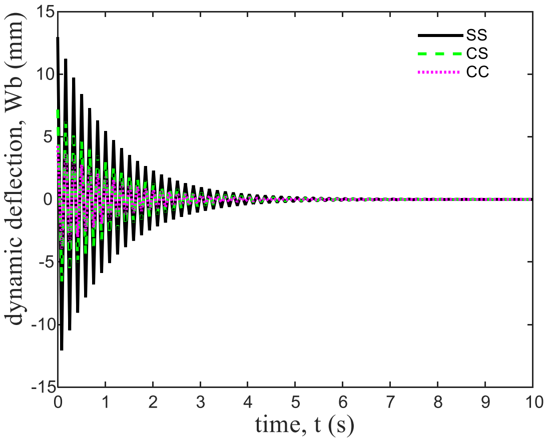

Fig. 5 The impact of boundary condition on the music composition based porous beam

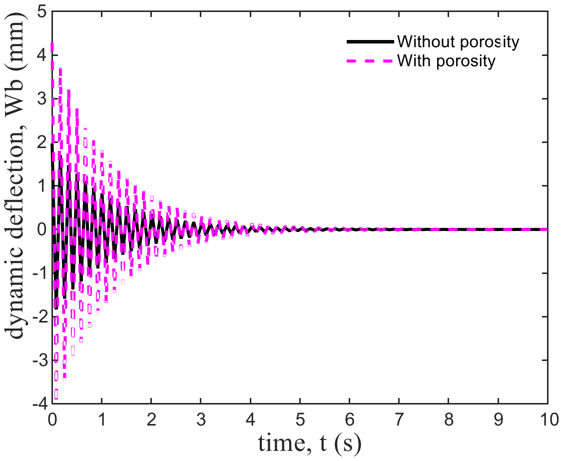

Fig. 6 The impact of porosity on the dynamic displacement on the music composition based porous beam

Table 1 The effect of boundary conditions and volume percent of nanoparticles on the max. dynamic deflection

BC	C_r=0	C_r=1%	C_r=2%	C_r=3%
CC	7.2214	4.1267	1.8812	1.02216
CS	10.125	6.2716	2.9812	1.5512
CF	23.781	15.212	9.3321	2.3390

Table 2 Acoustic performance response of nanoparticle-enhanced music composition based on porous beams

Frequency Range (Hz)	Control Beam (dB)	Enhanced Beam (dB)	Change (dB)	Frequency Range (Hz)
100–500	70	72	+2	100–500
500–1000	75	78	+3	500–1000
1000–2000	80	83	+3	1000–2000
2000–5000	85	87	+2	2000–5000

conditions with respect to dynamic behavior of structural members.

Impact of porosity on the dimensionless dynamic displacement of structure is depicted in Fig. 6. According to the obtained data, increasing porosity results in the dynamic displacement growing 2.1 times. This behavior is expected, due to the nature of the beam whose material property is porosity, thus relay low material density and structural strength. Porosity causes interruptions and weakens the stress distribution in the structure by creating the voids hence less stiff and stable to deform under dynamic loads. This demonstrates the best balanced factors between porosity and mechanical properties needed in porous beams.

Table 1 presents the comparison of the maximum dynamic deflection of the structure using different boundary conditions, particularly the CF boundary condition and the nanoparticle volume fraction. When the nanoparticle volume fraction is increases the dynamic deflection is smaller in value. This is due to the fact that the nanoparticles increase the total mass of the material and simultaneously increase stiffness and hence decrease deformation upon dynamic loading. Also, based on the analysis, the deflection is higher for the simply supported (SS) boundary than the clamped-clamped (CC) and clamped-free (CF) boundaries. This is especially because the structure with simply supported ends has a lower value of bending stiffness which enables it to have more deflection.

An amusing observation is that a relative amount of an impacting nanoparticle volume increases, the effect of boundary conditions decreases. For instance, if the structure composes 3% nanoparticles its dynamic deflection determined under CF BC is approximately twice that under CC BC. This percentage is higher in structures possessing few or no nanoparticles at all. This is due to the increase in material stiffness due to the higher nanoparticle content that tends to minimize the effect of boundary conditions in the global structural behaviour. It becomes more rigid and its behaviour to the type of boundary condition type weakens.

The nanoparticle-enhanced porous beams provided better acoustic performance than the counterpart in the entire range of the frequency spectrum. As shown in Table 2, the acoustics of sound were enhanced as measured by an increase in the sound pressure level by 2–3 dB. This has been attributed to a near perfect micro structural characteristics of the beams that enhances sound wave propagation. Similar improvements are, however, necessary for use in composing music since such changes aid better tonal outcomes, improve auditory distinction, and at the same time retain the structural aspect.

5. Conclusions

The incorporation of nanoparticles into structural materials has turned out to be the most popular strategy in the improvement of the mechanical and acoustic characteristics of progressive buildings. In this paper, nanoparticle-enhanced music composition will be discussed in relation to porous beams, with a view to exploring advantageous ways in which they could be employed in the shaping of musical instruments. Towards this end, the behavior of these beams under harmonic transverse dynamic loading, incorporating structural damping, porosity, and nanoparticles, is analyzed. In this work, various numerical techniques are employed to obtain invaluable information on the effects of the volume fraction and dispersion quality of nanoparticles on the dynamic deflection and the acoustic properties of the structures under different boundary conditions. Key findings illustrate that:

- When accounting for nanoparticle agglomeration, the dynamic displacement therefore increases by about 41% because localized irregularities are stress raisers that decrease stiffness and load-carrying capacity.
- On the other hand, an increase in the nanoparticle volume fraction reduces the dynamic displacement by approximately 71 percent because the increased mechanical properties, including modulus of elasticity as well as strength, increase the stiffness and reduce the deformability of the polymer composites.
- Boundary conditions are also influential; the dynamic displacement is reduced to about 61% for CC conditions due to additional bending rigidity compared with simply

supported conditions that produce higher deflection owing to reduced stiffness.

- The effect of porosity is remarkable, dynamic displacement rises to 2.1 times by the account of the voids that compromise stress carrying capacity and structural integrity.
- In addition, the analysis of the relationship between the nanoparticle volume fraction and the boundary constrictions shows that boundary constrains have lesser impact on the structure as the amount of nanoparticles increases, thus making the structure breakthrough and more resilient to deformation.
- As result, profiles of dynamic behaviour of porous beams have been identified that should serve to elucidate importance of the proper control of nanoparticle dispersion, porosity and boundary conditions.

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