Advances in Computational Design, *Vol. 8, No. 1 (2023) 77-96*
https://doi.org/10.12989/acd.2023.8.1.077

Computational continuum modelling to analysis the dynamic and static stability of a cantilever nano-scale system

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(Received December 11, 2022, Revised January 19, 2023, Accepted January 25, 2023)

Abstract. Calculating size-dependent mechanical properties of the nano-scale materials usually involves cumbersome numerical and theoretical works. In this paper, we aim to present a closed-form relation to calculate the length-dependent Young's modulus of carbon nanotubes (CNTs) based on nonlocal elasticity theory. In this regard, a single wall carbon nanotube (SWCNT) is considered as a rod structure and the governing nonlocal equations are developed under uniaxial tensile load. The equations are solved using analytical methods and strain distribution, total displacement and the size-dependent equivalent Young's modulus are obtained. Further, the results are compared with the molecular dynamics results from the literature. The outcome indicates that the calculated relations are coincident with the molecular dynamics results.

Keywords: carbon nanotube; nanocomposite; nonlocal elasticity; size-dependent properties; stability; Young's modulus

1. Introduction

Carbon nanotubes have received considerable attention from researchers, and many reports have been published on their extraordinary mechanical, electrical and thermal properties (Habibi *et al*. 2016, 2018a, b, 2019b, d, e, Ebrahimi *et al*. 2019b, Esmailpoor Hajilak *et al*. 2019, Pourjabari *et al*. 2019, Safarpour *et al*. 2019a, Zhu *et al*. 2022, Zheng *et al*. 2023). The mechanical behavior of the carbon nanotubes have been analyzed through several methods including molecular dynamics and continuum mechanics, and these studies predicts noteworthy mechanical properties for these small materials (Fazaeli *et al*. 2016, Habibi *et al*. 2017, 2019a, c, Safarpour *et al*. 2018, 2019b, 2020, Alipour *et al*. 2020, Ebrahimi *et al*. 2020a, Ghazanfari *et al*. 2020, Chen *et al*. 2022). Owing to these mechanical properties, carbon nanotubes have the potential to be employed in many future devices and nanostructured materials. As an example, high Young modulus accompanied by their low density, makes them a good choice for reinforcing material in composites (Ebrahimi *et al*. 2019c, d, 2020b, Hashemi *et al*. 2019, Moayedi *et al*. 2019, 2020a, b, Mohammadgholiha *et al*. 2019, Mohammadi *et al*. 2019, Habibi *et al*. 2020, Oyarhossein *et al*. 2020, Shariati *et al*. 2020a, b, Shokrgozar *et al*. 2020).

Experimental studies as well as atomic simulations demonstrate that the mechanical properties

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http://www.techno-press.org/?journal=acd&subpage=7 ISSN: 2383-8477 (Print), 2466-0523 (Online)

of materials in nano scales are highly dependent on the sizes of these materials (Hashemi *et al*. 2019, Al-Furjan *et al*. 2020c, d, e, f, Bai *et al*. 2020, Cheshmeh *et al*. 2020, Li *et al*. 2020a, Lori *et al*. 2020, Najaafi *et al*. 2020, Shariati *et al*. 2020c, Xiong *et al*. 2020, Guo *et al*. 2021b, Liu *et al*. 2021a). Carbon nanotubes, as nanoscale materials, also have size dependent properties (Adamian *et al*. 2020, Al-Furjan *et al*. 2020a, b, Li *et al*. 2020b, Liu *et al*. 2020b, 2021b, Zare *et al*. 2020, Dai *et al*. 2021b, Habibi *et al*. 2021, Heidari *et al*. 2021, Huang *et al*. 2021a, Zhang *et al*. 2021). Lee *et al* (2007) measured the elastic modulus of multi wall carbon nanotubes (MWCNTs) grown by catalytic chemical vapor deposition (CVD), and it is observed that 10-25 nm diameter MWCNTs exhibit considerable diameter dependent elastic modulus. They demonstrated that the elastic modulus of the MWCNTs decreases with increase in the diameter. On the other hand, atomic simulations show that the elastic modulus of 1-2nm diameter CNTs increases with increase in the diameter (Chang and Gao 2003). It is argued that the increase in elastic modulus in small diameter (<1.5 nm) is due to the excessive strain imposed on the graphene shells, and this effect is not prevalent in the experimental results that deal with 10-25 nm nanotubes. (Chang and Gao 2003) presented an analytical method based on molecular dynamics to calculate the elastic properties of carbon nanotubes as a function of their geometry parameters such as diameter and chirality. The results indicate that the Young modulus of SWCNT increases with increase in diameter and then converges to a constant value for large diameters. (Li and Chou 2003) calculated the young and shear modulus of single layer carbon nanotubes using a structural mechanics method. In their analysis, a C-C bond is modeled as a beam with specific Young, bending and shear moduli that were calculated by matching beam specifications with force field constants. Using this method, they observed that the Young modulus of CNTs reduces with increase in diameter. The shear modulus also shows similar dependency on the diameter. In recent years, length dependent properties of SWCNT is investigated by (Naumov *et al*. 2013, Rao *et al*. 2015, Zhu and Li 2017, Taati *et al*. 2020) and (Ranjbartoreh and Wang 2010). Anandatheertha *et al*. (2010) used molecular dynamics based finite element method to evaluate Young modulus of SWCNT. In lengths smaller than 60 nm, the Young modulus exhibits an increase when increasing in length of the CNT, and for longer lengths, it converges to a constant value. (Ranjbartoreh and Wang 2010) employed molecular dynamics simulation to predict behavior of SWCNT under various loading conditions. The results show that the Young modulus increases with increase in the length. There can be found several research works on the size dependent vibrational and buckling behavior of CNTs and CNT-reinforced nano-composites employing nonlocal and gradient theories of elasticity (Hosseini *et al*. 2017, 2018, Aydogdu *et al*. 2018, Boutaleb *et al*. 2019, Ebrahimi *et al*. 2019a, Soni *et al*. 2020). Nonlocal theory is also employed in obtaining size-dependent responses of properties other than mechanical ones. Coupled magnetic, thermal and elasticity responses in shape memory alloyed was investigated by Lata and Singh (2021, 2022)

In investigating the mechanical properties of CNTs, the classical continuum based modeling has also been adopted by many researchers (Liu *et al*. 2020a, Wang *et al*. 2020, Zhou *et al*. 2020, Dai *et al*. 2021a, Guo *et al*. 2021a, Shao *et al*. 2021, Wu and Habibi 2021, Kong *et al*. 2022). Employing classical theory of elasticity instead of atomic simulation, some complicated mechanical behavior such as vibrations and buckling of CNTs can be studied (Shariati *et al*. 2012, 2016a, b, Shariati *et al*. 2019, 2020d, e, f, g, h, i, j, 2021a, b, Fan *et al*. 2022, Luo *et al*. 2022b, Wang *et al*. 2022a, Xia *et al*. 2022). Another virtue of employing the classical theory of elasticity is that it has less computational costs than the atomic simulations. However, the classical continuum modeling cannot reflect the size dependency of properties in nano materials. In the constitutive equation of the classical continuum theory, the stress is assumed a function of the local strain, so nonlocal effects and size parameters are not observed in the equations of the classical elasticity theory. Nonlocal theory of elasticity (Eringen 1972) incorporating an internal length scale parameter into the constitutive equation, presents size-dependent mechanical properties in nano materials (Chaht *et al*. 2015, Zenkour and Abouelregal 2015, Lata and Singh 2019, Pham *et al*. 2021). Pisano and Fuschi (2003) presented a nonlocal formulation for a bar under uniaxial tension and their results indicated a non-uniform strain distribution in the bar. Failla *et al*. (2010) used approximate methods in order to obtain strain, displacement and strain energy in a nonlocal bar under uniaxial tension. After (Peddieson *et al*. 2003), the size dependent nonlocal theory of elasticity has been widely used in predicting mechanical behavior of nanomaterials. They formulated the deflection equation of a nonlocal Bernoulli-Euler beam, and showed that based on the nonlocal elasticity theory, the nonlocal effect manifest itself in the nano-scale devices. Sudak (2003) investigated the buckling of a multiwall carbon nanotube (MWCNT) using nonlocal elasticity theory. In the analysis, each individual CNT is modeled as a column and the buckling of the MWCNT is investigated by considering the interaction between adjacent CNTs as van der Walls interaction. The results demonstrated that the critical load of buckling is highly dependent on the scale parameter. In these studies, the results of the nonlocal elasticity are more conservative than those of the classical elasticity. Wang *et al*. (2006) investigated buckling of CNTs using both nonlocal column and shell models. In the nonlocal shell model, the critical load is found to be function of diameter as well as length of the CNT, where the column model cannot reflect the dependency of critical load on the diameter. Zhang *et al*. (2005) investigated free vibrations of DWCNT using nonlocal elasticity theory. Each CNT was modeled as a nonlocal beam and the interaction between two CNT is modeled as spring with a specific coefficient. They concluded that the classical theory of elasticity could overestimate the amount of the natural frequencies.

In nanocomposite materials, which are frequently reinforced with CNTs and other nanostructures, elasticity parameters are usually considered as constants (Bellal *et al*. 2020, Matouk *et al*. 2020, Rouabhia *et al*. 2020, Bouafia *et al*. 2021, Heidari *et al*. 2021, Kumar *et al*. 2021, Van Vinh and Tounsi 2021, Bendaida *et al*. 2022). However, a size dependent properties are more desirable in this context. Using embedded size-dependent theories in analyzing nanocomposite puts extra computational costs in calculation which could be easily avoided using approximate or exact closed-form relations (Al-Furjan *et al*. 2020h, i, 2021, Bendenia *et al*. 2020, Arshid *et al*. 2021, Huang *et al*. 2021d, Zerrouki *et al*. 2021). On the other hand, in chemical production of nanostructures, it is barely possible to control size of each nanostructure (Al-Furjan *et al*. 2020g, Bourada *et al*. 2020, Bousahla Abdelmoumen *et al*. 2020, Asgharnejad Lamraski *et al*. 2022, Moradi *et al*. 2022a, b, Vatanpour *et al*. 2022a, b). Moreover, novel methods of evaluating size and effects of nanostructures and nanoparticles are commonly relies on statistical approximations (Lingamdinne *et al*. 2023). Using numerical methods like finite element has its own drawbacks in terms of computational, accuracy and modeling time (Amelirad and Assempour 2019, 2021).

In this paper, the dependency of Young modulus of elasticity of CNTs on length is investigated via nonlocal elasticity theory. The exact size dependency of CNTs are often calculated from molecular dynamics simulation. However, in practical problems, like composite structures, a closed form relation is required to reduce computational costs. Specifically, in mass production of CNTs, length control of CNTs are very complicated. The closed form relation could be used in statistical analyses as well as simulating a portion of nanocomposites with limited number of CNTs. In this way, the nonlocal bar model is employed and a uniaxial tension is applied to two ends of the bar. A specific version of nonlocal constitutive equation is employed in order to calculate the nonuniform strain distribution along the length of the CNT. The governing equation of the nonlocal bar turns out to be a Volttera integral equation that is solved using analytical methods. Finally, The Young modulus of CNT is calculated by dividing the applied stress by the average amount of strain in the bar. The effects of the nonlocal parameters are studied and results are compared with the results of molecular dynamics based finite elements method.

2. Nonlocal theory of elasticity

Nonlocal theory of elasticity is one the theories that take into account the effects of the size in the mechanical properties (Ma *et al*. 2022, Zhao *et al*. 2022, Hou *et al*. 2021, Huang *et al*. 2021b, c, Jiao *et al*. 2021, Liu *et al*. 2021c, Moradi *et al*. 2021, Xu *et al*. 2021, Dong *et al*. 2022, Fan *et al*. 2022, Luo *et al*. 2022a, Luo *et al*. 2022b, Michael *et al*. 2022, Wang *et al*. 2022b, c, Yang *et al*. 2022a, b, Yu *et al*. 2022, Zheng *et al*. 2022, Zhu *et al*. 2022). The essence of incorporating size effects in the mechanical properties is that the stress at a point of the material is considered to be affected by not only the local strain but also the nonlocal strain field. The influence of the nonlocal strain is imposed on the stress by employing an attenuation function. In this way, strain at farther points (compared to internal characteristic length) has less influence on the stress than strain at the points near the reference point. The constitutive equation of a nonlocal linear homogenous elastic solid is given as follows:

$$\sigma_{ij}(\boldsymbol{x}) = \int_{\Omega} \alpha(|\boldsymbol{x} - \boldsymbol{x}'|) C_{ijkl} \varepsilon_{kl}(\boldsymbol{x}')\, d\Omega(\boldsymbol{x}') \tag{1}$$

where σ_{ij} are the nonlocal stress components, and ε_{ij} are the strain components for infinitesimal displacement components, and they are defined by the following equation:

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial X_j} + \frac{\partial u_j}{\partial X_i}\right) \tag{2}$$

where u_i are the displacement vector components. The fourth order tensor C_{ijkl} is the elasticity tensor of the classical elasticity (Fan *et al*. 2022, Luo *et al*. 2022b, Wang *et al*. 2022a, Xia *et al*. 2022).

As mentioned above, the influence of the nonlocal strain on the stress at point $\boldsymbol{x}$ is incorporated by an attenuation function $\alpha(|\boldsymbol{x} - \boldsymbol{x}'|)$. The attenuation function $\alpha(|\boldsymbol{x} - \boldsymbol{x}'|)$ is a positive scalar function of the Euclidean distance between point $\boldsymbol{x}'$ and the reference point $\boldsymbol{x}$. When the Euclidean distance is very large compared to internal length $|\boldsymbol{x} - \boldsymbol{x}'| \to \infty$ the attenuation function vanishes $\alpha \to 0$. However, in practice, the influence of nonlocal strain after an specific distance, called influence distance, vanishes, so that the attenuation function after that distance become $\alpha(|\boldsymbol{x} - \boldsymbol{x}'|) \simeq 0$ (Polizzotto 2001). For small distances, the value of the attenuation function α is considerable whereas at large distances the nonlocality effects substantially decrease. The influence distance is characterized by the internal characteristic length, and it is in the same order of the internal characteristic length. It is expected when the influence distance vanishes so that only local strain takes into account, the constitutive Eq. (1) become the local form of:

$$\sigma_{ij}(\boldsymbol{x}) = C_{ijkl} \varepsilon_{kl}(\boldsymbol{x}) \tag{3}$$

The attenuation function should fulfill the following condition:

$$\int_{\Omega_\infty} \alpha(|\boldsymbol{x} - \boldsymbol{x}'|)\, d\Omega = 1 \tag{4}$$

The domain Ω_∞ is an infinite domain contain the Ω. There are some types of functions that can be employed for attenuation function (Eringen 2002):

$$\alpha(r) = A\, exp\left(1 - \frac{r}{l}\right) \tag{5}$$

$$\alpha(r) = A\left(1 - \frac{r^2}{l^2}\right) \tag{6}$$

$$\alpha(r) = A\left(1 - \frac{r}{l}\right) \tag{7}$$

where the constant $l$is related to the internal characteristic length and the constant Acan be calculated using Eq. (4). In this article, the following form of the attenuation function is used (Altan 1989):

$$\alpha(r) = \zeta_1 \delta(r) + \zeta_2 \bar{\alpha}(r) \tag{8}$$

that gives the following constitutive equation:

$$\begin{aligned}\sigma_{ij}(\mathbf{x}) &= \zeta_1 \mathrm{C}_{ijkl}\, \varepsilon_{kl}(\mathbf{x}) \\ &+ \zeta_2 \int_\Omega \bar{\alpha}(|\mathbf{x} - \mathbf{x}'|) \mathrm{C}_{ijkl}\, \varepsilon_{kl}(\mathbf{x}') d\Omega(\mathbf{x}')\end{aligned} \tag{9}$$

Two constants ζ_1 and ζ_2 are the positive material constants with the constraint $\zeta_1 + \zeta_2 = 1$. Indeed, using influence function of Eq. (8), the material is conceived to be a two phase material. The first phase with influence factor ζ_1 represents the local part of influence function and consequently, the local part of constitutive Eq. (9). The second phase with influence factor ζ_2 represents the nonlocal part of influence function and constitutive Eq. (9). Applying condition of Eq. (4), it can be easily seen that the same condition should be imposed on $\bar{\alpha}$, that is:

$$\int_{\Omega_\infty} \bar{\alpha}(|\boldsymbol{x} - \boldsymbol{x}'|)\, d\Omega = 1 \tag{10}$$

3. Nonlocal elastic bar in tension

In this section, we consider an SWCNT with length L under uniaxial tension, as shown in Fig. 1a. For simplicity, the CNT is modeled as a one-dimensional nonlocal bar in tension under applied stress $\bar{\sigma}$ (Fig. 1b), and one end of it is pinned at $(x = 0)$. From equilibrium of the bar, it is concluded that the internal stress of the CNT is uniform and equals the applied stress $\bar{\sigma}$. The one-dimensional form of Eqs. (9) and (2) is as Eqs. (11) and (12), respectively:

$$\sigma(x) = \zeta_1 E\varepsilon(x) + \zeta_2 \int_0^L \bar{\alpha}(|x - x'|)\, E\varepsilon(x')dx' \tag{11}$$

$$\varepsilon(x) = \frac{du}{dx} \tag{12}$$

where E is the Young modulus of the classical elasticity. For the one-dimensional bar in tension the stress $\sigma(x) = \bar{\sigma}$ and the strain in the bar is obtained from equation (11):

$$\varepsilon(x) = \frac{\bar{\sigma}}{\zeta_1 E} - \frac{\zeta_2}{\zeta_1}\int_0^L \bar{\alpha}(|x - x'|)\, \varepsilon(x')dx' \tag{13}$$

This equation is the Fredholm equation of the second kind and it is indicated that, despite the fact that the stress state in the CNT is uniform, the strain is not uniform in the CNT. A solution for this equation with following form for attenuation function $\bar{\alpha}$ is given by (Pisano and Fuschi 2003).

$$\bar{\alpha}(r) = A\, exp\left(-\frac{r}{l}\right) \tag{14}$$

And, the solution for Eq. (13) is given by the following equation (Pisano and Fuschi 2003):

$$\varepsilon(x) = \frac{\bar{\sigma}}{E}\left\{1 + \frac{\zeta_2}{4\zeta_1}\left[e^{-\frac{x}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} + e^{-\frac{L-x}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)}\right]\right\} \tag{15}$$

Using Eq. (15) and integrating Eq. (12) the displacement for each point is obtained:

$$u(x) = \frac{\bar{\sigma}L}{E}\left\{\begin{matrix}\frac{x}{L} - \frac{l}{L}\frac{\frac{\zeta_2}{2\zeta_1}}{2\left(\frac{\zeta_2}{2\zeta_1}+1\right)} \times \\ \left[e^{-\frac{x}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} - e^{-\frac{L-x}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} + e^{-\frac{L}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} - 1\right]\end{matrix}\right\} \tag{16}$$

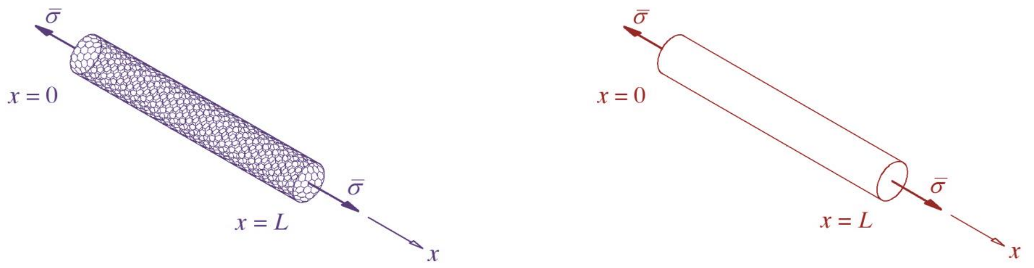
In order to calculate the Young modulus of the CNT, the applied stress is divided by the average strain inside the bar. The average strain of the CNT is obtained by following relation:

$$\begin{aligned}\varepsilon_{ave} &= \frac{1}{L}\int_0^L \varepsilon(x)dx = \frac{u(L)}{L} \\ &= \bar{\varepsilon}\left\{1 - \frac{l}{L}\frac{\zeta_2/2\zeta_1}{(\zeta_2/2\zeta_1+1)}\left[e^{-\frac{L}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} - 1\right]\right\}\end{aligned} \tag{17}$$

where the $\bar{\varepsilon}$ is the strain field produced with considering the classical constitutive equation that is $\bar{\varepsilon} = \bar{\sigma}/E$. Finally, the Young modulus of the CNT can be obtained as follows:

$$\frac{E^{nl}}{E} = \left\{1 - \frac{l}{L}\frac{\frac{\zeta_2}{2\zeta_1}}{\left(\frac{\zeta_2}{2\zeta_1}+1\right)}\left[e^{-\frac{L}{l}\left(\frac{\zeta_2}{2\zeta_1}+1\right)} - 1\right]\right\}^{-1} \tag{18}$$

where E^{nl} is the Young modulus of the CNT in the nonlocal elasticity theory. As seen, this equation gives the Young modulus of CNT as a function of the length of the CNT L. It can also be concluded that when $L/l >> 1$, the length of the CNT is larger than the characteristic length, the calculated Young modulus for nonlocal elasticity tends to become equal to the classical Young modulus.



(a) (b)

Fig. 1 (a) A CNT under uniaxial tension, (b) A bar model represented the CNT under uniaxial tension

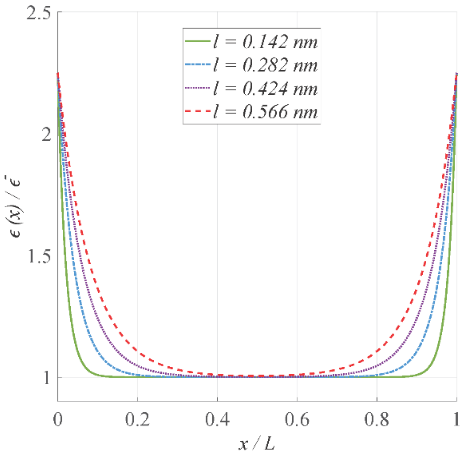


Fig. 2 Non-dimensional strain field in the CNT under uniaxial tension for $L = 5nm$, $\zeta_2/\zeta_1 = 5$, and various values of internal characteristic length l

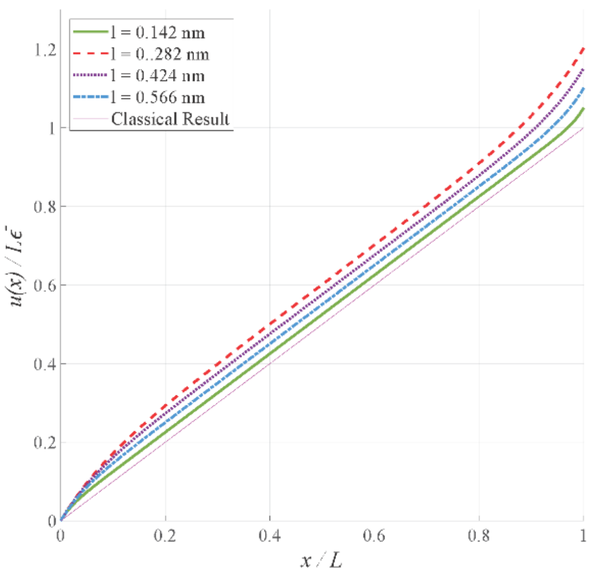


Fig. 3 Non-dimensional displacement along x-axis in the CNT under uniaxial tension for $L = 5nm$, $\zeta_2/\zeta_1 = 5$, and various values of internal characteristic length l

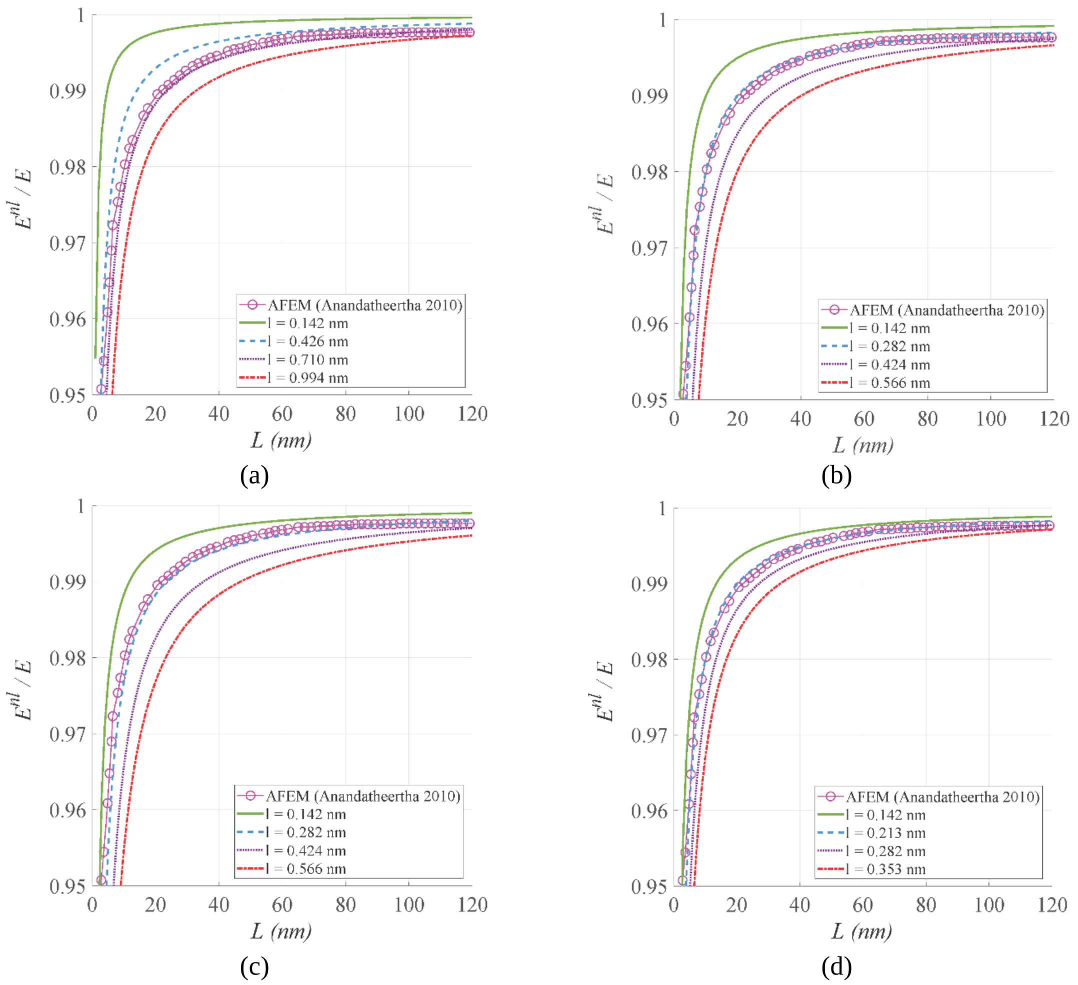


Fig. 4 Nondimensional Young modulus of the CNT under uniaxial tension as a function of length $L$for different values of internal characteristic length $l$and ζ_2/ζ_1, (a) $\zeta_2/\zeta_1 = 1$, (b) $\zeta_2/\zeta_1 = 5$, (c) $\zeta_2/\zeta_1 = 10$, (d) $\zeta_2/\zeta_1 = 50$

4. Numerical results and discussion

In this section, the numerical results of the nonlocal theory of elasticity for length dependent Young modulus of the CNT are presented. Eqs. (15) and (16) give the strain and displacement fields in the CNT as functions of the x, respectively, and they are shown in Figs. 2 and 3. As seen, at regions near the boundaries the nonlocal results differ significantly from the classical values. These differences near the boundaries are due to “boundary effects” that is discussed in details by (Pisano and Fuschi 2003). Briefly, at the region near the boundaries, the boundaries cut the influence distance and influence regions out of boundaries have no effect on the state inside the bar. On the other hand, at the region far from boundaries the all points of the influence region located inside the medium. Consequently, the strain and displacement behaviors at the boundary region are different from inside the bar. As seen in Fig. 3, the displacement at $x/L = 1$ in nonlocal results is greater than classical one that is the nonlocal elasticity predicts softer behavior for CNTs under uniaxial tension.

Eq. (18) gives the Young's modulus of the CNT as a function of CNT length. In figure through figure, the dependency of the Young modulus of the CNT on the length is presented. The results show that the Young modulus of the CNT is highly dependent on the length and its value increases with increasing the length, and it converges to the amount of Eindependently from the length, internal characteristic length and ζ_2/ζ_1. In these results, we omit to discuss on amount of the area of the CNT, and only the ratio of the Young modulus to its local value $E$is presented. The amount of Ecould be conceived as the Young modulus of a long CNT that was measured earlier (Yu *et al*. 2000).

As seen, the amount of non-dimensional Young's modulus of the CNT for length longer than 80 nm is independent of length. In fact, the results converges to the local elasticity theory which is indicates the applicability of the local theory of elasticity in large scales. On the over hand, in small lengths the results is highly dependent on the length, which demonstrate the role of nonlocality effects in the small scales. It should be mentioned that the internal characteristic length and the volume ratio are the material characteristics and their values are constant for a specific material. Because of lack of information on the exact values for these constants in CNTs, the different values presented here for internal characteristic length and ζ_2/ζ_1 in order to compare the current results with the result of the molecular dynamics based finite elements method (Anandatheertha *et al*. 2010). As seen in the figures, for some proper pair of the internal characteristic length and ζ_2/ζ_1, the results of the nonlocal theory overlap with the result of the molecular dynamics based finite elements method.

5. Conclusions

Based on earlier experiments and simulations the mechanical properties of nanomaterials such as carbon nanotubes are strongly dependent on length scales. The classical elasticity theory, because of its intrinsic nature, cannot present a size dependent result. In this paper, using nonlocal theory of elasticity, dependency of Young elasticity modulus of CNT on the length was investigated. The size exact size dependent of CNTs are often calculated from molecular dynamics simulation. However, in practical problems, like composite structures, a closed form relation is required to reduce computational costs. In practical application of mass production of CNTs, length control of CNTs are very complicated. The closed form relation in this applications could be useful in statistical analyses as well as simulating a portion of nanocomposites with limited number of CNTs. The CNT was modeled as a nonlocal uniform bar in tension. The nonlocal theory of elasticity was presented and applied to formulate the one dimensional stress-strain relation inside the CNT. Using an analytical solution of the equation obtained for the strain filed in the CNT, a closed form relation was obtained for the Young modulus. The results show that the state of strain and displacement at the regions near boundaries of the bar in the nonlocal theory of elasticity are different significantly from classical ones so that these differences result in prediction of softer behavior for CNTs in the nonlocal theory. However, in the regions far from the boundaries, strain and displacement behaviors are similar to the classical ones. The amount of differences are dependent on the length of the CNT. From the stain field, it is determined that the Young modulus of CNTs are highly dependent on the length, and this dependency is such that by increasing the length of the CNT the Young modulus increased so that for the long lengths (greater than 80 nm) the Young modulus, independent of length and nonlocal parameters, converges to a special amount. It can be concluded that from the nonlocal elasticity view point, the variation of Young modulus of CNTs are primarily due to the "boundary effects". The agreement of the nonlocal elasticity results with molecular dynamics based finite element method for, show that the nonlocal elasticity theory has a good potential in analyzing mechanical behavior of CNTs.

References

Adamian, A., Safari, K.H., Sheikholeslami, M., Habibi, M., Al-Furjan, M. and Chen, G. (2020), "Critical temperature and frequency characteristics of gpls-reinforced composite doubly curved panel", *Appl. Sci.*, **10**(9), 3251. https://doi.org/10.3390/app10093251.

Al-Furjan, M., Dehini, R., Khorami, M., Habibi, M. and won Jung, D. (2020a), "On the dynamics of the ultra-fast rotating cantilever orthotropic piezoelectric nanodisk based on nonlocal strain gradient theory", *Compos. Struct.*, 112990. https://doi.org/10.1016/j.compstruct.2020.112990.

Al-Furjan, M., Fereidouni, M., Habibi, M., Abd Ali, R., Ni, J. and Safarpour, M. (2020b), "Influence of in-plane loading on the vibrations of the fully symmetric mechanical systems via dynamic simulation and generalized differential quadrature framework", *Eng. Comput.*, 1-23. https://doi.org/10.1007/s00366-020-01177-7.

Al-Furjan, M., Fereidouni, M., Sedghiyan, D., Habibi, M. and won Jung, D. (2020c), "Three-dimensional frequency response of the CNT-Carbon-Fiber reinforced laminated circular/annular plates under initially stresses", *Compos. Struct.*, 113146. https://doi.org/10.1016/j.compstruct.2020.113146.

Al-Furjan, M., Habibi, M., won Jung, D. and Safarpour, H. (2020d), "Vibrational characteristics of a higher-order laminated composite viscoelastic annular microplate via modified couple stress theory", *Compos. Struct.*, 113152. https://doi.org/10.1016/j.compstruct.2020.113152.

Al-Furjan, M., Moghadam, S.A., Dehini, R., Shan, L., Habibi, M. and Safarpour, H. (2020e), "Vibration control of a smart shell reinforced by graphene nanoplatelets under external load: Semi-numerical and finite element modeling", *Thin Wall. Struct.*, 107242. https://doi.org/10.1016/j.tws.2020.107242.

Al-Furjan, M., Oyarhossein, M.A., Habibi, M., Safarpour, H. and Jung, D.W. (2020f), "Frequency and critical angular velocity characteristics of rotary laminated cantilever microdisk via two-dimensional analysis", *Thin Wall. Struct.*, **157**, 107111. https://doi.org/10.1016/j.tws.2020.107111.

Al-Furjan, M.S.H., Habibi, M., Jung, D.w., Sadeghi, S., Safarpour, H., Tounsi, A. and Chen, G. (2020g), "A computational framework for propagated waves in a sandwich doubly curved nanocomposite panel", *Eng. Comput.*, **38**(2), 1679-1696. https://doi.org/10.1007/s00366-020-01130-8.

Al-Furjan, M.S.H., Habibi, M., Ni, J., Jung, D.w. and Tounsi, A. (2020h), "Frequency simulation of viscoelastic multi-phase reinforced fully symmetric systems", *Eng. Comput.*, 1-17. https://doi.org/10.1007/s00366-020-01200-x.

Al-Furjan, M.S.H., Habibi, M., rahimi, A., Chen, G., Safarpour, H., Safarpour, M. and Tounsi, A. (2020i), "Chaotic simulation of the multi-phase reinforced thermo-elastic disk using GDQM", *Eng. Comput.*, 1-24. https://doi.org/10.1007/s00366-020-01144-2.

Al-Furjan, M.S.H., hatami, A., Habibi, M., Shan, L. and Tounsi, A. (2021), "On the vibrations of the imperfect sandwich higher-order disk with a lactic core using generalize differential quadrature method", *Compos. Struct.*, **257**, 113150. https://doi.org/10.1016/j.compstruct.2020.113150.

Alipour, M., Torabi, M.A., Sareban, M., Lashini, H., Sadeghi, E., Fazaeli, A., Habibi, M. and Hashemi, R. (2020), "Finite element and experimental method for analyzing the effects of martensite morphologies on the formability of DP steels", *Mech. Based Des. Struct.*, **48**(5), 525-541. https://doi.org/10.1080/15397734.2019.1633343.

Altan, S.B. (1989), "Uniqueness of initial-boundary value problems in nonlocal elasticity", *Int. J. Solid Struct.*, 25(11), 1271-1278. https://doi.org/10.1016/0020-7683(89)90091-7.

Amelirad, O. and Assempour, A. (2019), "Experimental and crystal plasticity evaluation of grain size effect on formability of austenitic stainless steel sheets", *J. Manuf. Proc.*, **47**, 310-323. https://doi.org/10.1016/j.jmapro.2019.09.035.

Amelirad, O. and Assempour, A. (2021), "Coupled continuum damage mechanics and crystal plasticity model and its application in damage evolution in polycrystalline aggregates", *Eng. Comput.*, 1-15. https://doi.org/10.1007/s00366-021-01346-2.

Anandatheertha, S., Naik, G.N., Gopalakrishnan, S. and Rao, P.S. (2010), "High accuracy curve fits for chirality, length and diameter dependent initial modulus of single walled carbon nanotubes", *Physica E*, **43**(1), 252-255.

Arshid, E., Khorasani, M., Soleimani-Javid, Z., Amir, S. and Tounsi, A. (2021), "Porosity-dependent vibration analysis of FG microplates embedded by polymeric nanocomposite patches considering hygrothermal effect via an innovative plate theory", *Eng. Comput.*, 1-22. https://doi.org/10.1007/s00366-021-01382-y.

Asgharnejad Lamraski, M.B., Naikoo, G.A., Zamani Pedram, M., Sohani, A., Hoseinzadeh, S. and Moradi, H. (2022), "Thermodynamic modeling of several alcohol-hydrocarbon binary mixtures at low to moderate conditions", *J. Mol. Liq.*, **346**, 117924. https://doi.org/10.1016/j.molliq.2021.117924.

Aydogdu, M., Arda, M. and Filiz, S. (2018), "Vibration of axially functionally graded nano rods and beams with a variable nonlocal parameter", *Adv. Nano Res.*, **6**(3), 257. https://doi.org/10.12989/anr.2018.6.3.257.

Bai, Y., Alzahrani, B., Baharom, S. and Habibi, M. (2020), "Semi-numerical simulation for vibrational responses of the viscoelastic imperfect annular system with honeycomb core under residual pressure", *Eng. Comput.*, 1-26. https://doi.org/10.1007/s00366-020-01191-9.

Bellal, M., Hebali, H., Heireche, H., Bousahla, A.A., Tounsi, A., Bourada, F., Mahmoud, S., Bedia, E. and Tounsi, A. (2020), "Buckling behavior of a single-layered graphene sheet resting on viscoelastic medium via nonlocal four-unknown integral model", *Steel Compos. Struct.*, **34**(5), 643-655. https://doi.org/10.12989/scs.2020.34.5.643.

Bendaida, M., Bousahla, A.A., Mouffoki, A., Heireche, H., Bourada, F., Tounsi, A., Benachour, A., Tounsi, A. and Hussain, M. (2022), "Dynamic properties of nonlocal temperature-dependent fg nanobeams under various thermal environments", *Transp. Porous Med.*, **142**(1), 187-208. https://doi.org/10.1007/s11242-021-01666-3.

Bendenia, N., Zidour, M., Bousahla Abdelmoumen, A., Bourada, F., Tounsi, A., Benrahou Kouider, H., Bedia, E.A.A., Mahmoud, S.R. and Tounsi, A. (2020), "Deflections, stresses and free vibration studies of FG-CNT reinforced sandwich plates resting on Pasternak elastic foundation", *Comput. Concr.*, **26**(3), 213-226. https://doi.org/10.12989/CAC.2020.26.3.213.

Bouafia, H., Chikh, A., Bousahla, A.A., Bourada, F., Heireche, H., Tounsi, A., Benrahou, K.H., Tounsi, A., Al-Zahrani, M.M. and Hussain, M. (2021), "Natural frequencies of FGM nanoplates embedded in an elastic medium", *Adv. Nano Res.*, **11**(3), 239-249. https://doi.org/10.12989/anr.2021.11.3.239.

Bourada, F., Bousahla Abdelmoumen, A., Tounsi, A., Bedia, E.A.A., Mahmoud, S.R., Benrahou Kouider, H. and Tounsi, A. (2020), "Stability and dynamic analyses of SW-CNT reinforced concrete beam resting on elastic-foundation", *Comput. Concr.*, **25**(6), 485-495. https://doi.org/10.12989/CAC.2020.25.6.485.

Bousahla Abdelmoumen, A., Bourada, F., Mahmoud, S.R., Tounsi, A., Algarni, A., Bedia, E.A.A. and Tounsi, A. (2020), "Buckling and dynamic behavior of the simply supported CNT-RC beams using an integral-first shear deformation theory", *Comput. Concr.*, **25**(2), 155-166. https://doi.org/10.12989/CAC.2020.25.2.155.

Boutaleb, S., Benrahou, K.H., Bakora, A., Algarni, A., Bousahla, A.A., Tounsi, A., Tounsi, A. and Mahmoud, S. (2019), "Dynamic analysis of nanosize FG rectangular plates based on simple nonlocal quasi 3D HSDT", *Adv. Nano Res.*, **7**(3), 191. https://doi.org/10.12989/anr.2019.7.3.191

Chaht, F.L., Kaci, A., Houari, M.S.A., Tounsi, A., Bég, O.A. and Mahmoud, S. (2015), "Bending and buckling analyses of functionally graded material (FGM) size-dependent nanoscale beams including the thickness stretching effect", *Steel Compos. Struct.*, **18**(2), 425-442. https://doi.org/10.12989/scs.2015.18.2.425.

Chang, T. and Gao, H. (2003), "Size-dependent elastic properties of a single-walled carbon nanotube via a molecular mechanics model", *J. Mech. Phys. Solids*, **51**(6), 1059-1074 10.1016/s0022-5096(03)00006-1.

Chen, F., Chen, J., Duan, R., Habibi, M. and Khadimallah, M.A. (2022), "Investigation on dynamic stability and aeroelastic characteristics of composite curved pipes with any yawed angle", *Compos*. *Struct*., 115195. https://doi.org/10.1016/j.compstruct.2022.115195.

Cheshmeh, E., Karbon, M., Eyvazian, A., Jung, D.w., Habibi, M. and Safarpour, M. (2020), "Buckling and vibration analysis of FG-CNTRC plate subjected to thermo-mechanical load based on higher order shear deformation theory", *Mech*. *Based Des*. *Struct*., 1-24. https://doi.org/10.1080/15397734.2020.1744005.

Dai, Z., Jiang, Z., Zhang, L. and Habibi, M. (2021a), "Frequency characteristics and sensitivity analysis of a size-dependent laminated nanoshell", *Adv*. *Nano Res*., **10**(2), 175-189. https://doi.org/10.12989/anr.2021.10.2.175.

Dai, Z., Zhang, L., Bolandi, S.Y. and Habibi, M. (2021b), "On the vibrations of the non-polynomial viscoelastic composite open-type shell under residual stresses", *Compos*. *Struct*., 113599. https://doi.org/10.1016/j.compstruct.2021.113599.

Dong, Y., Gao, Y., Zhu, Q., Moradi, Z. and Safa, M. (2022), "TE-GDQE implementation to investigate the vibration of FG composite conical shells considering a frequency controller solid ring", *Eng*. *Anal*. *Bound*. *Elem*., **138**, 95-107. https://doi.org/10.1016/j.enganabound.2022.01.017.

Ebrahimi, F., Dabbagh, A., Rabczuk, T. and Tornabene, F. (2019a), "Analysis of propagation characteristics of elastic waves in heterogeneous nanobeams employing a new two-step porosity-dependent homogenization scheme", *Adv*. *Nano Res*., **7**(2), 135. https://doi.org/10.12989/anr.2019.7.2.135.

Ebrahimi, F., Habibi, M. and Safarpour, H. (2019b), "On modeling of wave propagation in a thermally affected GNP-reinforced imperfect nanocomposite shell", *Eng*. *Comput*., **35**(4), 1375-1389. https://doi.org/10.1007/s00366-018-0669-4.

Ebrahimi, F., Hajilak, Z.E., Habibi, M. and Safarpour, H. (2019c), "Buckling and vibration characteristics of a carbon nanotube-reinforced spinning cantilever cylindrical 3D shell conveying viscous fluid flow and carrying spring-mass systems under various temperature distributions", *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, **233**(13), 4590-4605. https://doi.org/10.1177/0954406219832323.

Ebrahimi, F., Hashemabadi, D., Habibi, M. and Safarpour, H. (2020a), "Thermal buckling and forced vibration characteristics of a porous GNP reinforced nanocomposite cylindrical shell", *Microsyst*. *Technol*., **26**(2), 461-473. https://doi.org/10.1007/s00542-019-04542-9.

Ebrahimi, F., Mohammadi, K., Barouti, M.M. and Habibi, M. (2019d), "Wave propagation analysis of a spinning porous graphene nanoplatelet-reinforced nanoshell", *Wave Random Complex Med*., 1-27. https://doi.org/10.1080/17455030.2019.1694729.

Ebrahimi, F., Supeni, E.E.B., Habibi, M. and Safarpour, H. (2020b), "Frequency characteristics of a GPL-reinforced composite microdisk coupled with a piezoelectric layer", *Eur*. *Phys*. *J*. *Plus*, **135**(2), 144. https://doi.org/10.1140/epjp/s13360-020-00217-x.

Eringen, A.C. (1972), "Linear theory of nonlocal elasticity and dispersion of plane waves", *Int*. *J*. *Eng*. *Sci*., **10**(5), 425-435. https://doi.org/10.1016/0020-7225(72)90050-x.

Eringen, A.C. (2002), *Nonlocal continuum field theory*, Springer-Verlag, New York, U.S.A.

Esmailpoor Hajilak, Z., Pourghader, J., Hashemabadi, D., Sharifi Bagh, F., Habibi, M. and Safarpour, H. (2019), "Multilayer GPLRC composite cylindrical nanoshell using modified strain gradient theory", *Mech*. *Based Des*. *Struct*., **47**(5), 521-545. https://doi.org/10.1080/15397734.2019.1566743.

Failla, G., Santini, A. and Zingales, M. (2010), "Solution strategies for 1D elastic continuum with long-range interactions: Smooth and fractional decay", *Mech*. *Res*. *Commun*., **37**(1), 13-21. https://doi.org/10.1016/j.mechrescom.2009.09.006.

Fan, L., Huang, Y., Ji, D., Moradi, Z., Safa, M. and Amine Khadimallah, M. (2022), "Interaction of angular velocity and temperature rise in the thermo-inertia bifurcation buckling of FG laminated nanocomposite annular plates", *Eng*. *Struct*., **265**, 114518. https://doi.org/10.1016/j.engstruct.2022.114518.

Fazaeli, A., Habibi, M. and Ekrami, A.a. (2016), "Experimental and finite element comparison of mechanical properties and formability of dual phase steel and ferrite - pearlite steel with the same chemical composition", *Metall*. *Eng*., **19**(2), 84-93. https://doi.org/10.22076/me.2017.41458.1064.

Ghazanfari, A., Soleimani, S.S., Keshavarzzadeh, M., Habibi, M., Assempuor, A. and Hashemi, R. (2020), "Prediction of FLD for sheet metal by considering through-thickness shear stresses", *Mech. Based Des. Struct.*, 48(6), 755-772. https://doi.org/10.1080/15397734.2019.1662310.

Guo, J., Baharvand, A., Tazeddinova, D., Habibi, M., Safarpour, H., Roco-Videla, A. and Selmi, A. (2021a), "An intelligent computer method for vibration responses of the spinning multi-layer symmetric nanosystem using multi-physics modeling", *Eng. Comput.*, 1-22. https://doi.org/10.1007/s00366-021-01433-4.

Guo, Y., Mi, H. and Habibi, M. (2021b), "Electromechanical energy absorption, resonance frequency, and low-velocity impact analysis of the piezoelectric doubly curved system", *Mech. Syst. Signal Proc.*, **157**, 107723. https://doi.org/10.1016/j.ymssp.2021.107723.

Habibi, M., Darabi, R., Sa, J.C.d. and Reis, A. (2021), "An innovation in finite element simulation via crystal plasticity assessment of grain morphology effect on sheet metal formability", *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, **235**(8), 1937-1951. https://doi.org/10.1177/14644207211024686.

Habibi, M., Ghazanfari, A., Assempour, A., Naghdabadi, R. and Hashemi, R. (2017), "Determination of forming limit diagram using two modified finite element models", *Mech. Eng.*, **48**(4), 141-144. https://doi.org/10.22060/MEJ.2016.664.

Habibi, M., Hashemabadi, D. and Safarpour, H. (2019a), "Vibration analysis of a high-speed rotating GPLRC nanostructure coupled with a piezoelectric actuator", *Eur. Phys. J. Plus*, **134**(6), 307. https://doi.org/10.1140/epjp/i2019-12742-7.

Habibi, M., Hashemi, R., Ghazanfari, A., Naghdabadi, R. and Assempour, A. (2018a), "Forming limit diagrams by including the M–K model in finite element simulation considering the effect of bending", *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, **232**(8), 625-636. https://doi.org/10.1177/1464420716642258.

Habibi, M., Hashemi, R., Sadeghi, E., Fazaeli, A., Ghazanfari, A. and Lashini, H. (2016), "Enhancing the mechanical properties and formability of low carbon steel with dual-phase microstructures", *J. Mater. Eng. Perform.*, **25**(2), 382-389.

Habibi, M., Hashemi, R., Tafti, M.F. and Assempour, A. (2018b), "Experimental investigation of mechanical properties, formability and forming limit diagrams for tailor-welded blanks produced by friction stir welding", *J. Manuf. Proc.*, **31**, 310-323. https://doi.org/10.1016/j.jmapro.2017.11.009.

Habibi, M., Mohammadgholiha, M. and Safarpour, H. (2019b), "Wave propagation characteristics of the electrically GNP-reinforced nanocomposite cylindrical shell", *J. Brazil. Soc. Mech. Sci. Eng.*, **41**(5), 221. https://doi.org/10.1007/s40430-019-1715-x.

Habibi, M., Mohammadi, A., Safarpour, H. and Ghadiri, M. (2019c), "Effect of porosity on buckling and vibrational characteristics of the imperfect GPLRC composite nanoshell", *Mech. Based Des. Struct.*, 1-30. https://doi.org/10.1080/15397734.2019.1701490.

Habibi, M., Mohammadi, A., Safarpour, H., Shavalipour, A. and Ghadiri, M. (2019d), "Wave propagation analysis of the laminated cylindrical nanoshell coupled with a piezoelectric actuator", *Mech. Based Des. Struct.*, 1-19. https://doi.org/10.1080/15397734.2019.1697932.

Habibi, M., Safarpour, M. and Safarpour, H. (2020), "Vibrational characteristics of a FG-GPLRC viscoelastic thick annular plate using fourth-order Runge-Kutta and GDQ methods", *Mech. Based Des. Struct.*, 1-22. https://doi.org/10.1080/15397734.2020.1779086.

Habibi, M., Taghdir, A. and Safarpour, H. (2019e), "Stability analysis of an electrically cylindrical nanoshell reinforced with graphene nanoplatelets", J. Brazil. Soc. Mech. Sci. Eng., **175**, 107125. https://doi.org/10.1016/j.compositesb.2019.107125.

Hashemi, H.R., Alizadeh, A.a., Oyarhossein, M.A., Shavalipour, A., Makkiabadi, M. and Habibi, M. (2019), "Influence of imperfection on amplitude and resonance frequency of a reinforcement compositionally graded nanostructure", *Wave Random Complex Med.*, 1-27. https://doi.org/10.1080/17455030.2019.1662968.

Heidari, F., Taheri, K., Sheybani, M., Janghorban, M. and Tounsi, A. (2021), "On the mechanics of nanocomposites reinforced by wavy/defected/aggregated nanotubes", *Steel Compos. Struct.*, **38**(5), 533-545. https://doi.org/10.12989/SCS.2021.38.5.533.

Hosseini, M., Gorgani, H.H., Shishesaz, M. and Hadi, A. (2017), "Size-dependent stress analysis of single-wall carbon nanotube based on strain gradient theory", *Int. J. Appl. Mech.*, **9**(6), 1750087. https://doi.org/10.1142/s1758825117500879.

Hosseini, M., Hadi, A., Malekshahi, A. and Shishesaz, M. (2018), "A review of size-dependent elasticity for nanostructures", Journal of Computational Applied Mechanics. 49(1), 197-211.

Hou, F., Wu, S., Moradi, Z. and Shafiei, N. (2021), "The computational modeling for the static analysis of axially functionally graded micro-cylindrical imperfect beam applying the computer simulation", *Eng. Comput.*, 1-19. https://doi.org/10.1007/s00366-021-01456-x.

Huang, X., Hao, H., Oslub, K., Habibi, M. and Tounsi, A. (2021a), "Dynamic stability/instability simulation of the rotary size-dependent functionally graded microsystem", *Eng. Comput.*, 1-17. https://doi.org/10.1007/s00366-021-01399-3.

Huang, X., Zhang, Y., Moradi, Z. and Shafiei, N. (2021b), "Computer simulation via a couple of homotopy perturbation methods and the generalized differential quadrature method for nonlinear vibration of functionally graded non-uniform micro-tube", *Eng. Comput.*, 1-18. https://doi.org/10.1007/s00366-021-01395-7.

Huang, X., Zhu, Y., Vafaei, P., Moradi, Z. and Davoudi, M. (2021c), "An iterative simulation algorithm for large oscillation of the applicable 2D-electrical system on a complex nonlinear substrate", *Eng. Comput.*, 1-13. https://doi.org/10.1007/s00366-021-01320-y.

Huang, Y., Karami, B., Shahsavari, D. and Tounsi, A. (2021d), "Static stability analysis of carbon nanotube reinforced polymeric composite doubly curved micro-shell panels", *Arch. Civil Mech. Eng.*, **21**(4), 139. https://doi.org/10.1007/s43452-021-00291-7.

Jiao, J., Ghoreishi, S.-m., Moradi, Z. and Oslub, K. (2021), "Coupled particle swarm optimization method with genetic algorithm for the static–dynamic performance of the magneto-electro-elastic nanosystem", *Eng. Comput.*, 1-15. https://doi.org/10.1007/s00366-021-01391-x.

Kong, F., Dong, F., Duan, M., Habibi, M., Safarpour, H. and Tounsi, A. (2022), "On the vibrations of the Electrorheological sandwich disk with composite face sheets considering pre and post-yield regions", *Thin Wall. Struct.*, **179**, 109631. https://doi.org/10.1016/j.tws.2022.109631.

Kumar, Y., Gupta, A. and Tounsi, A. (2021), "Size-dependent vibration response of porous graded nanostructure with FEM and nonlocal continuum model", *Adv. Nano Res.*, **11**(1), 1-17. https://doi.org/10.12989/anr.2021.11.1.001.

Lata, P. and Singh, S. (2019), "Effect of nonlocal parameter on nonlocal thermoelastic solid due to inclined load", *Steel Compos. Struct.*, **33**(1), 123-131. https://doi.org/10.12989/scs.2019.33.1.123.

Lata, P. and Singh, S. (2021), "Effects due to two temperature and hall current in a nonlocal isotropic magneto-thermoelastic solid with memory dependent derivatives", *Coupled Syst. Mech.*, **10**(4), 351-369. https://doi.org/10.12989/csm.2021.10.4.351.

Lata, P. and Singh, S. (2022), "Rayleigh wave propagation in a nonlocal isotropic magneto-thermoelastic solid with multi-dual-phase lag heat transfer", *Int. J. Geomath.*, **13**(1), 5 https://doi.org/10.1007/s13137-022-00195-5.

Lee, K., Lukić, B., Magrez, A., Seo, J.W., Briggs, G.A.D., Kulik, A.J. and Forró, L. (2007), "Diameter-dependent elastic modulus supports the metastable-catalyst growth of carbon nanotubes", *Nano Lett.*, **7**(6), 1598-1602. https://doi.org/10.1021/nl070502b.

Li, C. and Chou, T.-W. (2003), "A structural mechanics approach for the analysis of carbon nanotubes", *Int. J. Solid Struct.*, **40**, 2487-2499. https://doi.org/10.1016/S0020-7683(03)00056-8.

Li, J., Tang, F. and Habibi, M. (2020a), "Bi-directional thermal buckling and resonance frequency characteristics of a GNP-reinforced composite nanostructure", *Eng. Comput.*, 1-22. https://doi.org/10.1007/s00366-020-01110-y.

Li, Y., Li, S., Guo, K., Fang, X. and Habibi, M. (2020b), "On the modeling of bending responses of graphene-reinforced higher order annular plate via two-dimensional continuum mechanics approach", *Eng. Comput.*, 1-22. https://doi.org/10.1007/s00366-020-01166-w.

Lingamdinne, L.P., Amelirad, O., Koduru, J.R., Karri, R.R., Chang, Y.-Y., Dehghani, M.H. and Mubarak, N.M. (2023), "Functionalized bentonite for removal of Pb(II) and As(V) from surface water: Predicting capability and mechanism using artificial neural network", *J. Water Proc. Eng.*, **51**, 103386. https://doi.org/10.1016/j.jwpe.2022.103386.

Liu, H., Shen, S., Oslub, K., Habibi, M. and Safarpour, H. (2021a), "Amplitude motion and frequency simulation of a composite viscoelastic microsystem within modified couple stress elasticity", *Eng. Comput.*, 1-15. https://doi.org/10.1007/s00366-021-01316-8.

Liu, H., Zhao, Y., Pishbin, M., Habibi, M., Bashir, M. and Issakhov, A. (2021b), "A comprehensive mathematical simulation of the composite size-dependent rotary 3D microsystem via two-dimensional generalized differential quadrature method", *Eng. Comput.*, 1-16. https://doi.org/10.1007/s00366-021-01419-2.

Liu, Y., Wang, W., He, T., Moradi, Z. and Larco Benítez, M.A. (2021c), "On the modelling of the vibration behaviors via discrete singular convolution method for a high-order sector annular system", *Eng. Comput.*, 1-23. https://doi.org/10.1007/s00366-021-01454-z.

Liu, Z., Su, S., Xi, D. and Habibi, M. (2020a), "Vibrational responses of a MHC viscoelastic thick annular plate in thermal environment using GDQ method", *Mech. Based Des. Struct.*, 1-26. https://doi.org/10.1080/15397734.2020.1784201.

Liu, Z., Wu, X., Yu, M. and Habibi, M. (2020b), "Large-amplitude dynamical behavior of multilayer graphene platelets reinforced nanocomposite annular plate under thermo-mechanical loadings", *Mech. Based Des. Struct.*, 1-25. https://doi.org/10.1080/15397734.2020.1815544.

Lori, E.S., Ebrahimi, F., Supeni, E.E.B., Habibi, M. and Safarpour, H. (2020), "The critical voltage of a GPL-reinforced composite microdisk covered with piezoelectric layer", *Eng. Comput.*, 1-20. https://doi.org/10.1007/s00366-020-01004-z.

Luo, J., Song, J., Moradi, Z., Safa, M. and Khadimallah, M.A. (2022a), "Effect of simultaneous compressive and inertia loads on the bifurcation stability of shear deformable functionally graded annular fabrications reinforced with graphenes", *Eur. J. Mech. A Solids*, 104581. https://doi.org/10.1016/j.euromechsol.2022.104581.

Luo, J., Wu, S., Hou, S., Moradi, Z., Habibi, M. and Khadimallah, M.A. (2022b), "Thermally nonlinear thermoelasticity of a one-dimensional finite domain based on the finite strain concept", *Eur. J. Mech. A Solids*, 104726. https://doi.org/10.1016/j.euromechsol.2022.104726.

Ma, L., Liu, X. and Moradi, Z. "On the chaotic behavior of graphene-reinforced annular systems under harmonic excitation", *Eng. Comput.*, 1-25. https://doi.org/10.1007/s00366-020-01210-9.

Matouk, H., Bousahla Abdelmoumen, A., Heireche, H., Bourada, F., Bedia, E.A.A., Tounsi, A., Mahmoud, S.R., Tounsi, A. and Benrahou, K.H. (2020), "Investigation on hygro-thermal vibration of P-FG and symmetric S-FG nanobeam using integral Timoshenko beam theory", *Adv. Nano Res.*, **8**(4), 293-305. https://doi.org/10.12989/anr.2020.8.4.293.

Michael, M., Meyyazhagan, A., Velayudhannair, K., Pappuswamy, M., Maria, A., Xavier, V., Balasubramanian, B., Baskaran, R., Kamyab, H. and Vasseghian, Y. (2022), "The content of heavy metals in cigarettes and the impact of their leachates on the aquatic ecosystem", *Sustainability*, **14**(8), 4752. https://doi.org/10.3390/su14084752.

Moayedi, H., Aliakbarlou, H., Jebeli, M., Noormohammadiarani, O., Habibi, M., Safarpour, H. and Foong, L. (2020a), "Thermal buckling responses of a graphene reinforced composite micropanel structure", *Int. J. Appl. Mech.*, **12**(1), 2050010. https://doi.org/10.1142/S1758825120500106.

Moayedi, H., Ebrahimi, F., Habibi, M., Safarpour, H. and Foong, L.K. (2020b), "Application of nonlocal strain–stress gradient theory and GDQEM for thermo-vibration responses of a laminated composite nanoshell", *Eng. Comput.*, 1-16. https://doi.org/10.1007/s00366-020-01002-1.

Moayedi, H., Habibi, M., Safarpour, H., Safarpour, M. and Foong, L. (2019), "Buckling and frequency responses of a graphene nanoplatelet reinforced composite microdisk", *Int. J. Appl. Mech.*, **11**(10), 1950102. https://doi.org/10.1142/S1758825119501023.

Mohammadgholiha, M., Shokrgozar, A., Habibi, M. and Safarpour, H. (2019), "Buckling and frequency analysis of the nonlocal strain–stress gradient shell reinforced with graphene nanoplatelets", *J. Vib. Control*, **25**(19-20), 2627-2640. https://doi.org/10.1177/1077546319863251.

Mohammadi, A., Lashini, H., Habibi, M. and Safarpour, H. (2019), "Influence of viscoelastic foundation on dynamic behaviour of the double walled cylindrical inhomogeneous micro shell using MCST and with the aid of GDQM", *J. Solid Mech.*, **11**(2), 440-453 10.22034/JSM.2019.665264.

Moradi, H., Atashi, P., Amelirad, O., Yang, J.K., Chang, Y.Y. and Kamranifard, T. (2022a), "Machine learning modeling and DOE-assisted optimization in synthesis of nanosilica particles via Stöber method", *Adv. Nano Res.*, **12**(4), 387-403. https://doi.org/10.12989/anr.2022.12.4.387

Moradi, H., Kim, D.S., Kim, S.H., Chang, Y.Y., Yang, J.K., Choi, E.H. and Kamranifard, T. (2022b), "Experimental and numerical study on diazinon removal using plasma bubble column reactor: Modeling, kinetics, mechanisms, and degradation products", *J. Environ. Chem. Eng.*, **10**(5), 108291. https://doi.org/10.1016/j.jece.2022.108291.

Moradi, Z., Davoudi, M., Ebrahimi, F. and Ehyaei, A.F. (2021), "Intelligent wave dispersion control of an inhomogeneous micro-shell using a proportional-derivative smart controller", *Wave Random Complex Med.*, 1-24. https://doi.org/10.1080/17455030.2021.1926572.

Najaafi, N., Jamali, M., Habibi, M., Sadeghi, S., Jung, D.w. and Nabipour, N. (2020), "Dynamic instability responses of the substructure living biological cells in the cytoplasm environment using stress-strain size-dependent theory", *J. Biomol. Struct. Dyn.*, 1-12. https://doi.org/10.1080/07391102.2020.1751297.

Naumov, A.V., Tsyboulski, D.A., Bachilo, S.M. and Weisman, R.B. (2013), "Length-dependent optical properties of single-walled carbon nanotube samples", *Chem, Phys.*, **422**, 255-263.

Oyarhossein, M.A., Alizadeh, A.a., Habibi, M., Makkiabadi, M., Daman, M., Safarpour, H. and Jung, D.W. (2020), "Dynamic response of the nonlocal strain-stress gradient in laminated polymer composites microtubes", *Sci. Rep.*, **10**(1), 1-19. https://doi.org/10.1038/s41598-020-61855-w.

Peddieson, J., Buchanan, G.R. and McNitt, R.P. (2003), "Application of nonlocal continuum models to nanotechnology", *Int. J. Eng. Sci.*, **41**(3-5), 305-312.

Pham, Q.H., Nguyen, P.C., Tran, V.K. and Nguyen-Thoi, T. (2021), "Finite element analysis for functionally graded porous nano-plates resting on elastic foundation", *Steel Compos. Struct.*, **41**(2), 149-166. https://doi.org/10.12989/scs.2021.41.2.149.

Pisano, A.A. and Fuschi, P. (2003), "Closed form solution for a nonlocal elastic bar in tension", *Int. J. Solid Struct.*, **40**(1), 13-23 https://doi.org/10.1016/s0020-7683(02)00547-4.

Polizzotto, C. (2001), "Nonlocal elasticity and related variational principles", *Int. J. Solid Struct.*, **38**(42-43), 7359-7380.

Pourjabari, A., Hajilak, Z.E., Mohammadi, A., Habibi, M. and Safarpour, H. (2019), "Effect of Porosity on free and forced vibration characteristics of the GPL reinforcement composite nanostructures", *Comput. Math. Appl.*, **77**(10), 2608-2626. https://doi.org/10.1016/j.camwa.2018.12.041.

Ranjbartoreh, A. and Wang, G. (2010), "Molecular dynamic investigation of length dependency of single-walled carbon nanotube", *Physica E*, **43**(1), 202-206.

Rao, P.S., Anandatheertha, S., Naik, G.N. and Gopalakrishnan, S. (2015), "Estimation of mechanical properties of single wall carbon nanotubes using molecular mechanics approach", *Sadhana*, **40**(4), 1301-1311.

Rouabhia, A., Chikh, A., Bousahla, A.A., Bourada, F., Heireche, H., Tounsi, A., Kouider Halim, B., Tounsi, A. and Al-Zahrani, M.M. (2020), "Physical stability response of a SLGS resting on viscoelastic medium using nonlocal integral first-order theory", *Steel Compos. Struct.*, **37**(6), 695-709. https://doi.org/10.12989/scs.2020.37.6.695.

Safarpour, H., Ghanizadeh, S.A. and Habibi, M. (2018), "Wave propagation characteristics of a cylindrical laminated composite nanoshell in thermal environment based on the nonlocal strain gradient theory", *Eur. Phys. J. Plus*, **133**(12), 532. https://doi.org/10.1140/epjp/i2018-12385-2.

Safarpour, H., Hajilak, Z.E. and Habibi, M. (2019a), "A size-dependent exact theory for thermal buckling, free and forced vibration analysis of temperature dependent FG multilayer GPLRC composite nanostructures restring on elastic foundation", *Int. J. Mech. Mater. Des.*, **15**(3), 569-583.

Safarpour, H., Pourghader, J. and Habibi, M. (2019b), "Influence of spring-mass systems on frequency behavior and critical voltage of a high-speed rotating cantilever cylindrical three-dimensional shell coupled with piezoelectric actuator", *J. Vib. Control*, **25**(9), 1543-1557. https://doi.org/10.1177/1077546319828465.

Safarpour, M., Ebrahimi, F., Habibi, M. and Safarpour, H. (2020), "On the nonlinear dynamics of a multi-scale hybrid nanocomposite disk", *Eng. Comput.*, 1-20. https://doi.org/10.1007/s00366-020-00949-5.

Shao, Y., Zhao, Y., Gao, J. and Habibi, M. (2021), "Energy absorption of the strengthened viscoelastic multi-curved composite panel under friction force", *Arch. Civil Mech. Eng.*, **21**(4), 1-29. https://doi.org/10.1007/s43452-021-00279-3.

Shariati, A., Habibi, M., Tounsi, A., Safarpour, H. and Safa, M. (2020a), "Application of exact continuum size-dependent theory for stability and frequency analysis of a curved cantilevered microtubule by considering viscoelastic properties", *Eng. Comput.*, 1-20. https://doi.org/10.1007/s00366-020-01024-9.

Shariati, A., Mohammad-Sedighi, H., Żur, K.K., Habibi, M. and Safa, M. (2020b), "On the vibrations and stability of moving viscoelastic axially functionally graded nanobeams", *Materials*, **13**(7), 1707. https://doi.org/10.3390/ma13071707.

Shariati, A., Mohammad-Sedighi, H., Żur, K.K., Habibi, M. and Safa, M. (2020c), "Stability and dynamics of viscoelastic moving rayleigh beams with an asymmetrical distribution of material parameters", *Symmetry*, **12**(4), 586. https://doi.org/10.3390/sym12040586.

Shariati, M., Azar, S.M., Arjomand, M.-A., Tehrani, H.S., Daei, M. and Safa, M. (2020d), "Evaluating the impacts of using piles and geosynthetics in reducing the settlement of fine-grained soils under static load", *Geomech. Eng.*, **20**(2), 87-101. https://doi.org/10.12989/gae.2020.20.2.087.

Shariati, M., Davoodnabi, S.M., Toghroli, A., Kong, Z. and Shariati, A. (2021a), "Hybridization of metaheuristic algorithms with adaptive neuro-fuzzy inference system to predict load-slip behavior of angle shear connectors at elevated temperatures", *Compos. Struct.*, 114524. https://doi.org/10.1016/j.compstruct.2021.114524.

Shariati, M., Faegh, S.S., Mehrabi, P., Bahavarnia, S., Zandi, Y., Masoom, D.R., Toghroli, A., Trung, N.-T. and Salih, M.N. (2019), "Numerical study on the structural performance of corrugated low yield point steel plate shear walls with circular openings", *Steel Compos. Struct.*, **33**(4), 569-581. https://doi.org/10.12989/scs.2019.33.4.569.

Shariati, M., Ghorbani, M., Naghipour, M., Alinejad, N. and Toghroli, A. (2020e), "The effect of RBS connection on energy absorption in tall buildings with braced tube frame system", *Steel Compos. Struct.*, **34**(3), 393-407. https://doi.org/10.12989/scs.2020.34.3.393.

Shariati, M., Lagzian, M., Maleki, S., Shariati, A. and Trung, N.T. (2020f), "Evaluation of seismic performance factors for tension-only braced frames", *Steel Compos. Struct.*, **35**(4), 599-609. https://doi.org/10.12989/scs.2020.35.4.599.

Shariati, M., Mafipour, M.S., Ghahremani, B., Azarhomayun, F., Ahmadi, M., Trung, N.T. and Shariati, A. (2020g), "A novel hybrid extreme learning machine–grey wolf optimizer (ELM-GWO) model to predict compressive strength of concrete with partial replacements for cement", *Eng. Comput.*, 1-23. https://doi.org/10.1007/s00366-020-01081-0.

Shariati, M., Mafipour, M.S., Mehrabi, P., Ahmadi, M., Wakil, K., Trung, N.T. and Toghroli, A. (2020h), "Prediction of concrete strength in presence of furnace slag and fly ash using Hybrid ANN-GA (Artificial Neural Network-Genetic Algorithm)", *Smart Struct. Syst.*, **25**(2), 183-195. https://doi.org/10.12989/sss.2020.25.2.183.

Shariati, M., Naghipour, M., Yousofizinsaz, G., Toghroli, A. and Tabarestani, N.P. (2020i), "Numerical study on the axial compressive behavior of built-up CFT columns considering different welding lines", *Steel Compos. Struct.*, **34**(3), 377-391 http://doi.org/10.12989/scs.2020.34.3.377.

Shariati, M., Shariati, A., Trung, N.T., Shoaei, P., Ameri, F., Bahrami, N. and Zamanabadi, S.N. (2021b), "Alkali-activated slag (AAS) paste: Correlation between durability and microstructural characteristics", *Constr. Build. Mater.*, **267**, 120886. https://doi.org/10.1016/j.conbuildmat.2020.120886.

Shariati, M., Sulong, N.R. and Khanouki, M.A. (2012), "Experimental assessment of channel shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Mater. Des.*, **34**, 325-331. https://doi.org/10.1016/j.matdes.2011.08.008.

Shariati, M., Sulong, N.R., Shariati, A. and Khanouki, M.A. (2016a), "Behavior of V-shaped angle shear connectors: experimental and parametric study", *Mater. Struct.*, **49**(9), 3909-3926. https://doi.org/10.1617/s11527-015-0762-8.

Shariati, M., Sulong, N.R., Shariati, A. and Kueh, A. (2016b), “Comparative performance of channel and angle shear connectors in high strength concrete composites: An experimental study”, *Constr. Build. Mater.*, **120**, 382-392. https://doi.org/10.1016/j.conbuildmat.2016.05.102.

Shariati, M., Tahmasbi, F., Mehrabi, P., Bahadori, A. and Toghroli, A. (2020j), “Monotonic behavior of C and L shaped angle shear connectors within steel-concrete composite beams: An experimental investigation”, *Steel Compos. Struct.*, **35**(2), 237-247. http://doi.org/10.12989/scs.2020.35.2.237.

Shokrgozar, A., Safarpour, H. and Habibi, M. (2020), “Influence of system parameters on buckling and frequency analysis of a spinning cantilever cylindrical 3D shell coupled with piezoelectric actuator”, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, **234**(2), 512-529. https://doi.org/10.1177/0954406219883312.

Soni, S.K., Thomas, B. and Kar, V.R. (2020), “A comprehensive review on CNTs and CNT-reinforced composites: syntheses, characteristics and applications”, *Mater. Today Commun.*, 101546.

Sudak, L.J. (2003), “Column buckling of multiwalled carbon nanotubes using nonlocal continuum mechanics”, *J. Appl. Phys.*, **94**(11), 7281-7287 http://doi.org/10.1063/1.1625437.

Taati, E., Borjalilou, V., Fallah, a., Famida and Ahmadian, M.T. (2020), “On size-dependent nonlinear free vibration of carbon nanotube-reinforced beams based on the nonlocal elasticity theory: Perturbation technique”, *Mech. Based Des. Struct.*, 1-23.

Van Vinh, P. and Tounsi, A. (2021), “The role of spatial variation of the nonlocal parameter on the free vibration of functionally graded sandwich nanoplates”, *Eng. Comput.*, 1-19. https://doi.org/10.1007/s00366-021-01475-8.

Vatanpour, V., Jouyandeh, M., Akhi, H., Mousavi Khadem, S.S., Ganjali, M.R., Moradi, H., Mirsadeghi, S., Badiei, A., Esmaeili, A., Rabiee, N., Habibzadeh, S., Koyuncu, I., Nouranian, S., Formela, K. and Saeb, M.R. (2022a), “Hyperbranched polyethylenimine functionalized silica/polysulfone nanocomposite membranes for water purification”, *Chemosphere*, **290**, 133363. https://doi.org/10.1016/j.chemosphere.2021.133363.

Vatanpour, V., Jouyandeh, M., Mousavi Khadem, S.S., Paziresh, S., Dehqan, A., Ganjali, M.R., Moradi, H., Mirsadeghi, S., Badiei, A., Munir, M.T., Mohaddespour, A., Rabiee, N., Habibzadeh, S., Mashhadzadeh, A.H., Nouranian, S., Formela, K. and Saeb, M.R. (2022b), “Highly antifouling polymer-nanoparticle-nanoparticle/polymer hybrid membranes”, *Sci. Total Environ.*, **810**, 152228. https://doi.org/10.1016/j.scitotenv.2021.152228.

Wang, H., Habibi, M., Marzouki, R., Majdi, A., Shariati, M., Denic, N., Zakić, A., Khorami, M., Khadimallah, M.A. and Ebid, A.A.K. (2022a), “Improving the self-healing of cementitious materials with a hydrogel system”, *Gels*, **8**(5), 278. https://doi.org/10.3390/gels8050278.

Wang, P., Gao, Z., Pan, F., Moradi, Z., Mahmoudi, T. and Khadimallah, M.A. (2022b), “A couple of GDQM and iteration techniques for the linear and nonlinear buckling of bi-directional functionally graded nanotubes based on the nonlocal strain gradient theory and high-order beam theory”, *Eng. Anal. Bound. Elem.*, **143**, 124-136. https://doi.org/10.1016/j.enganabound.2022.06.007.

Wang, Q., Zhou, G.Y. and Lin, K.C. (2006), “Scale effect on wave propagation of double-walled carbon nanotubes”, *Int. J. Solid Struct.*, **43**(20), 6071-6084.

Wang, Y., Yang, J., Moradi, Z., Safa, M. and Khadimallah, M.A. (2022c), “Nonlinear dynamic analysis of thermally deformed beams subjected to uniform loading resting on nonlinear viscoelastic foundation”, *Eur. J. Mech. A Solids*, **95**, 104638. https://doi.org/10.1016/j.euromechsol.2022.104638.

Wang, Z., Yu, S., Xiao, Z. and Habibi, M. (2020), “Frequency and buckling responses of a high-speed rotating fiber metal laminated cantilevered microdisk”, *Mech. Adv. Mater. Struct.*, 1-14. https://doi.org/10.1080/15376494.2020.1824284.

Wu, J. and Habibi, M. (2021), “Dynamic simulation of the ultra-fast-rotating sandwich cantilever disk via finite element and semi-numerical methods”, *Eng. Comput.*, 1-17. https://doi.org/10.1007/s00366-021-01396-6.

Xia, W., Du, J., Habibi, M., Shariati, M. and Khadimallah, M.A. (2022), “Application of Chebyshev-based GDQ and Newmark methods to viscothermoelasticity responses of FG composite annular systems”, *Eng. Anal. Bound. Elem.*, **143**, 28-42. https://doi.org/10.1016/j.enganabound.2022.06.003.

Xiong, Q.M., Chen, Z., Huang, J.T., Zhang, M., Song, H., Hou, X.F., Li, X.B. and Feng, Z.J. (2020), "Preparation, structure and mechanical properties of Sialon ceramics by transition metal-catalyzed nitriding reaction", *Rare Metals*, **39**(5), 589-596.

Xu, W., Pan, G., Moradi, Z. and Shafiei, N. (2021), "Nonlinear forced vibration analysis of functionally graded non-uniform cylindrical microbeams applying the semi-analytical solution", *Compos. Struct.*, 114395. https://doi.org/10.1016/j.compstruct.2021.114395.

Yang, N., Moradi, Z., Arvin, H., Muhsen, S. and Khadimallah, M.A. (2022a), "A study on small scale thermal dynamic instability of rotating GPL-reinforced microbeams under principal parametric resonance stimulation of axial and transversal modes regarding the proportional damping", *Thin Wall. Struct.*, **180**, 109806. https://doi.org/10.1016/j.tws.2022.109806.

Yang, N., Moradi, Z., Khadimallah, M.A. and Arvin, H. (2022b), "Application of the Chebyshev–Ritz route in determination of the dynamic instability region boundary for rotating nanocomposite beams reinforced with graphene platelet subjected to a temperature increment", *Eng. Anal. Bound. Elem.*, **139**, 169-179. https://doi.org/10.1016/j.enganabound.2022.03.013.

Yu, M.F., Files, B.S., Arepalli, S. and Ruoff, R.S. (2000), "Tensile loading of ropes of single wall carbon nanotubes and their mechanical properties", *Phys. Rev. Lett.*, **84**(24), 5552-5555 https://doi.org/10.1103/PhysRevLett.84.5552.

Yu, X., Maalla, A. and Moradi, Z. (2022), "Electroelastic high-order computational continuum strategy for critical voltage and frequency of piezoelectric NEMS via modified multi-physical couple stress theory", *Mech. Syst. Signal Proc.*, **165**, 108373. https://doi.org/10.1016/j.ymssp.2021.108373.

Zare, R., Najaafi, N., Habibi, M., Ebrahimi, F. and Safarpour, H. (2020), "Influence of imperfection on the smart control frequency characteristics of a cylindrical sensor-actuator GPLRC cylindrical shell using a proportional-derivative smart controller", *Smart Struct. Syst.*, **26**(4), 469-480. https://doi.org/10.12989/sss.2020.26.4.469.

Zenkour, A.M. and Abouelregal, A.E. (2015), "Thermoelastic interaction in functionally graded nanobeams subjected to time-dependent heat flux", *Steel Compos. Struct.*, **18**(4), 909-924. https://doi.org/10.12989/scs.2015.18.4.909.

Zerrouki, R., Karas, A., Zidour, M., Bousahla, A.A., Tounsi, A., Bourada, F., Tounsi, A., Benrahou, K.H. and Mahmoud, S. (2021), "Effect of nonlinear FG-CNT distribution on mechanical properties of functionally graded nano-composite beam", *Struct. Eng. Mech.*, **78**(2), 117-124. https://doi.org/10.12989/sem.2021.78.2.117.

Zhang, Y., Wang, Z., Tazeddinova, D., Ebrahimi, F., Habibi, M. and Safarpour, H. (2021), "Enhancing active vibration control performances in a smart rotary sandwich thick nanostructure conveying viscous fluid flow by a PD controller", *Wave Random Complex Med.*, 1-24. https://doi.org/10.1080/17455030.2021.1948627.

Zhang, Y.Q., Liu, G.R. and Xie, X.Y. (2005), "Free transverse vibrations of double-walled carbon nanotubes using a theory of nonlocal elasticity", *Phys. Rev. B*, **71**(19), 1-7. https://doi.org/10.1103/PhysRevB.71.195404.

Zhao, Y., Moradi, Z., Davoudi, M. and Zhuang, J. "Bending and stress responses of the hybrid axisymmetric system via state-space method and 3D-elasticity theory", *Eng. Comput.*, 1-23. https://doi.org/10.1007/s00366-020-01242-1.

Zheng, W., Liu, J., Oyarhossein, M.A., Safarpour, H. and Habibi, M. (2023), "Prediction of nth-order derivatives for vibration responses of a sandwich shell composed of a magnetorheological core and composite face layers", *Eng. Anal. Bound. Elem.*, **146**, 170-183. https://doi.org/10.1016/j.enganabound.2022.10.019.

Zheng, Y., Jin, H., Jiang, C., Moradi, Z., Khadimallah, M.A. and Moayedi, H. (2022), "Analyzing behavior of circular concrete-filled steel tube column using improved fuzzy models", *Steel Compos. Struct.*, **43**(5), 625-637. https://doi.org/10.12989/scs.2022.43.5.625.

Zhou, C., Zhao, Y., Zhang, J., Fang, Y. and Habibi, M. (2020), "Vibrational characteristics of multi-phase nanocomposite reinforced circular/annular system", *Adv. Nano Res.*, **9**(4), 295-307. https://doi.org/10.12989/anr.2020.9.4.295.

Zhu, L., Ren, H., Habibi, M., Mohammed, K.J. and Khadimallah, M.A. (2022), “Predicting the environmental economic dispatch problem for reducing waste nonrenewable materials via an innovative constraint multi-objective Chimp Optimization Algorithm”, *J. Clean. Prod.*, 132697. https://doi.org/10.1016/j.jclepro.2022.132697.

Zhu, X. and Li, L. (2017), “Longitudinal and torsional vibrations of size-dependent rods via nonlocal integral elasticity”, *Int. J. Mech. Sci.*, **133**, 639-650. https://doi.org/10.1016/j.ijmecsci.2017.09.030.

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