Nanotechnol Rev 2020; 9:230–258 DE GRUYTER

Review Article

Vikram Singh Chandel, Guannan Wang, and Mohammad Talha*

Advances in modelling and analysis of nano structures: a review

https://doi.org/10.1515/ntrev-2020-0020
Received Nov 19, 2019; accepted Dec 03, 2019

Abstract: Nanostructures are widely used in nano and micro-sized systems and devices such as biosensors, nano actuators, nano-probes, and nano-electro-mechanical systems. The complete understanding of the mechanical behavior of nanostructures is crucial for the design of nanodevices and systems. Therefore, the flexural, stability and vibration analysis of various nanostructures such as nanowires, nanotubes, nanobeams, nanoplates, graphene sheets and nanoshells has received a great attention in recent years. The focus has been made, to present the structural analysis of nanostructures under thermo-magneto-electro-mechanical loadings under various boundary and environmental conditions. This paper also provides an overview of analytical modeling methods, fabrication procedures, key challenges and future scopes of development in the direction of analysis of such structures, which will be helpful for appropriate design and analysis of nanodevices for the application in the various fields of nanotechnology.

Keywords: nanostructures, size-dependent continuum models, molecular dynamics, nonlocal doublet method, structural response

1 Introduction

Nanotechnology is an emerging research field which have different domains such as nanomedicine, nanoelectronics, nanomanufacturing, and nanomachines. These domains require new devices, such as nanoenergy harvester, nanomechanical resonators, oscillators, charge detectors, nanoscale mass sensors, field emission devices, biological tissue, and electromechanical nanoactuators. These devices are generally fabricated using nanostructures. Different fundamental nanostructures are nanoscale rods, rings, beams, plates, and shells as shown in Figure 1 [1]. Due to stunning mechanical and electrical properties of carbon nanostructures such as carbon nanotubes (CNTs), graphene sheets (GSs), and fullerenes have been used as fundamental structural units of small size devices [1–6]. Various carbon nanostructures are presented in Figure 2 [7]. During application, nanostructures are subjected to mechanical loads, thermal loads, strains, and stresses. Hence analyses of mechanical behavior and properties of nanostructures are important.

The present paper, for the first time, reviews the mechanical analysis of nanoscale structures using different types of tools. The objective of this work is to sum up the state of art and high light the possible future work in the flexural, stability, and vibration analysis of various nanostructures. This is organized as follows: Section 2 presents literature on processing techniques of nanostructures. In section 3, literatures on applications of nanostructures in different fields of nanotechnology are discussed. Section 4, presents the different solution methodologies used by the researchers to study the mechanical behavior of nanoscale structures. Section 5, presents the recent research reported on the flexural, stability and vibration analysis of various

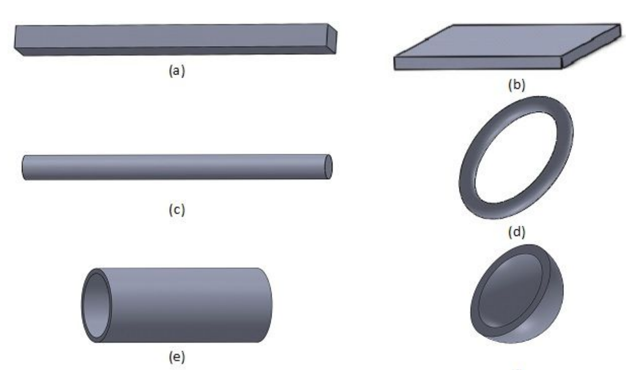

Figure 1: Different types of nanostructures: (a) nanobeam (b) nanoplate (c) nanobar (d) nanoring (e) single curved nanoshell (f) double curved nanoshell.

***Corresponding Author: Mohammad Talha:** School of Engineering, Indian Institute of Technology Mandi, Himachal Pradesh 175005, India; Email: talha@iitmandi.ac.in
Vikram Singh Chandel: School of Engineering, Indian Institute of Technology Mandi, Himachal Pradesh 175005, India
Guannan Wang: Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China

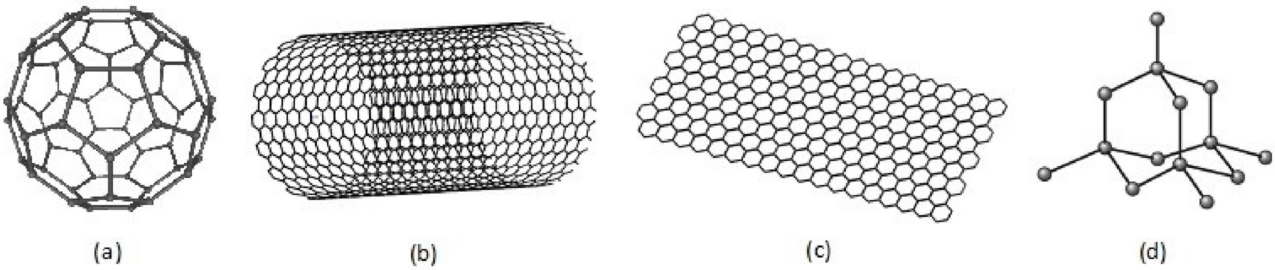

Figure 2: Different types of carbon nanostructures: (a) fullerene (b) nanotube (c) graphene sheet (d) diamond structure.

nanostructures. Finally, some concluding remarks are presented in Section 6.

2 Processing techniques of nanostructures

Main methods of single wall nanotubes (SWNTs) production are arc-discharge, laser ablation, and chemical vapour deposition (CVD). Arc-discharge and laser ablation methods produce SWNTs in few grams. Both methods consists the condensation of gaseous carbon atoms produced from the evaporation of solid carbon. Due to sophisticated equipment requirement and large amount of energy consumption in these methods, their use is limited to laboratory scale [8–10].

The CVD method can be easily scaled to industrial levels and become most important commercial method for SWNTs production. Main advantages of CVD over arc and laser methods are the scale up production to industrial level and more control on morphology and structure of the produced CNTs. This process involves heating a catalyst material to high temperatures (500–1000 °C) in a tube furnace and flow of a hydrocarbon gas through the tube reactor for particular time duration. The general CNT growth mechanism in this method involves the dissociation of hydrocarbon molecules catalysed by the transition metal, and dissolution as well as saturation of carbon atoms in the metal nanoparticle. The precipitation of carbon from the saturated metal nanoparticles results in the formation of tubular carbon solids [11].

SWNTs synthesis methods can be divided into two categories: bulk synthesis and surface synthesis. Bulk synthesis methods are methane CVD, high-pressure catalytic decomposition of carbon monoxide (HiPCO), CO CVD, and alcohol CVD. Surface synthesis of SWNTs has several advantages over bulk synthesis. Such as less defect formation, better performance, and introduction of pattern by various lithography techniques. Recent research in surface growth method involves control of diameters and orientation of SWNTs [12–16].

3 Applications

The interest for applications of nanostructures exhibits due to their superior mechanical, electrical, thermal and chemical properties than those of traditional materials [17–20]. After more than 25 years of research, applications of nanostructures are delivering in both expected and unexpected ways to benefit the society. Researchers shows its application in different fields, like nanomedicine, nanoelectronics, nanomanufacturing, and nanomachines. Nanostructures offer commitment in severe operating and loading conditions.

3.1 Electrochemical devices

Because of large surface areas of porous nanostructure arrays, these are used as electrodes for the devices which use electrochemical double-layer charge injection e.g. supercapacitors and electromechanical actuators. Capacitance of a capacitor is inversely proportional to the separation between two electrodes. This separation for a nanotube is about a nanometre and for ordinary dielectric capacitors is more than micrometre. Due to small separation and large surface area, the capacitance of CNT supercapacitor is very large as compared to ordinary capacitor [22–27].

Single-walled carbon nanotubes (SWCNTs) based macroscale electromechanical actuators are assemblies of billions of individual nanoscale actuators. In these, low operating voltages generate large actuator strains as compared with the 100 V used for piezoelectric stacks and the 1000 V used for electrostrictive actuators. These provide considerably higher work densities per cycle than any other technology [25].

Table 1: Classification of nano-sensors based on the type of variable being detected [21]

Sr No.	Type of variable	Properties
1	Mechanical	Position, acceleration, stress, strain, force, pressure, mass, density, viscosity, moment, torque
2	Acoustic	Wave amplitude, phase, polarization, velocity
3	Optical	Absorbance, reflectance, fluorescence, luminescence, refractive index, light scattering
4	Thermal	Temperature, flux, thermal conductivity, specific heat
5	Electrical	Charge, current, potential, dielectric constant, conductivity
6	Magnetic	Magnetic field, flux, permeability
7	Chemical	Components (identities, concentrations, states)
8	Biological	Biomass (identities, concentrations, states)

3.2 Field emission devices

SWNTs and MWNTs are using as field emission electron sources [28, 29] for x-ray [30] and microwave generators [31], flat panel displays [32], lamps [33], gas discharge tubes providing surge protection [34]. Nanotubes provide steady and uniform emission, long lifetimes, low emission threshold potentials [28, 33], and high current densities [35]. Nanotube field-emitting surfaces are comparatively easy to manufacture by screen printing nanotube pastes and do not distort in moderate vacuum (108 Torr). These are benefits over tungsten and molybdenum tip arrays, which require high vacuum of 1010 torr and are tougher to fabricate [36].

3.3 Sensors

Sensors are always in demand in scientific as well as industrial applications, and a search for advance materials in sensor applications continues at all times. Sensors using nanostructures have a smaller size and lower weight, leading to higher sensitivity, better specificity and exceptional stability [21, 37–40].

The working principle of a nanosensor is to access data from atomic scales and transfer this at macroscale as analysable data. According to the type of variables to be detected by nanosensors, they are classified into six groups: mechanical, electrical, optical, magnetic, chemical, and thermal. These are used to find different types of properties as listed in Table 1. Nanosensors have a wide range of applications, including liquid flow rate measurement, early disease detection, detection of gene mutations, DNA sequencing, gas detection, accurate monitors of material states, and monitoring glucose levels for diabetic subjects [41–48].

3.4 Probes

CNTs and carbide nanorods have high aspect ratios, such as nanometer order diameter and micrometer order length and a small tip radius with sharp cone. This shape is suitable for probe tips of a scanning probe microscope (SPM) [49–53]. These opens out the possibility of probing the deep crevices that occur in microelectronic circuits [51, 52], and improves the lateral resolution [53]. CNTs can be elastically buckled [50, 51] which makes them robust and also prevents damage to soft biological and organic samples by limiting the maximum force applied on the samples [53].

3.5 Composite structures

Various nanostructures are used to enhance the electrical, mechanical, and thermal properties of polymer-based composite materials, due to their exceptional properties and perfect atom arrangement [54–62]. Lau and his research team focused their study on the synthesis of coiled CNTs and their application to alter the mechanical properties of composite structures [63–65]. They investigated the applicability of coiled CNTs and randomly-oriented nanoclay-supported CNTs to improve the mechanical properties of epoxy resin under the cryogenic environment [66]. Further they investigated the pullout behavior of coiled CNTs by considering the thermal residual stresses under the cryogenic environment [67].

4 Solution methodologies

Number of experimental and theoretical studies dealing with mechanical responses of nanostructures can be seen in literature. It is very expensive, time consuming, and difficult to conduct and control the experiment at nanoscales and hence progress in experimental studies is limited. That's why research is focused on theoretical modeling. Theoretical modeling of nanostructures can be classify in atomistic modeling, continuum mechanics modeling, and hybrid atomistic-continuum mechanics modeling [68–70].

Atomistic modeling deals with analysis at atomic and molecular level. It includes classical molecular dynamics(MD), density functional theory techniques and tight binding molecular dynamics [71–76]. Atomistic modeling for a small scale structure with a large number of atoms/molecules demands huge computational effort so this becomes tedious and time consuming. So continuum mechanics modeling comes in to picture and played an important role in mechanical analysis of nanostructures. In this type of modeling, nanostructures are treated homogeneous and continuum while their internal atomic structures are not taken in to account. Hence computational cost and time using continuum mechanics approach is reduced by wiping out of unnecessary simulations. But accurate detection of crystal lattice structure using continuum mechanics approach is doubtful. Then atomistic–continuum modeling came in to picture and eliminates the drawbacks of atomistic modeling and continuum modeling. A linkage between two modelings is established by equating the molecular potential energy with mechanical strain energy of a given volume of the nanostructure of a continuum model [77–79].

Continuum mechanics can be categorized into classical (local) continuum mechanics and nonlocal continuum mechanics. In Classical continuum mechanics, various bulk material theories like classical (local) beam, plate, and shell are used for mechanical analysis of nanostructures for large scale systems [80–82]. Although a lot of research efforts are have been carried out using classical continuum mechanics, their application at the nanoscale is questionable. Because small scale effects such as Van der Waals (vdW) forces, surface effects, lattice spacing, electric forces, and chemical bond are neglected in classical continuum mechanics. Both experimental and atomistic simulation results represent that at the nanoscale, these small scale effect may not be neglected [83]. This is because at the small size the lattice spacing between the atoms becomes more important and discrete structure (internal) of the material can no longer be homogenized into a continuum [70]. To take care of small-scale effects, nonlocal continuum theories have been determined. These incorporate a size-dependent parameter in the modeling of the continuum to account small scale effect. Various nonlocal continuum theories are strain gradient theory, couple stress theory, micropolar theory, and nonlocal elasticity theory [84, 85].

4.1 Molecular dynamics

Molecular dynamics (MD) is a computer simulation technique to investigate the physical movements of atoms and molecules, in which atoms and molecules interact for a fixed period of time, giving a dynamic view of the considered system. The movement of atoms and molecules are obtained by numerically integrating Newton's equations of motion. The forces between the particles are calculated using inter atomic potentials or molecular mechanics force fields [86–90].

4.2 Surface elasticity

In order to avoid the large-scale computational efforts arisen from the molecular simulations, the continuum mechanics is still employed to model the effective and localized responses of nanomaterials, such as the nanowires, nanotubes, nanofibers, etc., which usually exhibit significantly distinct behavior from the macro-sized or even micro-sized structures. The mechanical difference caused by the surface effects due to the large surface-to-volume ratios is simulated using the surface-elasticity model described by Gurtin and Murdoch [91, 92], who treated the surfaces of the nanomaterials as zero-thickness smooth layers with distinct physical properties. The surface's properties are also dependent on the internal crystallic directions of the bulk materials. For instance, Miller and Shenoy [93] employed the atomistic simulations to generate the nano Aluminum's surface properties that were extensively employed. Later on, Steigmann and Ogden [94] extended the theory by considering the flexural resistance. Because of the easy mathematical characterization, the surface-elasticity models are continuously implemented in the recent two decades, including the nano-beams [95], nano-plates [96], nano-films [97], and functionally graded nanomaterials [98], and even heterogeneous materials with nanoscale inhomogeneities [99, 100]. A detailed review work is conducted by Wang *et al.* [101] and Chen *et al.* [102].

4.3 Nonlocal elasticity theory

This theory was provided by the Eringen [103–105] in 1972 and for the first time, Peddieson *et al.* [106] recommended this theory to analyze the mechanical behavior of nanoscale structures. According to this theory, stress tensor at a reference spot in an elastic continuum is dependent on the strain field at all spots in the domain. This assumption represents the long range intermolecular interactions and leads to a size-dependent theory of elasticity, which represents good agreement with the atomic theory of lattice dynamics and experimental examination on phonon dispersion. Neglecting the body forces, the most general form of the constitutive relation for linear homogeneous and isotropic elastic solids according to nonlocal elasticity theory are

$$\sigma_{ij}{}^{nl}(\xi) = \int_V K(\left|\xi' - \xi\right|, \mu)\sigma_{ij}{}^{l}(\xi')\, dV(\xi') \tag{1}$$

The terms $\sigma_{ij}^{nl},\ \sigma_{ij}{}^{l},\ K(\left|\xi' - \xi\right|, \mu), \left|\xi' - \xi\right|, and\, \mu$ are nonlocal stress tensor, local stress tensor, nonlocal modulus, distance in the euclidean form, and nonlocal parameter (this is dependent on the internal and external characteristic lengths), respectively.

The local stress σ_{ij}^{l} at a spot ξ' is associated to the strain ϵ_{ij} at that spot by generalized Hooke's law

$$\sigma_{ij}^{l}(\xi') = C_{ijkl}\,\epsilon_{kl}(\xi') \tag{2}$$

Where C_{ijkl} is the fourth-order elasticity tensor. For the ease of simplicity, equivalent differential form of the integral constitutive equations (1) and (2) was proposed which is as follows

$$(1 - \mu^2 \triangledown^2)\sigma_{ij}^{nl}(\xi) = \sigma_{ij}^{l}(\xi) \tag{3}$$

4.4 Nonlocal strain gradient theory

In literature, researchers observed disappearance of size effect after a certain length and only stiffness softening by using the nonlocal elasticity theory. But few researchers observed stiffness hardening, especially at higher lengths. Furthermore few researchers got the same results by nonlocal elasticity theory as given by classical theory [1]. To overcome these issues of using nonlocal elasticity theory, Lim *et al.* [107] presented a higher-order nonlocal strain gradient theory (NSGT) using two independent short length-scale parameters. According to NSGT, stress at a particular point is a function of strain as well as higher order strain gradient at all points in the domain. This theory takes into account both the inter-atomic forces and higher-order micro-structure deformation mechanism. The new theory observed both increase and decrease in stiffness of material at small-scale levels, also predicts scale effects in a long range of lengths. Afterwards, lot of research has been carried out to investigate the mechanical response of nanostructures by using NSGT [105, 108]. Researchers found that wave dispersion obtained by NSGT was very close with that predicted by molecular dynamic simulation (MDS) for the nanobeams [109].

According to NSGT, a new stress tensor is proposed as follows [110]:

$$\sigma_{ij} = \sigma_{ij}^{(0)} - \triangledown\sigma_{ij}^{(1)} \tag{4}$$

Here, $\sigma_{ij}^{(0)}$ and $\sigma_{ij}^{(1)}$ are the zero order nonlocal stress and the higher order nonlocal stress, respectively, and given as:

$$\sigma_{ij}{}^{(0)}(\xi) = \int_V K_0(\left|\xi' - \xi\right|, \mu_0)\sigma_{ij}{}^{l}(\xi')\, dV(\xi') \tag{5}$$

$$\sigma_{ij}{}^{(1)}(\xi) = l^2 \int_V K_1(\left|\xi' - \xi\right|, \mu_1) \triangledown \sigma_{ij}{}^{l}(\xi')\, dV(\xi') \tag{6}$$

The terms K_0 and K_1 are the modulus and mu_0 and mu_1 are the scale coefficients, while l is strain gradient coefficients.

In NSGT, constitutive relation of stress and strain components can be written as [107]:

$$\begin{aligned}[1 - \mu_1^2\triangledown^2][1 - \mu_0^2\triangledown^2]\sigma_{ij} = C_ijkl[1 - \mu_1^2\triangledown^2]\epsilon_{kl} \\ - C_{ijkl}l^2[1 - \mu_0^2\triangledown^2]\triangledown^2\,\epsilon_k l\end{aligned} \tag{7}$$

where $\triangledown^2$ is a Laplacian operator.

4.5 Nonlocal doublet mechanics

Doublet mechanics (DM) is a micro mechanics proposed by Granik in 1978 [111]. Unlike the other size dependent theories, DM directly depends on the micro/nano structure of the solid. In DM, micro stress and micro-strain relations are obtained for displacements of each particle in the domain. Then these micro stress-strains relations are connected to macro stress-strain relations and lead to the governing equations of the problem. These equations include material properties, macro deformations, and intrinsic length scale. In this, scale parameter for the materials are the real atomic distance and small scale displacements are expanded in Taylor series. Also, various numbers of terms in the Taylor series expansion are used to control the order of the equations. However, the accuracy of the theory is not dependent on the number of terms considered in the Taylor series. The number of terms of Taylor series taken in to account is only related to the discreteness of the domain. If we consider the only first term in the Taylor series expansion, then governing equations will reduce to classical elasticity theory [112–114].

5 Analysis

A review of the current state of the art is written with an emphasis to present flexural analysis, stability analysis, and vibration analysis of various nanostructures using different analytical methods proposed by several researchers without recognizing the detailed mathematical implication of different analytical and numerical methodologies.

5.1 Flexural analysis

5.1.1 Molecular dynamics

Iijima *et al.* [71] performed molecular dynamic simulations (MDS) using Tersoff-Brenner interaction between the carbon atoms and vdW interaction between the neighbor walls of MWNTs. They found that the bending of SWCNTs and multi-walled carbon nanotubes (MWCNTs) are fully reversed up to 110 ^{o}, despite the formation of kinks. This is due to the high flexibility of hexagonal structure, which maintains bond under high values of strain. Simulation with diameters, lengths, and helicities as varying parameters showed that the critical local curvature is independent on the length of the tube. Shibutani and Ogata [115] evaluated the bending and torsional deformations of SWNTs considering the Tersoff-Brenner type interatomic potential and found a hysteresis loop in bending due to the transformation from four hexagons to double pairs of heptagons and pentagons. While loop was absent in torsion deformation.

Using controlled SPM manipulation, Duan *et al.* [116] found "abrupt" and "gradual" two modes of CNTs buckling during the bending. Furthermore, these two modes are dependent on the diameter and thickness of CNTs. Wang *et al.* [117] solved fourth-order nonlinear ordinary differential equations using continuation algorithm to explain the buckling of CNTs under bending. In order to validate the results, they have used objective MDS. They found low and high strain phases during the bending process and divide this into three stages: low curvature stage, mixed curvature stage and high curvature stage. It was also found that the sectional ovalization reduced the bending stiffness of CNTs, which can be eliminated by the use of hydrogen-charged CNTs. Tian *et al.* [118] observed fivefold deformation twins at large bending angles for single-crystalline Cu nanowires(NWs) under bending loading, which was due to the reciprocal phase change from atoms of another 12-coordinate lattice to hexagonal close packed lattice.

Wu [119] performed 3-Dimensional MDS with embedded-atom-method potential under different loading rates at 0.01K constant temperature to study the bending behavior of the copper nanorod. He used gear algorithm to integrate Newton's equations of motion consisting fifth time derivative of the atom positions. He found two things: (i) mechanical response is non-linear for impact loading and (ii) free-loading state of copper nanorod is not a stress-free state due to the surface stress effect.

5.1.2 Nonlocal elasticity theory

Initially, when researchers developed nonlocal beam models to study the bending behavior of nanobeams. They did not find any influence of nonlocal elasticity on the bending of nanobeams under concentrated loads [106, 120, 121]. Then Wang and Liew [122] developed nonlocal Timoshenko beam theory (TBT) and Euler–Bernoulli beam theory (EBT) by considering concentrated loads as a Dirac delta function. Their results reported the effect of nonlocal elasticity on the bending behavior of nanobeams for the first time. Then Researchers formulated various nonlocal beam theories such as EBT, TBT, Reddy beam theory (RBT), and Levinson beam theory (LBT) and applied them to study the mechanical behavior of CNTs under loading. Based on the modified couple stress theory, Ma *et al.* presented a Timoshenko beam model to explain the static bending and free vibration problems. Yang *et al.* studied the nonlocal effect on the pull-in instability of nano-switches under electrostatic and inter-atomic forces [123–126]. Aydogdu [127] developed a generalized nonlocal beam theory, from which earlier formulated theories can be obtained as special cases. He investigated the effect of nonlocality and length on the structural response of nanobeams.

Challamel and Wang [128] solved a paradox: the absence of small scale effect in some bending solution. They developed a hybrid model by taking strain energy as a function of both local and nonlocal curvatures. Zhang *et al.* [129] used this model to study the static and dynamic behavior of nanobeams and found the different solutions of bending for clamped beams and cantilever beams. Civalek and Demir [130] formulated a nonlocal EBT for bending analysis of microtubules using the differential quadrature method (DQM).

Thai [131] proposed a nonlocal shear deformation beam theory to study the structural response of nanobeams without using shear correction factor. Zenkour and Sobhy [132] proposed a shear and normal deformations nonlocal theory for bending of nanobeams under thermal environment. Also, they investigated the effects of nonlocality, length of the beam, length-to-depth ratio, temperature parameters, shear and normal strains on the bending of nanobeams. Rosa and Franciosi [133] proposed a simpler method to calculate the effect of nonlocal elasticity by using Mohr analogy with EBT and TBT. Reddy and Borgi [134] formulated beam theories using Eringen's differential model with the modified von Kármán nonlinearity and developed finite element (FE) model. They studied the effect of nonlocal parameter on the bending behavior. Khodabakhshi and Reddy [135] proposed a nonlocal integro-differential model as a more generalized Eringen's nonlocal model for 3-Dimensional FE formulation. They solved the inconsistency in results found by several authors [106, 121, 122, 128, 136] for a cantilever when compared to other boundary conditions.

Saez *et al.* [137] used an integral form of Eringen nonlocality for the bending analysis of Euler–Bernoulli beam and solved the paradox which was appearing in the solution of a cantilever beam using the differential form of Eringen nonlocality. Tuna and Kirca [138] derived the exact solution of the integral form of Eringen nonlocal model for the bending analysis of Euler–Bernoulli and Timoshenko beams. Koutsoumaris *et al.* [139] investigated the static response of nanobeams using nonlocal integral elasticity with the modified kernel. Romano and Barretta [140] compared stress-driven and strain driven nonlocal integral models for nano-beams. Romano *et al.* [141] discussed issues in the solution of nonlocal elastostatic problems of beams. They found that the constitutive boundary conditions are not compatible with the equilibrium conditions imposed on the bending field. Barretta *et al.* [142] developed a stress-driven nonlocal integral model to study the thermoelastic behavior of nanobeams.

Jiang and Yan [143] derived explicit solutions to study the combined effects of residual surface stress, surface elasticity and shear deformation on the static bending of NWs using Timoshenko beam model. They found that stiffness may increase or decrease with residual surface stress depending on the boundary conditions, and shear deformation always makes the NWs softer compared with the Euler–Bernoulli beam model. Ansari and Sahmani [144] proposed explicit formulas to each type of beam theories (EBT, TBT, RBT, and LBT) to investigate the surface stress effects on bending and buckling behavior of nanobeams and found identical results as Jiang and Yan [143]. Juntarasaid *et al.* [145] took the first step to investigate the combined effect of surface stress and nonlocal elasticity on the bending and buckling of nanowires. Mahmoud *et al.* [146] developed a nonlocal FE model to study the effects of beam thickness as well as nonlocality on the rigidity and bending behavior of Euler-Bernoulli nanobeams including surface effects. Preethi *et al.* [147] presented a non-local nonlinear FE formulation for bending and free vibration analysis of Timoshenko beam with surface stress effects.

Yang *et al.* [148] performed nonlinear thermal bending analyses for the simply supported (SS), Clamped-clamped (C-C), and propped cantilever shear deformable nanobeams. They used the Timoshenko beam model with von Karman geometric nonlinearity. Najar *et al.*[149] modeled nanoactuator as a Euler–Bernoulli clamped-free (C-F) beam and C-C beam to study its nonlinear static and dynamic responses when subjected to a DC voltage. They took into account Casimir and vdW forces, an electrostatic force with fringing effect, and von Kármán nonlinear strains. Hamilton's principle and DQM are used to derive and discretize the governing equation respectively.

In addition to nanobeams, many researchers reported flexural analysis of nanoplates in the literature. Aghababaei and Reddy [150] reported size-dependent third-order shear deformation plate theory for the bending and vibration analyses of S-S rectangular nanoplates. Further, Reddy [151] developed the nonlinear nonlocal Kirchhoff and Mindlin plate theories with von Kármán nonlinearity.

Golmakani and Rezatalab [152] performed nonlinear nonlocal bending analysis of orthotropic nanoplates resting on an elastic matrix foundation using nonlocal first-order shear deformation theory (FSDT). They found that an increase in scale coefficient results rise in linear to nonlinear deflection ratio for the nanoplate without elastic foundation and reversed effect of scale coefficient on the mentioned ratio for the nanoplate with elastic foundation. They also found sharper deference in results of local and nonlocal theories for clamped boundary condition than the simply supported, under a large load. While under small loads it is sharper in simply supported than clamped one. Far and Golmakani [153] used same tools as in [152] to study the large deflection behavior of a bilayer GS resting on polymer matrix under thermo-mechanical loads. Yan *et al.* [154] derived an infinite higher-order governing differential equations to formulate nanoplate models for bending analysis. They studied the small scale effect on bending behavior of the circular nanoplates under different boundary conditions and observed that the variation trend is independent of the constraints.

Wang and Wang [155] developed a FE model for static and dynamic analysis of nanoscale plates based on a mathematical model developed by Lu *et al.* [156] with surface effects. Zhang and Jiang [157] incorporated the surface effects and the flexoelectricity into the Kirchhoff plate model to study the size-dependent properties of a bending piezoelectric nanoplate. Raghu *et al.* [158] developed nonlocal third-order shear deformation theory taking into account the surface stress effects, to study the bending and vibration of nanoplates.

5.1.3 Nonlocal strain gradient theory

Lu *et al.* [159] developed a size-dependent unified high-order beam model to study the structural response of simply supported nanobeams. They found that the nanobeam stiffness-softening effect and stiffness-hardening effect depends on the relative magnitude of the material length scale parameter and nonlocal parameter. Xu *et al.* [110] obtained the closed-form solutions for bending and buckling loads of geometrical imperfect nanobeams by using the NSGT. They found that the higher-order boundary conditions and the material length parameters have a prominent effect on the buckling loads. However static bending is not affected by the higher-order boundary conditions. Tang *et al.* [160] revealed that the NSGT with thickness effect, the stiffness-hardening and stiffness-softening effects are dependent on the thickness of the beam. For constant length, decreasing thickness leads to an increase in stiffness-hardening effect.

Rajasekaran and Khaniki [161] reported the same type analysis as Li *et al.* [162] for isotropic tapered nanobeams using the FE method. Fakher *et al.* [163] investigated bending behavior along with vibration behavior using three different forms of NSGT. Which are differential forms of nonlocal strain gradient, a basic form of integral nonlocal strain gradient without satisfying higher-order boundary conditions, integral nonlocal strain gradient with satisfying higher-order boundary conditions. They found a significant difference in results with different approaches. Ouakad et al [164] studied the nonlinear response of electrically actuated CNTs by modeling it as C-C Euler–Bernoulli beam, which accounts both nonlinear von-Karman strain and electric actuating force. Recently, Norouzzadeh *et al.* [165] studied the nonlinear bending behavior of FE modeled nanobeams.

5.1.4 Nonlocal doublet mechanics

Ebrahimian *et al.* [166] studied the effect of chirality on the softening or hardening behavior of a Euler-Bernoulli and Timoshenko nanobeams in bending. Incorporation of the scale parameter and chiral angle makes the nanobeam softer. However, as the chiral angle rises from 0 to 30 degrees, the nanobeam becomes stiffer. Under same loading and boundary conditions, Timoshenko nanobeam changes from a softening to a stiffening behavior with an increase in chiral angle. Recent work related to flexural analysis of nanostructures are listed briefly and explicitly in Table 2.

5.2 Buckling analysis

5.2.1 Molecular dynamics

Montazeri *et al.* [174] explored the effect of chemically adsorbed Hydrogen atoms on the buckling behavior of graphene nanoribbons (GNRs) at 0.01 K temperature by using Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) software. They found that an increase in hydrogen concentration reduces the stiffness of GNRs. Wu and Soh [175] observed that when the axial compressive force is below the critical value, the nanorod contracts in the axial direction. While rod exhibits buckling when the force reaches a critical value. Further, an increase in external loading results in post-buckling. Zhang and Shen [176] performed MDS to study buckling and post-buckling behavior of SWCNTs under combined loading (axial compressive and torsion) at 300 K, 800 K, and 1500 K. They found that the SWCNTs has higher temperature dependence under large axial load as compared to under low axial load.

MDS performed on SWCNTs with intermolecular junction (IMJ) revealed that the critical strain for SWCNTs depends on the loading velocity under high strain-rate compressions while this dependency is negligible under low strain-rate compression. Two more things were also found: (i) buckling modes of an IMJ may transfer from shell buckling to column buckling when its aspect ratio exceeds a threshold value and (ii) As compared to CNTs, IMJ has a lower critical aspect ratio at which the transition of buckling mode occurs. These results may suggest a reasonable loading velocity for MDS [177, 178].

Hao *et al.* [179] studied the effect of a single vacancy on the buckling behaviors of SWCNTs and double-walled carbon nanotubes (DWCNTs) under axially compressed loading. They observed that the ratio of the number of defects to the number of atoms in the tube influences the buckling behavior of SWCNTs. They reported that the location of defects has a strong effect on the buckling behavior of the DWCNTs. Akita *et al.* [180] examine the influence of the number of layers on the buckling behaviors of MWCNTs with the fixed outer diameter, using a nanomanipulation scanning probe microscopy (SEM) and MDS. Zhang *et al.* [181] compared the buckling behaviors of (5,5) CNTs, ((4,4), (10,10)) DWCNTs, ((5,5),(10,10)) DWC-

Table 2: Representation of published articles on the bending analysis of nanobeams/nano plates/nanoshells

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
1	[167]	Micropolar theory, TBT, Hamilton's principle, variational principle	A finite element approach is proposed for the scale dependent bending analysis of nanobeam using the micropolar theory in corporation with the nonlocal elasticity	Shear co-efficient is assumed
2	[168]	Euler -Bernoulli beam theory, nonlocal elasticity	A nonlocal nonlinear model of nanobeam with small initial curvature is developed and used for mechanical analysis of SWCT	Shear effect is not considered and this represents only stiffness softening
3	[169]	Higher order shear deformation theory, nonlocal elasticity theory	Influences of nonlocal parameter, applied electric potential, Winkler and Pasternak's parameters of foundation are investigated on the electro-elastic bending of piezoelectric doubly curved nanoshell	Magnetic and thermal effects are not considered
4	[170]	Principle of virtual work, FSDT, nonlocal strain gradient piezo-magneto-elasticity theory	Influences of electric and magnetic potentials, porosity volume fraction, geometrical characteristics, and foundation parameters on the bending behavior of the sandwich nanoplate are studied	Temperature effect is not considered and poison ratio is constant.
5	[171]	Kirchhoff's plate theory, NSGT, Navier's method, principle of the virtual works	Bending behavior of S-S isotropic, antisymmetric orthotropic cross and angle-ply laminated nanoplates of rectangular shape subjected to uniformly and sinusoidally distributed loads are studied	Only simple supported boundary conditions are used
6	[172]	Higher order refined curved nanobeam theory, Two power-law models, Hamilton's principle, Kelvin–Voigt model	The influences of nonlocal parameter, structural damping, elastic foundation coefficients, and strain gradient length scale parameter on bending, buckling, and vibration response of viscoelastic FG curved nanobeam are investigated	Poisson's ratio is considered constant and temperature effect is not considered
7	[173]	EBT, power-law distribution, principle of the calculus of variation, Duhamel's integration, concept of the neutral surface	Analytical solutions for static displacement, critical buckling load, free vibration frequencies and dynamic displacement are obtained. Also, emphasized on the influence of the excitation frequency and the moving load velocity on the mechanical behavior of FG nanobeam	Solution is only for simply supported end condition and considered only limited type of loading conditions. Also, simple-power law model is used

NTs, ((6,6), (10,10)) DWCNTs, and ((7,7), (10,10)) DWCNTs by analyzing the van der Waals (vdW) forces. They used Tersoff–Brenner potential to describe the interaction of atoms in the tube, while Lennard–Jones potential to describe the van der Waals force between inner and outer tubes during the MDS. Wang [182] found that the CNTs containing polyethylene molecules buckle with the same process as CNTs, but the buckling strain is reduced by 35% as compared to empty CNTs.

Guo *et al.* [183] compared the buckling behaviors of gold-filled SWCNTs with gas-filled SWCNTs subjected to axial loading. They found that the gas or fullerenes filled SWCNTs collapses directly from the elastic region at the critical strain, while Au filled SWCNTs results in an elastic–inelastic transition before the critical strain. Which is a consequence of the difference between vdW forces and metallic interactions. Ansari *et al.* [184] investigated the mechanical properties and buckling behavior of diethyltoluenediamines functionalized CNTs using LAMMPS. In this, they implemented the Nose–Hoover thermostat algorithm within velocity-Verlet integrator algorithm to reduce the fluctuations in temperature. They used conjugate gradient algorithm to reach sufficient minimum relative energies and minimize the energy of the simulation system. Their results show a linear increase in Young's modulus and critical buckling force for both regular and random polymer distributions, while critical strain decreases with different modes depending on the type of polymer distribution. Jing *et al.* [185] performed MDS with Stillinger–Weber potential to study the effects of simulation temperature, wire length, and strain rate on buckling behavior of single-crystalline silicon NWs under the uniaxial load. They found that critical load decreases with increase in temperature, decrease in strain rate and increase of wire length.

Salmalian *et al.* [186] employed LAMMPS MD code with adaptive Intermolecular Reactive Empirical Bond Order (AIREBO) potential function and velocity Verlet algorithm to study the effects of side length, atomic structure and aspect ratio on the critical compressive force and critical strain of GSs. They found that for a constant aspect ratio, smaller GSs acquire larger buckling forces, but buckle at smaller strains. They also found two more things (i) critical forces of zigzag GSs greater than the armchair GSs and (ii) decrease in the critical strain as well as the critical force of GSs with an increase in the number of acetylene links. Jeong and Kim [89] performed MDS to investigate the failure behaviors of C60 fullerenes filled SWCNTs under tensile, compressive, torsional, and combined loads at 300K temperature. Inter atomic forces are modeled using modified Reactive Empirical Bond Order potential function and vdW interactions are modeled using Lennard-Jones potential.

Wong and Vijayaraghavan [90] performed MDS with Brenner's second-generation bond order function coupled with the long-range Lennard-Jones potential to study the buckling behavior of the non-uniform CNT bundle such as P–C, P–S and C–S bundle. They found that the C–S bundle have lower critical strain and buckling load compared to the C–C bundle. Nishimura *et al.* [187] investigated the local buckling of defective and non-defective five-walled CNTs under compression and bending load, using MDS with AIREBO potential. In general, it has been observed that temperature, diameter, length, and chirality of nanotubes affect Young's modulus, strain, and buckling mode of the nanotubes. Results show that Stress is very sensitive to helicity under large strain at 0 K temperature while Young's modulus has more dependence on the diameter than on the helicity [188, 189]. Chandra *et al.* [190] observed that critical buckling temperature of precompressed boron-nitride nanotubes increases with decrease in chiral angle as well as decrease in the diameter of the nanotube.

5.2.2 Nonlocal elasticity theory

There has been extensive research on the buckling of nanostructures, from the formulation of nonlocal models of EBT, TBT, and LBT beam theories to the nonlocal classical and shear deformation beam and plate theories using von Karman nonlinear strains [123, 151, 191–194]. Few researchers studied the buckling behavior of nanobeams using nonlocal integral and two-phase nonlocal integral model of Eringen [138, 195].

Roque *et al.* [196] used meshless method to obtain numerical solutions for bending, buckling and free vibration of nonlocal Timoshenko nanobeams. Then compared numerical solutions with the available analytical solutions. Emam [197] developed a general nonlocal nonlinear model to present analytical solutions for the critical buckling load and the nonlinear static amplitude in the postbuckling state for nanobeams. He found that increase in nonlocal parameter results in decrease in critical buckling load and increase in postbuckling amplitude. Chen *et al.* [198] developed a EBT based piezoelectricity and viscoelasticity coupled nonlocal beam model, to study the buckling, post-buckling, and nonlinear dynamic stability for the piezoelectric viscoelastic nanobeams under the action of vdW forces. Baghani *et al.* [199] studied the influence of compressive axial load, surface energy, and magnetic field on the dynamic and stability response of the rotating nanobeams.

Lim and his research group [200, 201] studied the nonlinear buckling of nanorods and shear deformable nanocolumns using the TBT and nonlocal elasticity, under the thermal load. Their results revealed that the critical buckling loads are higher in nonlocal theory as compared to classical theories with or without shear deformation. They also found that at room temperatures, increase in temperature change led to rise in buckling load of nanostructures, while increase in temperature change leads to decrease in buckling load at high temperature. Tounsi *et al.* [202] incorporated the nonlocal effects and von karman nonlinearity in the higher order beam model given by Shi and Voyiadjis [203], for thermal buckling analysis of nanobeams. In recent years, buckling and post buckling of piezoelectric nanobeams are investigated under thermo-electro-mechanical loads [204, 205].

Many researchers investigated the buckling behavior of nanostructures such as a nanobeams, nanorods, and nanotubes in a temperature field. Using variational principle. Lim et al [201] proposed a nonlocal thermoelastic model to study the effects of nonlocal parameter and temperature change on buckling behavior of nanorods. Yang and Lim studied [200] the thermal and nonlocal parameter effects on buckling of shear deformable nanocolumns by using nonlocal stress theory with von Kármán nonlinearity. Tounsi et al [202] extended the nonlocal beam model developed by Thai and Tai [131], for the buckling behavior of nanobeams under the thermal field. Liu *et al.* [205] investigated the buckling and post-buckling behaviors of piezoelectric nanobeams by using the nonlocal TBT with von Kármán geometric nonlinearity. They concluded that an increase in the nonlocal parameter as well as temperature results in a decrease in both critical buckling load and post-buckling strength. They also found that positive voltage leads to decrease in the critical buckling load and post-buckling strength, while for negative voltage this effect is reversed. Jandaghian and Rahmani [204] studied the buckling behavior of the piezoelectric nonlocal Euler-Bernoulli beam under thermo-electro-mechanical loadings. Their results were similar to the reults obtained by Liu *et al.* [205].

Yan *et al.* [206] studied the effect of temperature, scale parameter and wavenumber on the critical axial buckling load of triple-walled CNTs with the initial axial stress, using nonlocal Donnell's shell model as used in [207]. They found that the small scale effect increases gradually with the increase in wavenumber. Furthermore, the axial buckling load increases with increase in temperature at room temperature range, while at high temperature range the axial buckling load decreases with increase in temperature.

5.2.3 Nonlocal strain gradient theory

In addition to the use of nonlocal elasticity theory, lot of research has been carried out to investigate the buckling response of nanobeams by using NSGT [110, 159, 161, 162]. Khaniki and his research team emphasized on the buckling response of tapered nanobeams using the NSGT and EBT [208, 209]. Li and his research team explored the nonlinear buckling response of the isotropic and FG nanobeams with various geometric nonlinearities by using the NSGT in conjunction with the EBT. Also, they employed the size dependent effects and higher order strain gradients along with the thickness of nanobeams and studied the influence of thickness on the post buckling response of the nanobeams. Results revealed that the stiffness-softening and stiffness-hardening effects in nanobeams depend not only on the ratio of nonlocal parameter to strain-gradient parameter, but also on the thickness of nanobeams [210–212]. Sahmani and his research team emphasized on the investigation of nonlinear buckling response of supramolecular nano-tubules and lipid protein nano-tubules nanostructures using the NSGT and third-order shear deformable beam model [213, 214].

In addition to the focus on nanobeams, researchers are now investigating nanoplates using NSGT. Farajpour *et al.* [215] developed a nonlocal strain gradient plate model based on the higher-order NSGT, to study the thermal buckling of orthotropic nanoplates resting on a two-parameter elastic foundation. Three different kinds of scale parameters considered in the formulation for better results at nanoscale. The higher-order governing differential equation are derived by virtual work principle and solved using the differential quadrature method. Based on physical neutral surface concept Radic [216] studied the buckling behaviors of porous double-layered FG nanoplates in hygrothermal environment.

Malikan and Nguyen [217] developed a one variable first order shear deformation plate theory for the buckling analysis of piezo-magnetoelectric nanoplates resting on an elastic matrix in hygrothermal environment. In this, size effect are incorporated by the higher order NSGT and considered plate is subjected to external in-plane mechanical forces along with magnetic and electric potentials between the upper and bottom faces. Moreover, the Navier's and Galerkin's solutions were used to solve the stability equations to get the numerical results with several boundary conditions. Results revealed that the critical buckling load is more influenced by the magnetic potential than the electric potential. An increase in magnetic potential leads to a significant rise in critical buckling loads and electric potential rise have reversed effect on it. Hygral region potential has more significant influence on the critical buckling loads than the thermal environment. Increase in the moisture percentage leads to stiffness softening of the plate which was more significant at lower temperatures than the high temperatures.

Sahmani and Fattahi [218] developed a comprehensive size-dependent shell model using the NSGT and a refined exponential shear deformation shell theory. In the continuation, authors investigated the nonlinear buckling and post buckling response of magneto-electro-elastic composite nanoshells. Governing differential equations are derived containing the coupling terms between the mechanical load, external magnetic and electrical potential. The nonlinear buckling and the large postbuckling displacements are taken into account based upon the boundary layer theory of shell buckling. Results revealed that a negative magnetic potential and a positive electric potential leads to increase in influence of nonlocality and strain gradient effects on the nonlinear buckling behavior of considered nanoshells, while a positive magnetic potential and a negative electric potential play an opposite role [219]. Author continued his study to investigate the nonlinear instability of FG multilayer GPLs reinforced composite nanoshells using the nonlocal strain gradient hyperbolic shear deformable shell model [220].

5.2.4 Nonlocal doublet mechanics

In the last two years, Gul and Aydogdu reported an extensive study on mechanical analysis of various nanostructures using the DM. They performed static deformation, buckling, vibration and wave propagation analysis of nanorods and nanobeams by using doublet mechanics in conjunction with the Classical rod theory and EBT. They found that the natural frequencies and critical buckling loads reduce with rising in the doublet distance, especially for short lengths. While bending of the beams, critical buckling loads, vibration frequencies, elongation of the rod, and wave properties predicted by the DM approach to the classical mechanics results with decreasing the doublet distance. In wave propagation of the graphite, DM results reported a better agreement with the experimental results compared to strain gradient models and classical models [221]. In continuation, the authors investigated the buckling behavior of double nanobeams system embedded in an elastic medium based on a Euler-Bernoulli beam model and scale-dependent doublet mechanics theory. They obtained governing equations based on the minimum potential energy principle and reported the exact solution for the critical buckling loads of the considered system [114]. Authors continued their study to investigate the vibration and buckling response of embedded nanotubes using the size-dependent DM. Nanotube was modeled based on the Euler–Bernoulli beam embedded in an elastic medium and reported solution for Free vibration frequencies and critical buckling loads under simply supported and clamped boundary conditions [222]. Furthermore, authors modeled embedded DWCNTs based on the Euler-Bernoulli beams within the framework of DM and reported numerical results for free vibration and buckling of considered DWCNTs system, for simply supported boundary conditions. They found that the elastic medium increases the dimensionless frequency parameter [113]. Recent work related to buckling analysis of nanostructures are listed briefly and explicitly in Table 3.

5.3 Vibration analysis

5.3.1 Nonlocal elasticity theory

Since nanostructures are extensively used as resonators in nano-electro-mechanical systems, pioneering studies on vibration response of nanostructures are carried out by many researchers in the last decade of years. The nonlocal elasticity theory in conjunction with other classical theories has been broadly adopted for analyzing the vibration response of nanostructures [1, 235–237]. Lee and Chang [238] applied the nonlocal elastic theory to investigate the surface and small-scale effects on the frequency response of a tapered nanobeam with fixed-free boundary condition. Mechab *et al.* [239] investigated the free vibration response of orthotropic beams by using the nonlocal higher-order shear deformation laminates theory including the Poisson effect. Apuzzo *et al.* [240] formulated a stress-driven integral model for Bernoulli-Euler nanobeams and computed the fundamental natural frequencies of nanobeams with various boundary conditions. Khaniki [241] emphasized on the Eringen's two-phase nonlocal integral model to study the vibration response of double-layered nanobeam systems with various boundary conditions. This model overcomes the limitations of differential form of Eringen's nonlocal elastic theory in the analysis of nanostructures.

Many researchers employed nonlocal elasticity theory in various local plate theories such as classical plate theory [242–245], first- order shear deformation plate theory [246, 247], two-variable refined plates [248, 249], and higher-order shear deformation plate theory [250–252] to study the linear vibration response of nanoplates.

Malekzadeh and Farajpour [253] examined the free and forced vibrations response of embedded single and double-layered circular nanoplates under the initial in-plane radial stresses. They found that the natural frequencies of considered nanoplates decreases with increase in the value of nonlocal scale parameter. Also, the higher-order natural frequencies are more sensitive to the nonlocal parameter and the plate radius. Furthermore, increasing the magnitude of the initial radial tensile stresses increases the natural frequencies. Kiani [251] studied the in-plane and out-of-plane free vibrations of a conducting nanoplate under the unidirectional in-plane steady magnetic field by incorporating the nonlocal elasticity into the Kirchhoff, Mind- lin, and Reddy plate theories.

Table 3: Representation of published articles on analysis of nanobeams/nano plates/nanoshell using nonlocal elasticity.

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
1	[223]	Weighted residual approach, modified nonlocal theory, Euler–Bernoulli beam theory	The variational consistent higher order boundary conditions are formulated for the three characteristic-lengths featured size-dependent gradient-nanobeam and closed form solution for buckling load is obtained	Material is isotropic and shear effect is not considered
2	[224]	Fractional calculus, nonlocal fractional derivative model, TBT, Galerkin method	The free vibration and buckling of a nanobeam is studied based on the conformable fractional derivatives	Only simply supported boundary condition is considered
3	[225]	Extended Hamilton's principle, and extended Galerkin's approach	Influence of piezoelectric voltage and surface effects on the vibration and stability behavior of double nanobeam system is reported. Furthermore divergence and flutter analysis performed	Material is isotropic and temperature effect is not considered
4	[226]	Kelvin–Voigt model, Hamilton's variational principle, TBT, Navier's, and Bolotin's approach	Effects of magnetic field, nonlocal parameter, length to thickness ratio, structural damping, static load factor, power-law index and porosity volume index, foundation type on the dynamic stability characteristics of nanobeam are investigated.	Temperature effect and geometric imperfection is not considered. Also, shear correction factor is assumed
5	[227]	Nonlocal elasticity, Mindlin theory, Kantorovich method, finite element method	A coupled finite strip–finite element formulation is developed to study the buckling and vibration response of an imperfect nanoplate	The obtained solutions are only approximated
6	[228]	Refined plate theory, Galerkin method, Reuss micro-mechanical scheme, Hamilton's principle	Influences of material variation, temperature changes, and scale parameters on the buckling response of nanoplate are presented	Material properties are varying only in thickness direction and power law model is used to assume material properties
7	[229]	TBT, Variation principle, weighted residual method	The variationally consistent boundary conditions corresponding to the equations of motion of nonlocal strain gradient Timoshenko beams are reformulated using the weighted residual method and closed form solution for buckling load is obtained	Material is considered isotropic
8	[230]	NSGT, EBT, Hamilton's principle, two-step perturbation method	Influences of geometrical, material, and elastic foundation parameters on the nonlinear mechanical behaviors of nanobeams are examined	Temperature effect is not considered
9	[231]	Refined plate theory, Hamilton's principle, Rayleigh-Ritz method	Using various plate theories, results of nonlocal strain theory and nonlocal stress theory are compared for the buckling load and natural frequency	Mindlin's nonlocal plate theory is not considered
10	[232]	higher-order nonlocal strain gradient theory, Liapunov method, EBT	A dynamic stability and instability problem of a nanobeam is investigated by considering the stochastic parametric vibrations	Inertia effect and shear effects are not considered
11	[233]	Nonlocal couple stress theory, higher order refined beam theory, Chebyshev–Ritz method	Chebyshev–Ritz method is implemented for static stability and vibration analysis of FG nanobeam	Material properties are graded only following power law
12	[234]	Eringen's nonlocal elasticity theory and TBT	The critical loads in the nanobeams were obtained assuming a functional dependence of the nonlocal parameters on the state of stress and vibrational frequency	Small-scale effect in the shearing force is neglected

Farajpour and his research team explored the vibration response of coupled piezoelectric nanoplate systems with various boundary conditions. They studied the influence of various parameters such as initial stress, nonlocal parameter, external electric voltage, elastic foundation parameter, temperature change, aspect ratio, length-to-thickness ratio, and mode number on the vibration characteristics of the considered systems [254–256]. Furthermore, they developed a nonlocal continuum model for the size-dependent nonlinear free vibration of magneto-electro-elastic nanoplates under the action of external electric and magnetic potentials. They modeled geometric nonlinearity based on von Kármán's assumptions. They obtained the closed-form solutions for the nonlinear natural frequencies, critical external electric voltages and critical magnetic potentials of considered nanoplates with distinct boundary conditions. Also, they emphasized on the influence of initial edge displacement on obtained solutions [257, 258].

Together with the analysis of nanobeams and nanoplates, the vibration response of nanorods [259–261], embedded nanorods [262, 263], double nanorod systems [264, 265], and tapered nanorods [266] has been examined using the nonlocal continuum mechanics in the literature. Murmu *et al.* [267] presented the analytical solution for the axial vibration of embedded nanorods under the excitation of a transverse magnetic field by using the nonlocal rod theory. They revealed that the transverse magnetic field weakens the influence of nonlocal effect. Also, the alteration of frequency with the axial stiffness parameter of a nanorod in an elastic medium and magnetic field becomes more nonlinear by considering the nonlocal effect. Karlicic and his research team emphasized on the longitudinal vibration analysis of nonlocal viscoelastic coupled multi-nanorod system and the influence of transverse magnetic field on vibration response of the multi-nanorod systems [265, 268].

Li *et al.* [269] employed the nonlocal elasticity theory in the Bishop-Love rod theories to develop a nonlocal higher-order model for studying the axial free vibration of nanorods. The developed model consists of radial inertia and deformation effect. Furthermore, by using the nonlocal elasticity theory and Love rod Li *et al.* [270] studied the vibration response of a nanorod carrying a tip mass. They found that the attached mass and inertia of radial motion reduces the resonance frequencies, however, large tip mass rises the frequency shift, irrespective of considering or neglecting the nonlocal effect. Numanoglu *et al.* [271] investigated the longitudinal free vibration characteristics of nanorods carrying tip mass with various boundary conditions.

Recently, Karlicic *et al.* [272] obtained the exact closed-form solutions for the fundamental frequencies of the multiple nanorods system installed on an elastic medium with various boundary conditions. The governing equations of motion of the system are determined by using the nonlocal elasticity theory, Bishop's rod theory, and Hamilton's principle. They concluded that the increase of elastic medium stiffness coefficients leads to an increase of natural frequencies, while the rise in the number of nanorods has reversed effect on the natural frequency of the system.

5.3.2 Nonlocal strain gradient theory

NSGT based models have been also reported for the vibration response of nanoscale beams [161–164, 273]. Lu *et al.* [274] developed a size-dependent sinusoidal shear deformation beam model based on the NSGT. Hamilton's principle was employed to derive the governing equations and boundary conditions. Moreover, analytical solutions for natural frequencies of S-S nanobeams obtained by Navier's method. They found higher natural frequencies by the NSGT than those obtained by nonlocal theory and lower than those predicted by strain gradient theory. Furthermore, they observed the higher influence of shear deformation for nanobeams with lower values of slenderness ratios and at higher modes. Apuzzo *et al.* [275] obtained an exact solution for axial and flexural free vibrations of the cantilever and fully-clamped Euler-Bernoulli nanobeams using the modified nonlocal strain gradient elasticity model developed in [276]. Zhen *et al.* [277] explored the free vibration response of viscoelastic nanotubes under the action of a longitudinal magnetic field by utilizing the Timoshenko beam model and Kelvin-Voigt model in conjunction with the NSGT. Wang *et al.* [278] investigated the transverse free vibration response of axially moving Euler-Bernoulli nanobeams based on NSGT with the consideration of geometrical nonlinearity. They revealed that the increase in material characteristic parameter leads to a rise in critical velocity and nonlocal parameter has reversed effect on it. Also, the first few natural frequencies can be raised by reducing the axial speed in the subcritical range or raising the axial speed in the supercritical range. But considered nanobeam loses stability with an increase in axial speed. In continuation, the author explored the dynamic vibration behavior of an axially moving viscoelastic nanobeams [279]. Also, the exact solution was presented by Khaniki and Hashemi [280] for dynamic transverse vibration behavior of tapered nanobeams by utilizing the generalized DQM. Moreover, Guo *et al.* [281] promoted the dynamic transverse vibration characteristics of axially moving and rotating nanobeams using Hamilton's principle and Galerkin approach.

Nonlocal strain gradient rod models have been also proposed for the vibration analysis of nanorods. Li *et al.* [282] used Hamilton's principle to formulate the equations of motion and boundary conditions for the vibration analysis of nanorods. They determined the analytical solutions for the natural frequencies and mode shapes of the nanorods. Also, a FE method is developed to solve the vibration problems, which accounts both classical and nonclassical boundary conditions. They extended their study to solve the dynamic vibration problem of a nanorod [283].

The first time, Simsek [284] investigated the axial vibration response of an embedded nanorod using NSGT. Xu *et al.* [285] reformulated the variational consistent boundary conditions for the nonlocal strain gradient nanorods with the help of the weighted residual method. They identify and solve the boundary value problems to determine the frequency of the nanorods. Furthermore, they studied the asymptotic dynamic behaviors of nanorods.

Adeli *et al.* [286] emphasized on the torsional vibration response of nano-cone in the framework of NSGT, Hamilton's principle and the generalized DQM. Borgi *et al.* [287] modeled a viscoelastic nanorod embedded in an elastic medium in the framework of NSGT and velocity gradient theory. This model consists of three length-scale parameters, which are nonlocal, strain gradient and velocity gradient parameter. These parameters help to account both softening and stiffening of the nanorods. Also, Kelvin–Voigt viscoelastic damping model is used to model the viscoelastic behavior of the nanorod. They obtained both exact analytical and numerical solutions for frequencies and damping ratios by utilizing a Locally adaptive DQM.

In addition to nanorods, vibration responses of nanotubes are also investigated. Shafiei and She [288] predicted the thermal vibration behavior of two- dimensional FG nanotubes using the NSGT and higher-order beam model presented in [289] for tubes. The temperature considered to be uniform across the radius. However, material properties of the nanotubes vary both in the length and radial direction. They utilized Hamilton's principle to derive the size-dependent governing equations and solved these equations using the generalized differential quadrature method. Authors continued their study to determine the vibration characteristics of porous FG nanotubes in a thermal environment using a refined beam model [290]. They found softening and stiffening of the considered nanotube depending on the values of nonlocal and the strain gradient parameters. Also, the rise in volume fraction index and temperature leads to reduced natural frequencies. However, the effect of porosity on the natural frequency is dependent on the value of volume fraction index.

Nanoplates such as silver nanoplates [291], GSs [292], and metallic carbon nanosheets [293] have a remarkable potential applications in various fields of nanotechnology. Hence, number of researcher reported the vibration analysis of nanoplates in last few years [294–296].

Lu *et al.* [2] determined the exact analytical solution for the natural frequencies of S-S nanoplates using the surface elasticity theory, Kirchhoff and Mindlin plate model. It was reported that the influence of surface effects on the vibration response of nanoplates is dependent on the size of nanoplates. Moreover, the influence of nonlocal stress and strain gradient on the vibration behavior is more prominent for nanoplate with lower length-to-thickness ratio and higher aspect ratio. Besides rectangular FG nanoplates, the vibration response of circular FG nanoplates has also been reported in the literature.

In addition to vibration analysis of nanoplates and GSs using NSGT, many researchers have been also reported the NSGT based vibration analysis of nanoshells in literature [297, 298]. Barati [299] modeled porous FG nanoshells in an elastic medium based on the FSDT in conjunction with the NSGT and reported the numerical solution for the natural frequency of nanoshells based on Galerkin's method. The parametric study revealed that the rise in porosity volume fraction leads to smaller natural frequencies. But, uneven porosity distribution gave larger frequencies compared with even porosity distribution. Also, increasing the radius-to-thickness and length-to-thickness ratios led to smaller frequencies, while increasing the foundation coefficients has reversed effect on frequencies.

5.3.3 Nonlocal doublet mechanics

In addition to bending and buckling analysis of nanostructures using DM, many researchers used it for vibration analysis too. Vajari and Imam [300] presented a DM with a length scale parameter based exact solution for axial vibration of SWCNTs. A fourth-order partial differential governing equation of motion was derived and solved for natural frequency of SWCNTs. Results reported that the length scale parameter decreases the natural frequency compared to results predicted by the classical continuum mechanics models. Furthermore, they studied the effect of scale parameter radius on CNTs and chirality on the torsional vibration of SWCNTs using scale-dependent DM [301]. In the next paper [302], they applied size-dependent DM to investigate the radial breathing like mode vibration of SWCNTs. A second-order partial differential governing equation of motion was derived and solved for natural frequency of SWCNTs. With the scale parameter, they found the less natural frequency of vibration than the frequency predicted by the classical continuum models. However, with an increase in the radius of SWCNTs, the influence of the scale parameter on the natural frequency decreases. Vajari [303] continued their study to investigate the radial breathing like mode vibration of DWCNTs based on the size-dependent DM. He assumed DWCNTs as two concentric cylindrical shells restrained together with Len-Jones potential modeled vdW forces. He derived two coupled second-order partial differential governing equations

Table 4: Representation of published articles on vibration analysis of nanobeams/nano plates/nanoshells

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
1	[304]	Von Karman nonlinear relations, Kelvin–Voigt model, Hamilton's principle, Galerkin Technique, multiple scale method	Nonlinear frequency response of piezoelectric sandwich nanoplates under the influence of electric voltage exerted on piezoelectric layer and shock force pulse is reported	Material is isotropic and temperature effect is not considered
2	[305]	Extended Melnikov method, perturbation analyses	The homoclinic behavior and chaotic motions of the buckled double layered nanoplates are studied	Limited boundary conditions are considered
3	[306]	FEM, principle of total potential energy, nonlocal integral elasticity theory, classical plate theory	A finite element formulation is reported for free vibration analyses of nanoplates	Temperature effect is not considered and material is isotropic
4	[307]	Laplace transformation techniques	The scale-dependent thermo-electro-mechanical responses of multi-layered piezoelectric nanoplates are examined for the vibration control	Material is isotropic. Also, initial imperfection and humidity effect are not considered.
5	[308]	Classical thermo-elasticity	Thermo-elastic damping of in-plane vibration of a FG nanoplate is examined	Material properties are graded only following power law
6	[309]	Hamilton's principle, Galerkin method	Dynamical instability of an axially-moving nanoplate embedded on a viscoelastic foundation is explored	Material is isotropic and temperature effect is not considered
7	[310]	Hamilton principle, polynomial based DQM, Sinc DQM, and Discrete singular convolution DQM	Sinc DQM and Discrete singular convolution DQM are examined to study vibration characteristics of elastically supported piezoelectric nanobeams embedded on nonlinear Winkler–Pasternak foundation	Accuracy of the results depends on the type of shape functions used and material is isotropic
8	[311]	Nonlocal elasticity, refined beam theory, Finite element method	Finite element formulation is presented for vibration analysis of porous metal foam nanobeams resting on an elastic medium	Poison ratio is considered constant and shear correction factor is not used.
9	[312]	FSDT, Hamilton's principle, method of multiple scales, Kelvin–Voigt structural damping, and perturbation method	The free vibrations and dynamic response of orthotropic laminated beam under the action of transient and harmonic loads are investigated	Only axial force is considered in dynamic response analysis and temperature effect is not considered
10	[313]	FEM, Hamilton's principal, Galerkin method	Influences of the crack position, crack length, temperature gradient, boundary conditions and the foundation stiffness, on the vibration response of the cracked nanobeams resting on an elastic foundations is discussed by including thermal effects	Crack is assumed as a torsional spring and obtained solutions are only approximated

Table 4: ...continued

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
11	[314]	EBT,nonlinear von Karman theory, and Galerkin method	Emphasized on the influence of parametric excitation, by considering the instability regions and bifurcation points during the nonlinear vibration behavior and dynamic instability investigation of a nanobeam under thermo-magneto-mechanical loads	Material is isotropic and shear effect is not considered
12	[315]	EBT, Galerkin approximation method, Runge–Kutta numerical method	The primary resonance and chaotic vibration of a curved SWCNT resting on a viscoelastic foundation exposed to axial thermomagnetic and transverse harmonic forces are studied.	The obtained solutions are approximated
13	[316]	Zener model, Laplace transform, Bessel functions theory and the binominal series	The fractional Zener model is employed for dynamic analysis of a viscoelastic nanobeam	Only simple supported boundary condition and uniform distributed load are considered.
14	[317]	Hamilton's concept, Love's shell theory, Fourier decomposition and DQM	The vibration response of rotating CNT with various boundary conditions is examined	Material is isotropic, and temperature effect is not considered
15	[318]	Galerkin method, FEM, Monte Carlo simulations, Newmark method, Bochner-Khinchin theorem	Transverse vibration behavior of a SWCNT under random loading condition is investigated.	Only clamped-clamped boundary condition is used.
16	[319]	Hamilton's Principle, Non-local elasticity theory	Torsional vibration analysis of a bio-molecular motor is carried out by model it as a DWCNT system embedded in a viscoelastic medium.	Material is considered continuum and isotropic
17	[320]	Parabolic shear deformation theory	The effects of Poisson's ratio and nonlocal parameter in thickness direction are studied	Considered only hinged-hinged boundary conditions
18	[321]	Inverse Laplace transform approach, refined beam theory, Galerkin's method	Transient vibration analyses of porosity - dependent FG nanobeam under various impulsive loadings are studied	Only even and uneven distribution of porosity are considered.
19	[322]	EBT,TBT, Galerkin's method, Laplace transform method, surface elasticity	The forced vibration behaviors of nano beams with surface effects subjected to a moving harmonic load travelling with a constant velocity are examined and obtained closed-form solution for the critical velocities	Only S-S boundary condition is considered and variation in velocity of moving harmonic load is not considered
20	[323]	EBT, DQM, first order nonlocal strain gradient model, Winkler elastic foundation model	Dynamical behavior of nanobeam resting on constant, linear, parabolic, and sinusoidal types of Winkler elastic foundations are investigated. Also, influence of non-uniform parameter and Winkler modulus parameter on the frequency parameters is studied	Temperature effect is not taken into account

Table 4: ...continued

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
21	[324]	NSGT, Kelvin-Voigt model, Hamilton principle	Effect of viscoelasticity and initial imperfection on the nonlinear vibration response of CNT with large deformation is reported	Only C-C boundary condition is considered and temperature effect is not taken into count
22	[325]	Reddy's third-order shear deformation plate theory, improved perturbation technique, von Karman nonlinearity, Galerkin procedure and the Hamilton's principle	The nonlinear vibrational behavior of a VdW bonded double-layered nanoplates subjected to thermal load is studied	Only S-S and C-C boundary conditions are considered
23	[326]	Refined plate model, NSGT, Hamilton's principle, Galerkin's method	The effects of nonlocal parameter, strain gradient, porosity distributions and porosity coefficient, foundation parameters on vibration characteristics of metal foam coupled nanoplates are examined	Poison ratio is considered constant and influence of temperature change is not considered
24	[327]	Refined exponential shear deformation theory, closed-cell Gaussian random field scheme, Halpin–Tsai micro-mechanical modeling, variational approach, improved perturbation technique, Galerkin method	A vibrational response of axially loaded FG porous nanoplate reinforced with GPLs is investigated within prebuckling and postbuckling domain	Poison ratio and temperature is considered constant, and only axial loading is taken into account.
25	[328]	FSDT, Hamilton's principle, Gurtin-Murdoch surface elasticity model, and generalized DQM	Influences of surface elastic properties, residual surface stress, and surface mass density on the vibration response of cylindrical shell are investigated at different values of size-dependent parameters	Temperature effect is not considered
26	[329]	EBT, Kelvin-Voigt approach, Hamilton principle, Galerkin method	A scale-dependent coupled longitudinal-transverse nonlinear formulation is presented for the mechanical behavior analysis of viscoelastic CNTs	Shear effects are not considered
27.	[330]	HSDT, modified power law rule, Hamiltonian principle, Navier method	Influences of small scale parameters, geometry conditions, material compositions, porosities and thermal environment on the free vibration analysis of doubly-curved nanoshells are examined	Only S-S edges boundary condition is considered.
28	[331]	Modified NSGT	A nanorod model is developed based on the modified NSGT to study the extensional behavior of nanorods and CNTs	Only extensional behavior is investigated

Table 4: ...continued

Sr no.	Ref.	Theory/Method used	Major outcome	Limitation
29	[332]	NSGT, refined higher order shear deformation beam model, Hamilton's principle, two steps perturbation method, power-law	Analytical solution is obtained to carry out a nonlinear vibration analysis of nanotube and influences of inner temperature, nonlocal parameter, strain gradient parameter, scale parameter ratio, slenderness ratio, radius, volume indexes, different beam models on the linear and nonlinear frequencies are studied	Only power law of material gradation is used.
30	[333]	TBT, Hamilton's principle, Modified Fourier series method, weighted residual method	An analytical solution for dynamic analysis of the hetero-junction carbon nanotubes based mass nanosensors is proposed	Damping and temperature effects are not considered

and solved to obtain the vibration of DWCNTs. He found higher frequencies of the Zigzag DWCNT than that of the Armchair. Also, the in-phase mode of DWCNTs has the lowest frequency while the anti-phase mode has the highest frequency of vibration.

Gul *et al.* [112] reported the axial vibration analysis of CNTs embedded in an elastic medium using scale-dependent DM. They derived governing equations and corresponding boundary conditions based on the variational principle and obtained the natural frequencies. Detailed parametric analyses were conducted to examine the influences of elastic medium stiffness, length and doublet separation distance on the axial vibration. They reported that the dimensionless frequency parameter predicted by the DM approach decreases with increase in doublet distance specifically for higher modes.

In addition to CNTs, Vajari and Imam [334] investigated the lateral vibration of single-layered GSs based on DM with scale parameter. They derived a sixth-order partial differential governing equation and solved for natural frequency of GSs. They found that the length scale parameter decreases the natural frequency. However, the influence of scale parameter decreases with increase in the length of the GSs. They also found that the frequency ratio for Zigzag GSs is slightly higher than the Armchair one.

Vajari and Azimzadeh [335] investigated the nonlinear axial vibration of SWCNTs based on Homotopy perturbation method and DM. They derived a second-order partial differential governing equation and obtained the nonlinear natural frequency in axial vibration mode using Homotopy perturbation method. They reported a parametric study to investigate the influences of boundary conditions, radius, length, amplitude of vibration, and changes in vibration modes on the nonlinear axial vibration characteristics of SWCNTs. They found that the rise of maximum vibration amplitude leads to decrease in natural frequency. However, at large tube length, the effect of the amplitude on the natural frequency is negligible. Also, the amount and change of nonlinear natural frequency are more prominent in the higher mode of vibration and clamped-clamped boundary conditions. Recent work related to vibration analysis of nanostructures are listed briefly and explicitly in Table 4.

6 Conclusion

A comprehensive review is given in the present paper, in which different type of fabrication techniques, specific applications of nanostructures, different methods adopted for static and dynamic response of nanostructures has been discussed. Also, critical review of various investigations on the static, buckling and vibration analyses of nanostructures including nanorods,nanobeams, nanoplates and nanoshells has been carried out. The general observations from the present literature review are listed as.

1. Among the various methods like MDs, nonlocal DM, nonlocal elasticity theory, and NSGT employed for the analysis of nanostructures, nonlocal elasticity theory is extensively used. Some modification has also been incorporated in nonlocal elasticity theory by the researchers time to time, to increase the accuracy of results.
2. TBT in conjunction with nonlocal elasticity theory and NSGT is extensively applied for the structural analysis of nanobeams and CNTs.
3. Nonlocal parameter has stiffness softening effect, while strain gradient parameter has stiffness hardening effect on the buckling, bending and vibration analysis of all type of nanostructures.
4. Effect of nonlocal parameter is more prominent on the buckling and vibration as compared to the bending of nanostructures. Increasing nonlocal parameter leads to decline in buckling load and natural frequency, while increment in the deflection.
5. Generally, the influence of small scale parameter, aspect ratio, porosity index, porosity distribution, external voltage, magnetic field, hygro-thermal environment, boundary conditions, surface energy, initial curvature and geometric nonlinearity on the structure response of isotropic, orthotropic and FG nanostructures are analysed.
6. According to NSGT, increase or decrease of stiffness depends on the relative magnitude of the material length scale and nonlocal parameters. So critical buckling load, deflection and natural frequency may rise or fall depending on the relative magnitude of two parameters.
7. Computational cost of NSGT is high as compared to the nonlocal elasticity theory.
8. Bending analysis of nanoplates using NSGT is not explored to much.
9. Finding the structural response of nanostructures with internal junction using the nonlocal elasticity theory and NSGT is not reported yet.
10. Accuracy of upgraded continuum theories depends on the calibration of parameters.
11. Very few papers dealing with structural responses of sandwitch nanostructures, cracked nanostructures and reinforced nanocomposites are reported. In addition, compared to free and forced vibration analysis, the damped vibration analysis of nanostructures has not been studied comprehensively.

References

[1] Farajpour A., Ghayesh M.H., Farokhi H., A review on the mechanics of nanostructures, Int. J. Eng. Sci., 2018, 133, 12, 231-263.

[2] Lu L., Guo X., Zhao J., On the mechanics of Kirchhoff and Mindlin plates incorporating surface energy, Int. J. Eng. Sci., 2018, 124, 3, 24-40.

[3] Rafiee R., Moghadam R.M., On the modeling of carbon nanotubes: a critical review, Compos. Part B: Eng., 2014, 56, 1, 435-449.

[4] Yengejeh S.I., Kazemi S.A., Oechsner A., Advances in mechanical analysis of structurally and atomically modified carbon nanotubes and degenerated nanostructures: A review, Compos. Part B: Eng., 2016, 86, 2, 95-107.

[5] Ansari R., Rouhi H., Sahmani S., Calibration of the analytical nonlocal shell model for vibrations of double-walled carbon nanotubes with arbitrary boundary conditions using molecular dynamics, Int. J. Mech. Sci., 2011, 53, 9, 786-792.

[6] Shahsavari D., Karami B., Li L., Damped vibration of a graphene sheet using a higher-order nonlocal strain-gradient Kirchhoff plate model, Comptes Rendus Mécanique, 2018, 346, 12, 1216-1232.

[7] Al-Jumaili A., Alancherry S., Bazaka K., Jacob M., Review on the antimicrobial properties of carbon nanostructures, Materials, 2017, 10, 9, 1066.

[8] Thess A., Lee R., Nikolaev P., Dai H., Petit P., Robert J., et al., Crystalline ropes of metallic carbon nanotubes, Science, 1996, 273, 5274, 483-487.

[9] Bethune D., Kiang C.H., De Vries M., Gorman G., Savoy R., Vazquez J., et al., Cobalt-catalysed growth of carbon nanotubes with single-atomic-layer walls, Nature, 1993, 363, 6430, 605-607.

[10] Journet C., Maser W., Bernier P., Loiseau A., de La Chapelle M.L., Lefrant d.S., et al., Large-scale production of single-walled carbon nanotubes by the electric-arc technique, Nature, 1997, 388, 6644, 756.

[11] Dai H., Carbon nanotubes: opportunities and challenges, Surf. Sci., 2002, 500, 1-3, 218-241.

[12] Liu J., Fan S., Dai H., Recent advances in methods of forming carbon nanotubes, MRS Bulletin, 2004, 29, 4, 244-250.

[13] Javey A., Guo J., Wang Q., Lundstrom M., Dai H., Ballistic carbon nanotube field-effect transistors, nature, 2003, 424, 6949, 654.

[14] Javey A., Kim H., Brink M., Wang Q., Ural A., Guo J., et al., High-κ dielectrics for advanced carbon-nanotube transistors and logic gates, Nature Mater., 2002, 1, 4, 241.

[15] Rosenblatt S., Yaish Y., Park J., Gore J., Sazonova V., McEuen P.L., High performance electrolyte gated carbon nanotube transistors, Nano Lett., 2002, 2, 8, 869-872.

[16] Fuhrer M., Kim B., Dürkop T., Brintlinger T., High-mobility nanotube transistor memory, Nano Lett., 2002, 2, 7, 755-759.

[17] Lau K.T., Hui D., Effectiveness of using carbon nanotubes as nano-reinforcements for advanced Compos. Struct., Carbon, 2002, 9, 40, 1605-1606.

[18] Lau A.K.T., Hui D., The revolutionary creation of new advanced materials-carbon nanotube composites, Compos. Part B: Eng., 2002, 33, 4, 263-277

[19] Lau K.T., Chipara M., Ling H.Y., Hui D., On the effective elastic moduli of carbon nanotubes for nanocomposite structures, Compos. Part B: Eng., 2004, 35, 2, 95-101.

[20] Alizada A., Sofiyev A., Modified Young's moduli of nanomaterials taking into account the scale effects and vacancies, Meccanica, 2011, 46, 5, 915-920
[21] Wang Q., Arash B., A review on applications of carbon nanotubes and graphenes as nano-resonator sensors, Comput. Mater. Sci., 2014, 82, 350-360.
[22] An K.H., Kim W.S., Park Y.S., Moon J.M., Bae D.J., Lim S.C., et al., Electrochemical properties of high-power supercapacitors using single-walled carbon nanotube electrodes, Adv. Funct. Mater., 2001, 11, 5, 387-392.
[23] Niu C., Sichel E.K., Hoch R., Moy D., Tennent H., High power electrochemical capacitors based on carbon nanotube electrodes, Appl. Phys. Lett., 1997, 70, 11, 1480-1482.
[24] Malik S., Maqbool M., Hussain S., Irfan H., Carbon nanotubes: description, properties and applications, J. Pak. Mater. Soc., 2008, 2, 1, 21-26.
[25] Baughman R.H., Cui C., Zakhidov A.A., Iqbal Z., Barisci J.N., Spinks G.M., et al., Carbon nanotube actuators, Science, 1999, 284, 5418, 1340-1344.
[26] Bandaru P.R., Yamada H., Narayanan R., Hoefer M., The role of defects and dimensionality in influencing the charge, capacitance, and energy storage of graphene and 2D materials, Nanotechnol. Rev., 2017, 6, 5, 421-433.
[27] Majeed S., Zhao J., Zhang L., Anjum S., Liu Z., Xu G., Synthesis and electrochemical applications of nitrogen-doped carbon nanomaterials, Nanotechnol. Rev., 2013, 2, 6, 615-635.
[28] De Heer W.A., Chatelain A., Ugarte D., A carbon nanotube fieldemission electron source, Science, 1995, 270, 5239, 1179-1180.
[29] Rinzler A., Hafner J., Nikolaev P., Nordlander P., Colbert D., Smalley R., et al., Unraveling nanotubes: field emission from an atomic wire, Science, 1995, 269, 5230, 1550-1553.
[30] Sugie H., TanemuraM., Filip V., Iwata K., Takahashi K., Okuyama F., Carbon nanotubes as electron source in an x-ray tube, Appl. Phys. Lett., 2001, 78, 17, 2578-2580.
[31] Brand O., Fedder G.K., Carbon Nanotube Devices: Properties, Modeling, Integration and Applications, vol. 8, John Wiley & Sons, 2008.
[32] Lee N., Chung D., Han I., Kang J., Choi Y., Kim H., et al., Application of carbon nanotubes to field emission displays, Diamond Related Mater., 2001, 10, 2, 265-270.
[33] Saito Y., Uemura S., Field emission from carbon nanotubes and its application to electron sources, Carbon, 2000, 38, 2, 169-182.
[34] Rosen R., Simendinger W., Debbault C., Shimoda H., Fleming L., Stoner B., et al., Application of carbon nanotubes as electrodes in gas discharge tubes, Appl. Phys. Lett., 2000, 76, 13, 1668-1670.
[35] Zhu W., Bower C., Zhou O., Kochanski G., Jin S., Large current density from carbon nanotube field emitters, Appl. Phys. Lett., 1999, 75, 6, 873-875.
[36] Kwo J.L., Tsou C., Yokoyama M., Lin I.N., Lee C.C., Wang W.C., et al., Field emission characteristics of carbon nanotube emitters synthesized by arc discharge, J. Vacuum Sci. Technol. B: Microelectr. Nanomet. Struct. Proces., Measurem. Phenom., 2001, 19, 1, 23-26.
[37] Sorkin V., Zhang Y.W., Graphene-based pressure nano-sensors, J. Molec. Model., 2011, 17, 11, 2825-2830.
[38] Power A.C., Gorey B., Chandra S., Chapman J., Carbon nanomaterials and their application to electrochemical sensors: a review, Nanotechnol. Rev., 2018, 7, 1, 19-41.
[39] Li Z., Xu K., Wei F., Recent Progress on Photodetectors Based on Low Dimensional Nanomaterials, Nanotechnol. Rev., 2018.
[40] Zhe Z., Yuxiu A., Nanotechnology for the oil and gas industry-an overview of recent progress, Nanotechnol. Rev., 2018, 7, 4, 341-353.
[41] Wu S., Lin Q., Yuen Y., Tai Y.C., MEMS flow sensors for nanofluidic applications, Sensors and Actuators A: Physical, 2001, 89, 1-2, 152-158.
[42] Khanna V.K., Nanosensors: physical, chemical, and biological, CRC Press, 2016.
[43] Arash B., Wang Q., Wu N., Gene detection with carbon nanotubes, J. Nanotechnol. Eng. Med., 2012, 3, 2, 020902.
[44] Modi A., Koratkar N., Lass E., Wei B., Ajayan P.M., Miniaturized gas ionization sensors using carbon nanotubes, Nature, 2003, 424, 6945, 171, 80.
[45] Kong J., Franklin N.R., Zhou C., Chapline M.G., Peng S., Cho K., et al., Nanotube molecular wires as chemical sensors, Science, 2000, 287, 5453, 622-625.
[46] Malekzad H., Zangabad P.S., Mirshekari H., Karimi M., Hamblin M.R., Noble metal nanoparticles in biosensors: recent studies and applications, Nanotechnol. Rev., 2017, 6, 3, 301-329.
[47] Koyani R., Pérez-Robles J., Cadena-Nava R.D., Vazquez-Duhalt R., Biomaterial-based nanoreactors, an alternative for enzyme delivery, Nanotechnol. Rev., 2017, 6, 5, 405-419.
[48] Saini D., Synthesis and functionalization of graphene and application in electrochemical biosensing, Nanotechnol. Rev., 2016, 5, 4, 393-416.
[49] Arie T., Akita S., Nakayama Y., Growth of tungsten carbide nanoneedle and its application as a scanning tunnelling microscope tip, J. Physics D: Applied Physics, 1998, 31, 14, L49
[50] Dai H., Franklin N., Han J., Exploiting the properties of carbon nanotubes for nanolithography, Appl. Phys. Lett., 1998, 73, 11, 1508-1510.
[51] Dai H., Hafner J.H., Rinzler A.G., Colbert D.T., Smalley R.E., Nanotubes as nanoprobes in scanning probe microscopy, Nature, 1996, 384, 6605, 147.
[52] Nagy G., Levy M., Scarmozzino R., Osgood Jr R., Dai H., Smalley R., et al., Carbon nanotube tipped atomic force microscopy for measurement of< 100 nm etch morphology on semiconductors, Appl. Phys. Lett., 1998, 73, 4, 529-531.
[53] Wong S.S., Harper J.D., Lansbury P.T., Lieber C.M., Carbon nanotube tips: high-resolution probes for imaging biological systems, J. Amer. Chem. Soc., 1998, 120, 3, 603-604.
[54] Lau K.t., Gu C., Hui D., A critical review on nanotube and nanotube/nanoclay related polymer composite materials, Compos. Part B: Eng., 2006, 37, 6, 425-436.
[55] Alizada A., Sofiyev A., On the mechanics of deformation and stability of the beam with a nanocoating, J. Reinforced Plastics Compos., 2011, 30, 18, 1583-1595.
[56] Alizada A., Sofiyev A., Kuruoglu N., Stress analysis of a substrate coated by nanomaterials with vacancies subjected to uniform extension load, Acta Mechanica, 2012, 223, 7, 1371-1383.
[57] Sofiyev A., Hui D., Najafov A., Turkaslan S., Dorofeyskaya N., Yuan G., Influences of shear stresses and rotary inertia on the vibration of functionally graded coated sandwich cylindrical shells resting on the Pasternak elastic foundation, J. Sandwich Structures & Materials, 2015, 17, 6, 691-720.
[58] Sofiyev A., Turkaslan B.E., Bayramov R., Salamci M., Analytical solution of stability of FG-CNTRC conical shells under external

pressures, Thin-Walled Structures, 2019, 144, 106338.
[59] Das S., Srivastava V.C., An overview of the synthesis of CuO ZnO nanocomposite for environmental and other applications, Nanotechnol. Rev., 2018, 7, 3, 267-282.
[60] Anwar A., Kanwal Q., Akbar S., Munawar A., Durrani A., Farooq M.H., Synthesis and characterization of pure and nanosized hydroxyapatite bioceramics, Nanotechnol. Rev., 2017, 6, 2, 149-157.
[61] NB R.K., Crasta V., Praveen B., Kumar M., Studies on structural, optical and mechanical properties ofMWCNTs and ZnO nanoparticles doped PVA nanocomposites, Nanotechnol. Rev., 2015, 4, 5, 457-467.
[62] Kalinitchev A., Multicomponent mass transfer kinetics in nanocomposite (NC) bifunctional matrixes: NC selectivity and diffusion concentration waves, Nanotechnol. Rev., 2014, 3, 5, 467-497.
[63] Lau K.T., Lu M., Hui D., Coiled carbon nanotubes: Synthesis and their potential applications in advanced Compos. Struct., Compos. Part B: Eng., 2006, 37, 6, 437-448.
[64] Chipara M., Artiaga R., Lau K., Chipara D., Hui D., Dynamical mechanical analysis of multiwall carbon nanotubes-styreneisoprene- styrene block copolymer nanocomposite, Compos. Commun., 2017, 3, 23-27.
[65] Ma H.L., Jia Z., Lau K.T., Li X., Hui D., Shi S.Q., Enhancement on mechanical strength of adhesively-bonded composite lap joints at cryogenic environment using coiled carbon nanotubes, Compos. Part B: Eng., 2017, 110, 396-401.
[66] Lau K.t., Wong T.T., Leng J., Hui D., Rhee K.Y., Property enhancement of polymer-based composites at cryogenic environment by using tailored carbon nanotubes, Compos. Part B: Eng., 2013, 54, 41-43.
[67] Ma H.L., Lau K.T., Hui D., Shi S.Q., Poon C.K., Theoretical analysis on the pullout behavior of carbon nanotube at cryogenic environment with the consideration of thermal residual stress, Compos. Part B: Eng., 2017, 128, 67-75.
[68] Falvo M.R., Clary G., Taylor Ii R., Chi V., Brooks Jr F., Washburn S., et al., Bending and buckling of carbon nanotubes under large strain, Nature, 1997, 389, 6651, 582
[69] Wang Y., Li F., Dynamical properties of nanotubes with nonlocal continuum theory: A review, Science China Physics, Mech. Astron., 2012, 55, 7, 1210-1224.
[70] Arash B., Wang Q., A review on the application of nonlocal elastic models in modeling of carbon nanotubes and graphenes, Comput. Mater. Sci., 2012, 51, 1, 303-313.
[71] Iijima S., Brabec C., Maiti A., Bernholc J., Structural flexibility of carbon nanotubes, J. Chem. Phys., 1996, 104, 5, 2089-2092.
[72] Hernandez E., Goze C., Bernier P., Rubio A., Elastic properties of C and B x C y N z composite nanotubes, Phys. Rev. Lett., 1998, 80, 20, 4502.
[73] Sánchez-Portal D., Artacho E., Soler J.M., Rubio A., Ordejón P., Ab initio structural, elastic, and vibrational properties of carbon nanotubes, Phys. Rev. B, 1999, 59, 19, 12678.
[74] Yakobson B., Campbell M., Brabec C., Bernholc J., High strain rate fracture and C-chain unraveling in carbon nanotubes, Computational Mater. Sci., 1997, 8, 4, 341-348.
[75] Liew K., Wong C., He X., Tan M., Meguid S., Nanomechanics of single and multiwalled carbon nanotubes, Phys. Rev. B, 2004, 69, 11, 115429.
[76] Li C., Chou T.W., Elastic wave velocities in single-walled carbon nanotubes, Phys. Rev. B, 2006, 73, 24, 245407.
[77] Xiang P., Liew K.M., Free vibration analysis of microtubules based on an atomistic-continuum model, J. Sound Vibr., 2012, 331, 1, 213-230.
[78] Arghavan S., Singh A., On the vibrations of single-walled carbon nanotubes, J. Sound Vibr., 2011, 330, 13, 3102-3122.
[79] Yan J., Liew K., He L., Free vibration analysis of single-walled carbon nanotubes using a higher-order gradient theory, J. Sound Vibr., 2013, 332, 15, 3740-3755.
[80] Krishnan A., Dujardin E., Ebbesen T., Yianilos P., Treacy M., Young's modulus of single-walled nanotubes, Phys. Rev. B, 1998, 58, 20, 14013.
[81] Yakobson B.I., Brabec C., Bernholc J., Nanomechanics of carbon tubes: instabilities beyond linear response, Phys. Rev. Lett., 1996, 76, 14, 2511.
[82] Parnes R., Chiskis A., Buckling of nano-fibre reinforced composites: a re-examination of elastic buckling, J. Mech. Phys. Solids, 2002, 50, 4, 855-879.
[83] Behera L., Chakraverty S., Recent researches on nonlocal elasticity theory in the vibration of carbon nanotubes using beam models: A Review, Arch. Comput. Meth. Eng., 2017, 24, 3, 481-494.
[84] Liu Y., Reddy J., A nonlocal curved beam model based on a modified couple stress theory, Int. J. Struct. Stabil. Dynam., 2011, 11, 03, 495-512.
[85] Park S., Gao X., Bernoulli-Euler beam model based on a modified couple stress theory, J. Micromech. Microeng., 2006, 16, 11, 2355.
[86] Rahman A., Correlations in the Motion of Atoms in Liquid Argon, Phys. Rev., 1964, 136, A405-A411.
[87] Dauxois T., Fermi, Pasta, Ulam and a mysterious lady, arXiv preprint arXiv:0801.1590, 2008
[88] Alder B.J., Wainwright T.E., Studies in molecular dynamics. I. General method, J. Chem. Phys., 1959, 31, 2, 459-466.
[89] Jeong B.W., Kim H.Y., Molecular dynamics simulations of the failure behaviors of closed carbon nanotubes fully filled with C60 fullerenes, Comput. Mater. Sci., 2013, 77, 7-12.
[90] Wong C., Vijayaraghavan V., Nanomechanics of imperfectly straight single walled carbon nanotubes under axial compression by using molecular dynamics simulation, Comput. Mater. Sci., 2012, 53, 1, 268-277.
[91] Gurtin M.E., Murdoch A.I., A continuum theory of elastic material surfaces, Archive for Rational Mechanics and Analysis, 1975, 57, 4, 291-323.
[92] Gurtin M.E., Murdoch A.I., Surface stress in solids, Int. J. Solids Struct., 1978, 14, 6, 431-440.
[93] Miller R.E., Shenoy V.B., Size-dependent elastic properties of nanosized structural elements, Nanotechnology, 2000, 11, 3, 139
[94] Steigmann D., Ogden R., Elastic surface-substrate interactions, Proc. Royal Soc. London Series A: Math., Phys. Eng. Sci., 1999, 455, 1982, 437-474.
[95] Yan Z., Jiang L., The vibrational and buckling behaviors of piezoelectric nanobeams with surface effects, Nanotechnology, 2011, 22, 24, 245703.
[96] Ansari R., Sahmani S., Surface stress effects on the free vibration behavior of nanoplates, Int. J. Eng. Sci., 2011, 49, 11, 1204-1215.
[97] Guo J.G., Zhao Y.P., The size-dependent elastic properties of nanofilms with surface effects, J. Appl. Phys., 2005, 98, 7, 074306.

[98] Lü C., Chen W., Lim C.W., Elastic mechanical behavior of nano scaled FGM films incorporating surface energies, Compos. Sci. Technol., 2009, 69, 7-8, 1124-1130.
[99] Wang G., Chen Q., He Z., Pindera M.J., Homogenized moduli and local stress fields of unidirectional nano-composites, Compos. Part B: Eng., 2018, 138, 265-277.
[100] Chen Q., Wang G., Pindera M.J., Finite-volume homogenization and localization of nanoporous materials with cylindrical voids. Part 1: Theory and validation, Europ. J. Mech. A: Solids, 2018, 70, 141-155.
[101] Wang J., Huang Z., Duan H., Yu S., Feng X., Wang G., et al., Surface stress effect in mechanics of nanostructured materials, Acta Mechanica Solida Sinica, 2011, 24, 1, 52-82.
[102] Chen Q., Wang G., Pindera M.J., Homogenization and localization of nanoporous composites-A critical review and new developments, Compos. Part B: Eng., 2018, 155, 329-368.
[103] Eringen A.C., Edelen D., On nonlocal elasticity, Int. J. Eng. Sci., 1972, 10, 3, 233-248.
[104] Eringen A.C., Nonlocal continuum field theories, Springer Science & Business Media, 2002.
[105] Eringen A.C., On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves, J. Appl. Phys., 1983, 54, 9, 4703-4710.
[106] Peddieson J., Buchanan G.R., McNitt R.P., Application of nonlocal continuum models to nanotechnology, Int. J. Eng. Sci., 2003, 41, 3-5, 305-312.
[107] Lim C., Zhang G., Reddy J., A higher-order nonlocal elasticity and strain gradient theory and its applications in wave propagation, J. Mech. Phys. Solids, 2015, 78, 298-313.
[108] Aifantis E.C., On the role of gradients in the localization of de formation and fracture, Int. J. Eng. Sci., 1992, 30, 10, 1279-1299.
[109] Li L., Hu Y., Ling L., Wave propagation in viscoelastic single-walled carbon nanotubes with surface effect under magnetic field based on nonlocal strain gradient theory, Physica E: Low-dim. Syst. Nanostr., 2016, 75, 118-124.
[110] Xu X.J., Wang X.C., Zheng M.L., Ma Z., Bending and buckling of nonlocal strain gradient elastic beams, Compos. Struct., 2017, 160, 366-377.
[111] Granik V., Microstructural mechanics of granular media. Technique Report IM/MGU 78-241, Institute of Mechanics of Moscow State University, 1978.
[112] Gul U., Aydogdu M., Gaygusuzoglu G., Axial dynamics of a nanorod embedded in an elastic medium using doublet mechanics, Compos. Struct., 2017, 160, 1268-1278.
[113] Gul U., Aydogdu M., Noncoaxial vibration and buckling analysis of embedded double-walled carbon nanotubes by using doublet mechanics, Compos. Part B: Eng., 2018, 137, 60-73.
[114] Aydogdu M., Gul U., Buckling analysis of double nanofibers embeded in an elastic mediumusing doublet mechanics theory, Compos. Struct., 2018, 202, 355-363.
[115] Shibutani Y., Ogata S., Mechanical integrity of carbon nanotubes for bending and torsion, Model. Simul. Mater. Sci. Eng., 2004, 12, 4, 599.
[116] Duan X., Tang C., Zhang J., Guo W., Liu Z., Two distinct buckling modes in carbon nanotube bending, Nano Lett., 2007, 7, 1, 143-148.
[117] Wang C., Liu Y., Al-Ghalith J., Dumitrică T., Wadee M.K., Tan H., Buckling behavior of carbon nanotubes under bending: from ripple to kink, Carbon, 2016, 102, 224-235.
[118] Tian X., Cui J., Zhang C., Ma Z., Wan R., Zhang Q., Investigations on the deformation mechanisms of single-crystalline Cu nanowires under bending and torsion, Comput. Mater. Sci., 2014, 83, 250-254.
[119] Wu H., Molecular dynamics simulation of loading rate and surface effects on the elastic bending behavior of metal nanorod, Comput. Mater. Sci., 2004, 31, 3-4, 287-291.
[120] Li C., Yao L., Chen W., Li S., Comments on nonlocal effects in nano-cantilever beams, Int. J. Eng. Sci., 2015, 87, 47-57.
[121] Wang C., Kitipornchai S., Lim C., Eisenberger M., Beam bending solutions based on nonlocal Timoshenko beam theory, J. Eng. Mech., 2008, 134, 6, 475-481.
[122] Wang Q., Liew K., Application of nonlocal continuummechanics to static analysis of micro-and nano-structures, Phys. Lett. A, 2007, 363, 3, 236-242.
[123] Reddy J., Nonlocal theories for bending, buckling and vibration of beams, Int. J. Eng. Sci., 2007, 45, 2-8, 288-307.
[124] Reddy J., Pang S., Nonlocal continuum theories of beams for the analysis of carbon nanotubes, J. Appl. Phys., 2008, 103, 2, 023511
[125] Yang J., Jia X., Kitipornchai S., Pull-in instability of nanoswitches using nonlocal elasticity theory, J. Phys. D: Appl. Phys., 2008, 41, 3, 035103.
[126] Ma H., Gao X.L., Reddy J., A microstructure-dependent Timoshenko beam model based on a modified couple stress theory, J. Mech. Phys. Solids, 2008, 56, 12, 3379-3391.
[127] Aydogdu M., A general nonlocal beam theory: its application to nanobeam bending, buckling and vibration, Physica E: Low-dim. Syst. Nanostr., 2009, 41, 9, 1651-1655.
[128] Challamel N., Wang C., The small length scale effect for a nonlocal cantilever beam: a paradox solved, Nanotechnology, 2008, 19, 34, 345703
[129] Zhang Y., Wang C., Challamel N., Bending, buckling, and vibration of micro/nanobeams by hybrid nonlocal beam model, J. Eng. Mech., 2009, 136, 5, 562-574.
[130] Civalek Ö., Demir Ç., Bending analysis of microtubules using nonlocal Euler-Bernoulli beam theory, Appl. Math. Model., 2011, 35, 5, 2053-2067.
[131] Thai H.T., A nonlocal beam theory for bending, buckling, and vibration of nanobeams, Int. J. Eng. Sci., 2012, 52, 56-64.
[132] Zenkour A.M., Sobhy M., A simplified shear and normal deformations nonlocal theory for bending of nanobeams in thermal environment, Physica E: Low-dim. Syst. Nanostruct., 2015, 70, 121-128
[133] De Rosa M., Franciosi C., A simple approach to detect the nonlocal effects in the static analysis of Euler-Bernoulli and Timoshenko beams, Mech. Res. Commun., 2013, 48, 66-69.
[134] Reddy J., El-Borgi S., Eringen's nonlocal theories of beams accounting for moderate rotations, Int. J. Eng. Sci., 2014, 82, 159-177.
[135] Khodabakhshi P., Reddy J., A unified integro-differential nonlocal model, Int. J. Eng. Sci., 2015, 95, 60-75.
[136] Challamel N., Zhang Z., Wang C., Reddy J., Wang Q., Michelitsch T., et al., On nonconservativeness of Eringen's nonlocal elasticity in beam mechanics: correction from a discrete-based approach, Arch. Appl. Mech., 2014, 84, 9-11, 1275-1292.
[137] Fernández-Sáez J., Zaera R., Loya J., Reddy J., Bending of Euler-Bernoulli beams using Eringen's integral formulation: a paradox resolved, Int. J. Eng. Sci., 2016, 99, 107-116.

[138] Tuna M., Kirca M., Exact solution of Eringen's nonlocal integral model for bending of Euler-Bernoulli and Timoshenko beams, Int. J. Eng. Sci., 2016, 105, 80-92.
[139] Koutsoumaris C.C., Eptaimeros K., Tsamasphyros G., A different approach to Eringen's nonlocal integral stress model with applications for beams, Int. J. Solids Struct., 2017, 112, 222-238.
[140] Romano G., Barretta R., Stress-driven versus strain-driven nonlocal integral model for elastic nano-beams, Compos. Part B, 2017, 114, 184-188.
[141] Romano G., Barretta R., Diaco M., de Sciarra F.M., Constitutive boundary conditions and paradoxes in nonlocal elastic nanobeams, Int. J. Mech. Sci., 2017, 121, 151-156.
[142] Barretta R., Čanađija M., Luciano R., de Sciarra F.M., Stress-driven modeling of nonlocal thermoelastic behavior of nanobeams, Int. J. Eng. Sci., 2018, 126, 53-67.
[143] Jiang L., Yan Z., Timoshenko beam model for static bending of nanowires with surface effects, Physica E: Low-dim. Syst. Nanostr., 2010, 42, 9, 2274-2279.
[144] Ansari R., Sahmani S., Bending behavior and buckling of nanobeams including surface stress effects corresponding to different beam theories, Int. J. Eng. Sci., 2011, 49, 11, 1244-1255.
[145] Juntarasaid C., Pulngern T., Chucheepsakul S., Bending and buckling of nanowires including the effects of surface stress and nonlocal elasticity, Physica E: Low-dim. Syst. Nanostr., 2012, 46, 68-76.
[146] Mahmoud F., Eltaher M., Alshorbagy A., Meletis E., Static analysis of nanobeams including surface effects by nonlocal finite element, J. Mech. Sci. Technol., 2012, 26, 11, 3555-3563.
[147] Kasirajan P., Amirtham R., Reddy J.N., Surface and non-local effects for non-linear analysis of Timoshenko beams, Int. J. Non-Linear Mech., 2015, 76, 100-111.
[148] Yang Q., Lim C., Xiang Y., Nonlinear thermal bending for shear deformable nanobeams based on nonlocal elasticity theory, Int. J. Aerospace Lightweight Struct. (IJALS), 2011, 1, 1.
[149] Najar F., El-Borgi S., Reddy J., Mrabet K., Nonlinear nonlocal analysis of electrostatic nanoactuators, Compos. Struct., 2015, 120, 117-128.
[150] Aghababaei R., Reddy J., Nonlocal third-order shear deformation plate theory with application to bending and vibration of plates, J. Sound Vibr., 2009, 326, 1-2, 277-289.
[151] Reddy J., Nonlocal nonlinear formulations for bending of classical and shear deformation theories of beams and plates, Int. J. Eng. Sci., 2010, 48, 11, 1507-1518.
[152] Golmakani M., Rezatalab J., Nonlinear bending analysis of orthotropic nanoscale plates in an elastic matrix based on nonlocal continuum mechanics, Compos. Struct., 2014, 111, 85-97.
[153] Far M.S., Golmakani M., Large deflection of thermo-mechanical loaded bilayer orthotropic graphene sheet in/on polymermatrix based on nonlocal elasticity theory, Comp. Math. Applic., 2018, 76, 9, 2061-2089.
[154] Yan J., Tong L., Li C., Zhu Y., Wang Z., Exact solutions of bending deflections for nano-beams and nano-plates based on nonlocal elasticity theory, Compos. Struct., 2015, 125, 304-313.
[155] Wang K.,Wang B., A finite element model for the bending and vibration of nanoscale plates with surface effect, Finite Elements in Analysis and Design, 2013, 74, 22-29
[156] Lu P., He L., Lee H., Lu C., Thin plate theory including surface effects, Int. J. Solids Struct., 2006, 43, 16, 4631-4647.
[157] Zhang Z., Jiang L., Size effects on electromechanical coupling fields of a bending piezoelectric nanoplate due to surface effects and flexoelectricity, J. Appl. Phys., 2014, 116, 13, 134308.
[158] Raghu P., Preethi K., Rajagopal A., Reddy J.N., Nonlocal third-order shear deformation theory for analysis of laminated plates considering surface stress effects, Compos. Struct., 2016, 139, 13-29.
[159] Lu L., Guo X., Zhao J., A unified nonlocal strain gradient model for nanobeams and the importance of higher order terms, Int. J. Eng. Sci., 2017, 119, 265-277.
[160] Tang H., Li L., Hu Y., Coupling effect of thickness and shear deformation on size-dependent bending of micro/nano-scale porous beams, Appl. Math. Model., 2019, 66, 527-547.
[161] Rajasekaran S., Khaniki H.B., Bending, buckling and vibration of small-scale tapered beams, Int. J. Eng. Sci., 2017, 120, 172-188.
[162] Li X., Li L., Hu Y., Ding Z., Deng W., Bending, buckling and vibration of axially functionally graded beams based on nonlocal strain gradient theory, Compos. Struct., 2017, 165, 250-265.
[163] Fakher M., Hosseini-Hashemi S., Bending and free vibration analysis of nanobeams by differential and integral forms of nonlocal strain gradient with Rayleigh-Ritz method, Mater. Res. Express, 2017, 4, 12, 125025.
[164] Ouakad H.M., El-Borgi S., Mousavi S.M., Friswell M.I., Static and dynamic response of CNT nanobeam using nonlocal strain and velocity gradient theory, Appl. Math. Model., 2018, 62, 207-222.
[165] Norouzzadeh A., Ansari R., Rouhi H., Nonlinear bending analysis of nanobeams based on the nonlocal strain gradient model using an isogeometric finite element approach, Iran. J. Sci. Technol., Trans. Civil Eng., 2019, 43, 1, 533-547.
[166] Ebrahimian M., Imam A., Najafi M., Doublet mechanical analysis of bending of Euler-Bernoulli and Timoshenko nanobeams, ZAMM-J. Appl. Math. Mechanics/ Zeitschrift für Angewandte Mathematik und Mechanik, 2018, 98, 9, 1642-1665.
[167] Faraji-Oskouie M., Norouzzadeh A., Ansari R., Rouhi H., Bending of small-scale Timoshenko beams based on the integral/ differential nonlocal-micropolar elasticity theory: a finite element approach, Appl. Math. Mechanics, 2019, 40, 6, 767-782.
[168] Huang K., Zhang S., Li J., Li Z., Nonlocal nonlinear model of Bernoulli-Euler nanobeam with small initial curvature and its application to single-walled carbon nanotubes, Microsyst. Technol., 2019, 1-8.
[169] Arefi M., Rabczuk T., A nonlocal higher order shear deformation theory for electro-elastic analysis of a piezoelectric doubly curved nano shell, Compos. Part B: Eng., 2019, 168, 496-510.
[170] Arefi M., Kiani M., Rabczuk T., Application of nonlocal strain gradient theory to size dependent bending analysis of a sandwich porous nanoplate integrated with piezomagnetic face-sheets, Compos. Part B: Eng., 2019, 168, 320-333.
[171] Cornacchia F., Fantuzzi N., Luciano R., Penna R., Solution for cross-and angle-ply laminated Kirchhoff nano plates in bending using strain gradient theory, Compos. Part B: Eng., 2019, 107006.
[172] Allam M.N., Radwan A.F., Nonlocal strain gradient theory for bending, buckling, and vibration of viscoelastic functionally graded curved nanobeam embedded in an elastic medium, Adv. Mech. Eng., 2019, 11, 4, 1687814019837067.
[173] Şimşek M., Some closed-form solutions for static, buckling, free and forced vibration of functionally graded (FG) nanobeams using nonlocal strain gradient theory, Compos. Struct., 2019, 224, 111041.

[174] Montazeri A., Ebrahimi S., Rafii-Tabar H., A molecular dynamics investigation of buckling behaviour of hydrogenated graphene, Molecular Simulation, 2015, 41, 14, 1212-1218
[175] Wu H., Soh A., Atomistic simulation of the buckling behavior of metal nanorod, Int. J. Nonlinear Sci. Numer. Simul., 2003, 4, 3, 233-238.
[176] Zhang C.L., Shen H.S., Buckling and postbuckling of single-walled carbon nanotubes under combined axial compression and torsion in thermal environments, Phys. Rev. B, 2007, 75, 4, 045408.
[177] Kang Z., Li M., Tang Q., Buckling behavior of carbon nanotube-based intramolecular junctions under compression: Molecular dynamics simulation and finite element analysis, Comput. Mater. Sci., 2010, 50, 1, 253-259.
[178] LiM., Kang Z., Yang P.,Meng X., Lu Y.,Molecular dynamics study on buckling of single-wall carbon nanotube-based intramolecular junctions and influence factors, Comput. Mater. Sci., 2013, 67, 390-396.
[179] Hao X., Qiang H., Xiaohu Y., Buckling of defective single-walled and double-walled carbon nanotubes under axial compression by molecular dynamics simulation, Compos. Sci. Technol., 2008, 68, 7-8, 1809-1814.
[180] Akita S., Nishio M., Nakayama Y., Buckling of multiwall carbon nanotubes under axial compression, Jap. J. Appl. Phys., 2006, 45, 6S, 5586.
[181] Zhang H., Wang L., Wang J., Computer simulation of buckling behavior of double-walled carbon nanotubes with abnormal interlayer distances, Comput. Mater. Sci., 2007, 39, 3, 664-672.
[182] Wang Q., Compressive buckling of carbon nanotubes containing polyethylene molecules, Carbon, 2011, 49, 2, 729-732.
[183] Guo S., Zhu B., Ou X., Pan Z., Wang Y., Deformation of gold-filled single-walled carbon nanotubes under axial compression, Carbon, 2010, 48, 14, 4129-4135.
[184] Ansari R., Ajori S., Rouhi S., Elastic properties and buckling behavior of single-walled carbon nanotubes functionalized with diethyltoluenediamines using molecular dynamics simulations, Superlatt. Microstr., 2015, 77, 54-63.
[185] Jing Y., Meng Q., Gao Y., Molecular dynamics simulation on the buckling behavior of silicon nanowires under uniaxial compression, Comput. Mater. Sci., 2009, 45, 2, 321-326.
[186] Salmalian K., Rouhi S., Mehran S., Molecular dynamics simulations of the buckling of graphyne and its family, Physica B: Condensed Matt., 2015, 457, 135-139.
[187] Nishimura M., Takahashi N., Takagi Y., Relationship between local buckling and atomic elastic stiffness in multi-walled carbon nanotubes under compression and bending deformations, Comput. Mater. Sci., 2017, 130, 214-221.
[188] Wang Y., Wang X.x., Ni X.g., Wu H.a., Simulation of the elastic response and the buckling modes of single-walled carbon nanotubes, Comput. Mater. Sci., 2005, 32, 2, 141-146.
[189] Ozaki T., Iwasa Y., Mitani T., Stiffness of single-walled carbon nanotubes under large strain, Phys. Rev. Lett., 2000, 84, 8, 1712
[190] Chandra A., Patra P.K., Bhattacharya B., Thermomechanical buckling of boron nitride nanotubes using molecular dynamics, Mater. Res. Express, 2016, 3, 2, 025005.
[191] Wang C., Zhang Y., Ramesh S.S., Kitipornchai S., Buckling analysis of micro-and nano-rods/tubes based on nonlocal Timoshenko beam theory, J. Phys. D: Appl. Phys., 2006, 39, 17, 3904.
[192] Ghannadpour S.A.M., Mohammadi B., Buckling analysis of micro-and nano-rods/tubes based on nonlocal Timoshenko beam theory using Chebyshev polynomials, In: Adv. Mater. Res., Trans. Tech. Publ., 2010, 123, 619-622.
[193] Liu T., Hai M., Zhao M., Delaminating buckling model based on nonlocal Timoshenko beam theory for microwedge indentation of a film/substrate system, Eng. Fract. Mech., 2008, 75, 17, 4909-4919.
[194] Xu S., Wang C., Xu M., Buckling analysis of shear deformable nanorods within the framework of nonlocal elasticity theory, Physica E: Low-dim. Syst. Nanostruct., 2012, 44, 7-8, 1380-1385.
[195] Zhu X., Wang Y., Dai H.H., Buckling analysis of Euler-Bernoulli beams using Eringen's two-phase nonlocal model, Int. J. Eng. Sci., 2017, 116, 130-140.
[196] Roque C., Ferreira A., Reddy J., Analysis of Timoshenko nanobeams with a nonlocal formulation and meshless method, Int. J. Eng. Sci., 2011, 49, 9, 976-984.
[197] Emam S.A., A general nonlocal nonlinear model for buckling of nanobeams, Appl. Math. Model., 2013, 37, 10-11, 6929-6939.
[198] Chen C., Li S., Dai L., Qian C., Buckling and stability analysis of a piezoelectric viscoelastic nanobeamsubjected to van derWaals forces, Commun. Nonlin. Sci. Numer. Simul., 2014, 19, 5, 1626-1637.
[199] Baghani M., Mohammadi M., Farajpour A., Dynamic and stability analysis of the rotating nanobeam in a nonuniform magnetic field considering the surface energy, Int. J. Appl. Mech., 2016, 8, 4, 1650048.
[200] Yang Q., Lim C.W., Thermal effects on buckling of shear deformable nanocolumns with von Kármán nonlinearity based on nonlocal stress theory, Nonlin. Analysis: Real World Appl., 2012, 13, 2, 905-922.
[201] Lim C.W., Yang Q., Zhang J., Thermal buckling of nanorod based on non-local elasticity theory, Int. J. Non-Linear Mech., 2012, 47, 5, 496-505.
[202] Tounsi A., Semmah A., Bousahla A.A., Thermal buckling behavior of nanobeams using an eflcient higher-order nonlocal beam theory, J. Nanomech. Micromech., 2013, 3, 3, 37-42.
[203] Shi G., Voyiadjis G.Z., A sixth-order theory of shear deformable beams with variational consistent boundary conditions, J. Appl. Mech., 2011, 78, 2, 021019
[204] Jandaghian A.A., Rahmani O., On the buckling behavior of piezoelectric nanobeams: an exact solution, J. Mech. Sci. Technol., 2015, 29, 8, 3175-3182.
[205] Liu C., Ke L., Wang Y., Yang J., Kitipornchai S., Buckling and post-buckling of size-dependent piezoelectric Timoshenko nanobeams subject to thermo-electro-mechanical loadings, Int. J. Struct. Stab. Dynam., 2014, 14, 03, 1350067.
[206] Yan Y.,WangW., Zhang L., Nonlocal effect on axially compressed buckling of triple-walled carbon nanotubes under temperature field, Appl. Math. Model., 2010, 34, 11, 3422-3429.
[207] Sofiyev A., Hui D., On the vibration and stability of FGM cylindrical shells under external pressures with mixed boundary conditions by using FOSDT, Thin-Walled Struct., 2019, 134, 419-427.
[208] Khaniki H.B., Hosseini-Hashemi S., Nezamabadi A., Buckling analysis of nonuniform nonlocal strain gradient beams using generalized differential quadrature method, Alexandria Eng. J., 2018, 57, 3, 1361-1368.
[209] Khaniki H.B., Hosseini-Hashemi S., Buckling analysis of tapered nanobeams using nonlocal strain gradient theory and a generalized differential quadrature method, Mater. Res. Express, 2017, 4, 6, 065003.

[210] Li L., Hu Y., Buckling analysis of size-dependent nonlinear beams based on a nonlocal strain gradient theory, Int. J. Eng. Sci., 2015, 97, 84-94.
[211] Li L., Hu Y., Post-buckling analysis of functionally graded nanobeams incorporating nonlocal stress and microstructure dependent strain gradient effects, Int. J. Mech. Sci., 2017, 120, 159-170.
[212] Li L., Tang H., Hu Y., The effect of thickness on the mechanics of nanobeams, Int. J. Eng. Sci., 2018, 123, 81-91.
[213] Sahmani S., Aghdam M., Nonlinear vibrations of pre-and post buckled lipid supramolecular micro/nano-tubules via nonlocal strain gradient elasticity theory, J. Biomech., 2017, 65, 49-60.
[214] Sahmani S., Aghdam M., Nonlocal strain gradient beam model for postbuckling and associated vibrational response of lipid supramolecular protein micro/nano-tubules, Math. Bio- Sci., 2018, 295, 24-35.
[215] Farajpour A., Yazdi M.H., Rastgoo A., Mohammadi M., A higherorder nonlocal strain gradient plate model for buckling of orthotropic nanoplates in thermal environment, Acta Mechanica, 2016, 227, 7, 1849-1867.
[216] Radić N., On buckling of porous double-layered FG nanoplates in the Pasternak elastic foundation based on nonlocal strain gradient elasticity, Compos. Part B: Eng., 2018, 153, 465-479.
[217] Malikan M., Nguyen V.B., Buckling analysis of piezo- magnetoelectric nanoplates in hygrothermal environment based on a novel one variable plate theory combining with higher-order nonlocal strain gradient theory, Physica E: Low-dim. Syst. Nanostruct., 2018, 102, 8-28.
[218] Sahmani S., Fattahi A., Small scale effects on buckling and postbuckling behaviors of axially loaded FGM nanoshells based on nonlocal strain gradient elasticity theory, Appl. Math. Mech., 2018, 39, 4, 561-580.
[219] Sahmani S., Aghdam M., Nonlocal strain gradient shell model for axial buckling and postbuckling analysis of magneto-electroelastic composite nanoshells, Compos. Part B: Eng., 2018, 132, 258-274.
[220] Sahmani S., Aghdam M., A nonlocal strain gradient hyperbolic shear deformable shell model for radial postbuckling analysis of functionally graded multilayer GPLRC nanoshells, Compos. Struct., 2017, 178, 97-109.
[221] Gul U., Aydogdu M., Structural modelling of nanorods and nanobeams using doublet mechanics theory, Int. J. Mech. Mater. Design, 2018, 14, 2, 195-212.
[222] Gul U., Aydogdu M., Gaygusuzoglu G., Vibration and buckling analysis of nanotubes (nanofibers) embedded in an elastic medium using Doublet Mechanics, J. Eng. Math., 2018, 109, 1, 85-111.
[223] Yu Y.J., Zhang K., Deng Z.C., Buckling analyses of three characteristic-lengths featured size-dependent gradient-beam with variational consistent higher order boundary conditions, Appl. Math. Model., 2019, 74, 1-20.
[224] Mohammadi F.S., Rahimi Z., Sumelka W., Xiao-Jun Y., Investigation of Free Vibration and Buckling of Timoshenko Nano-beam Based on a General Form of Eringen Theory Using Conformable Fractional Derivative and Galerkin Method, Eng. Trans., 2019, 67(3), 347-367.
[225] Bahaadini R., Hosseini M., Khalili-Parizi Z., Electromechanical stability analysis of smart double-nanobeam systems, Europ. Phys. J. Plus, 2019, 134, 7, 320.
[226] Jalaei M., Civalek ., On dynamic instability of magnetically embedded viscoelastic porous FG nanobeam, Int. J. Eng. Sci., 2019, 143, 14-32.
[227] Ruocco E., Mallardo V., Buckling and vibration analysis nanoplates with imperfections, Appl. Math. Comput., 2019, 357, 282-296.
[228] Karami B., Karami S., Buckling analysis of nanoplate-type temperature-dependent heterogeneous materials, Adv. Nano Res., 2019, 7, 51-61.
[229] Xu X., Zheng M., Analytical solutions for buckling of sizedependent Timoshenko beams, Appl. Math. Mech., 2019, 40, 7, 953-976.
[230] Zhang B., Shen H., Liu J., Wang Y., Zhang Y., Deep postbuckling and nonlinear bending behaviors of nanobeams with nonlocal and strain gradient effects, Appl. Math. Mech., 2019, 40, 4, 515-548.
[231] Chwał M., Muc A., Buckling and Free Vibrations of Nanoplates-Comparison of Nonlocal Strain and Stress Approaches, Appl. Sci., 2019, 9, 7, 1409.
[232] Pavlović I.R., Pavlović R., Janevski G., Dynamic stability and instability of nanobeams based on the higher-order nonlocal strain gradient theory, Quart. J. Mech. Appl. Math., 2019, 72, 2, 157-178.
[233] Ebrahimi F., Barati M.R., Civalek Ö., Application of Chebyshev-Ritz method for static stability and vibration analysis of nonlocal microstructure-dependent nanostructures, Eng. Computers, 2019, 1-12.
[234] Glabisz W., Jarczewska K., Hołubowski R., Stability of Timoshenko beams with frequency and initial stress dependent nonlocal parameters, Arch. Civil Mech. Eng., 2019, 19, 4, 1116-1126.
[235] Wang K., Wang B., Kitamura T., A review on the application of modified continuum models in modeling and simulation of nanostructures, Acta Mechanica Sinica, 2016, 32, 1, 83-100.
[236] Eltaher M., Khater M., Emam S.A., A review on nonlocal elastic models for bending, buckling, vibrations, and wave propagation of nanoscale beams, Appl. Math. Model., 2016, 40, 5-6, 4109-4128.
[237] Ghayesh M.H., Farajpour A., A review on the mechanics of functionally graded nanoscale and microscale structures, Int. J. Eng. Sci., 2019, 137, 8-36.
[238] Lee H.L., Chang W.J., Surface and small-scale effects on vibration analysis of a nonuniform nanocantilever beam, Physica E: Low-dim. Syst. Nanostruct., 2010, 43, 1, 466-469.
[239] Mechab I., El Meiche N., Bernard F., Free vibration analysis of higher-order shear elasticity nanocomposite beams with consideration of nonlocal elasticity and Poisson effect, J. Nanomech. Micromech., 2016, 6, 3, 04016006
[240] Apuzzo A., Barretta R., Luciano R., de Sciarra F.M., Penna R., Free vibrations of Bernoulli-Euler nano-beams by the stress-driven nonlocal integral model, Compos. Part B: Eng., 2017, 123, 105-111.
[241] Khaniki H.B., On vibrations of nanobeamsystems, Int. J. Eng. Sci., 2018, 124, 85-103.
[242] Pradhan S., Phadikar J., Nonlocal elasticity theory for vibration of nanoplates, J. Sound Vibr., 2009, 325, 1-2, 206-223
[243] Pouresmaeeli S., Ghavanloo E., Fazelzadeh S., Vibration analysis of viscoelastic orthotropic nanoplates resting on viscoelastic medium, Compos. Struct., 2013, 96, 405-410.
[244] Wang C., Murmu T., Adhikari S., Mechanisms of nonlocal effect on the vibration of nanoplates, Appl. Phys. Lett., 2011, 98, 15,

153101.
[245] Farajpour M., Shahidi A., Farajpour A., A nonlocal continuum model for the biaxial buckling analysis of composite nanoplates with shape memory alloy nanowires, Mater. Res. Express, 2018, 5, 3, 035026.
[246] Pradhan S., Phadikar J., Small scale effect on vibration of embedded multilayered graphene sheets based on nonlocal continuum models, Phys. Lett. A, 2009, 373, 11, 1062-1069.
[247] Hosseini-Hashemi S., Zare M., Nazemnezhad R., An exact analytical approach for free vibration of Mindlin rectangular nanoplates via nonlocal elasticity, Compos. Struct., 2013, 100, 290-299.
[248] Malekzadeh P., Shojaee M., Free vibration of nanoplates based on a nonlocal two-variable refined plate theory, Compos. Struct., 2013, 95, 443-452.
[249] Karimi M., Haddad H.A., Shahidi A.R., Combining surface effects and non-local two variable refined plate theories on the shear/biaxial buckling and vibration of silver nanoplates, Micro & Nano Lett., 2015, 10, 6, 276-281.
[250] Pradhan S., Sahu B., Vibration of single layer graphene sheet based on nonlocal elasticity and higher order shear deformation theory, J. Comput. Theoret. Nanosci., 2010, 7, 6, 1042-1050.
[251] Kiani K., Free vibration of conducting nanoplates exposed to unidirectional in-plane magnetic fields using nonlocal shear deformable plate theories, Physica E: Low-dim. Syst. Nanostruct., 2014, 57, 179-192.
[252] Daneshmehr A., Rajabpoor A., Hadi A., Size dependent free vibration analysis of nanoplates made of functionally graded materials based on nonlocal elasticity theory with high order theories, Int. J. Eng. Sci., 2015, 95, 23-35.
[253] Malekzadeh P., Farajpour A., Axisymmetric free and forced vibrations of initially stressed circular nanoplates embedded in an elastic medium, Acta Mechanica, 2012, 223, 11, 2311-2330.
[254] Asemi S.R., Farajpour A., Thermo-electro-mechanical vibration of coupled piezoelectric-nanoplate systems under non-uniform voltage distribution embedded in Pasternak elastic medium, Curr. Appl. Phys., 2014, 14, 5, 814-832.
[255] Asemi S.R., Farajpour A., Vibration characteristics of doublepiezoelectric- nanoplate-systems, Micro & Nano Lett., 2014, 9, 4, 280-285.
[256] Asemi S., Farajpour A., Asemi H., Mohammadi M., Influence of initial stress on the vibration of double-piezoelectric-nanoplate systems with various boundary conditions using DQM, Physica E: Low-dim. Syst. Nanostruct., 2014, 63, 169-179.
[257] Farajpour A., Yazdi M.H., Rastgoo A., Loghmani M., Mohammadi M., Nonlocal nonlinear plate model for large amplitude vibration of magneto-electro-elastic nanoplates, Compos. Struct., 2016, 140, 323-336.
[258] Farajpour M., Shahidi A., Hadi A., Farajpour A., Influence of initial edge displacement on the nonlinear vibration, electrical andmagnetic instabilities ofmagneto-electro-elastic nanofilms, Mech. Adv. Mater. Struct., 2018, 1-13.
[259] Aydogdu M., Axial vibration of the nanorods with the nonlocal continuumrod model, Physica E: Low-dim. Syst. Nanostruct., 2009, 41, 5, 861-864.
[260] Huang Z., Nonlocal effects of longitudinal vibration in nanorod with internal long-range interactions, Int. J. Solids Struct, 2012, 49, 15-16, 2150-2154.
[261] Lim C.W., Li C., Yu J., Free torsional vibration of nanotubes based on nonlocal stress theory, J. Sound Vibr., 2012, 331, 12, 2798-2808.
[262] Aydogdu M., Axial vibration analysis of nanorods (carbon nanotubes) embedded in an elastic medium using nonlocal elasticity, Mech. Res. Comm., 2012, 43, 34-40.
[263] Adhikari S.,Murmu T., McCarthy M., Frequency domain analysis of nonlocal rods embedded in an elastic medium, Physica E: Low-dim. Syst. Nanostruct., 2014, 59, 33-40
[264] Murmu T., Adhikari S., Nonlocal effects in the longitudinal vibration of double-nanorod systems, Physica E: Low-dim. Syst. Nanostruct., 2010, 43, 1, 415-422.
[265] Karličić D., Kozić P., Adhikari S., Cajić M., Murmu T., Lazarević M., Nonlocal mass-nanosensor model based on the damped vibration of single-layer graphene sheet influenced by in-plane magnetic field, Int. J. Mech. Sci., 2015, 96, 132-142.
[266] Danesh M., Farajpour A., Mohammadi M., Axial vibration analysis of a tapered nanorod based on nonlocal elasticity theory and differential quadrature method, Mech. Res. Comm., 2012, 39, 1, 23-27.
[267] Murmu T., Adhikari S., McCarthy M., Axial vibration of embedded nanorods under transverse magnetic field effects via nonlocal elastic continuum theory, J. Comput. Theoret. Nanosci., 2014, 11, 5, 1230-1236.
[268] Karličić D., Kozić P.,Murmu T., Adhikari S., Vibration insight of a nonlocal viscoelastic coupled multi-nanorod system, Europ. J. Mech. A: Solids, 2015, 54, 132-145.
[269] Li X.F., Shen Z.B., Lee K.Y., Axial wave propagation and vibration of nonlocal nanorods with radial deformation and inertia, ZAMM-J. Appl. Math. Mech./ Zeitschrift für Angewandte Mathematik und Mechanik, 2017, 97, 5, 602-616.
[270] Li X.F., Tang G.J., Shen Z.B., Lee K.Y., Size-dependent resonance frequencies of longitudinal vibration of a nonlocal Love nanobar with a tip nanoparticle, Math. Mech. Solids, 2017, 22, 6, 1529-1542.
[271] Numanoğlu H.M., Akgöz B., Civalek Ö., On dynamic analysis of nanorods, Int. J. Eng. Sci., 2018, 130, 33-50.
[272] Karličić D.Z., Ayed S., Flaieh E., Nonlocal axial vibration of the multiple Bishop nanorod system, Math. Mech. Solids, 2018, 1081286518766577.
[273] Aria A.I., Biglari H., Computational vibration and buckling analysis of microtubule bundles based on nonlocal strain gradient theory, Appl. Math. Comput., 2018, 321, 313-332.
[274] Lu L., Guo X., Zhao J., Size-dependent vibration analysis of nanobeams based on the nonlocal strain gradient theory, Int. J. Eng. Sci., 2017, 116, 12-24.
[275] Apuzzo A., Barretta R., Faghidian S., Luciano R., de Sciarra F.M., Free vibrations of elastic beams by modified nonlocal strain gradient theory, Int. J. Eng. Sci., 2018, 133, 99-108.
[276] Barretta R., de Sciarra F.M., Constitutive boundary conditions for nonlocal strain gradient elastic nano-beams, Int. J. Eng. Sci., 2018, 130, 187-198.
[277] Zhen Y.X., Wen S.L., Tang Y., Free vibration analysis of viscoelastic nanotubes under longitudinal magnetic field based on nonlocal strain gradient Timoshenko beam model, Physica E: Low-dim. Syst. Nanostruct, 2019, 105, 116-124.
[278] Wang J., Shen H., Zhang B., Liu J., Zhang Y., Complex modal analysis of transverse free vibrations for axially moving nanobeams based on the nonlocal strain gradient theory, Physica E: Low-dim. Syst. Nanostruct., 2018, 101, 85-93
[279] Wang J., Shen H., Zhang B., Liu J., Studies on the dynamic stability of an axially moving nanobeam based on the nonlocal strain

gradient theory, Modern Phys. Lett. B, 2018, 32, 16, 1850167
[280] Khaniki H.B., Hosseini-Hashemi S., Dynamic transverse vibration characteristics of nonuniform nonlocal strain gradient beams using the generalized differential quadrature method, Europ. Phys. J. Plus, 2017, 132, 11, 500.
[281] Guo S., He Y., Liu D., Lei J., Li Z., Dynamic transverse vibration characteristics and vibro-buckling analyses of axially moving and rotating nanobeams based on nonlocal strain gradient theory, Microsyst. Technol., 2018, 24, 2, 963-977.
[282] Li L., Hu Y., Li X., Longitudinal vibration of size-dependent rods via nonlocal strain gradient theory, Int. J. Mech. Sci., 2016, 115, 135-144.
[283] Zhu X., Li L., On longitudinal dynamics of nanorods, Int. J. Eng. Sci., 2017, 120, 129-145.
[284] Şimşek M., Axial vibration analysis of a nanorod embedded in elastic medium using nonlocal strain gradient theory, J. Cukurova Univ. Faculty of Eng., 2016, 31, 1, 213-222.
[285] Xu X.J., Zheng M.L., Wang X.C., On vibrations of nonlocal rods: Boundary conditions, exact solutions and their asymptotics, Int. J. Eng. Sci., 2017, 119, 217-231.
[286] Adeli M.M., Hadi A., Hosseini M., Gorgani H.H., Torsional vibration of nano-cone based on nonlocal strain gradient elasticity theory, Europ. Phys. J. Plus, 2017, 132, 9, 393.
[287] El-Borgi S., Rajendran P., Friswell M., Trabelssi M., Reddy J., Torsional vibration of size-dependent viscoelastic rods using nonlocal strain and velocity gradient theory, Compos. Struct., 2018, 186, 274-292.
[288] Shafiei N., She G.L., On vibration of functionally graded nanotubes in the thermal environment, Int. J. Eng. Sci., 2018, 133, 84-98.
[289] Zhang P., Fu Y., A higher-order beam model for tubes, Europ. J. Mech. A: Solids, 2013, 38, 12-19.
[290] She G.L., Ren Y.R., Yuan F.G., Xiao W.S., On vibrations of porous nanotubes, Int. J. Eng. Sci., 2018, 125, 23-35.
[291] Chen S., Carroll D.L., Synthesis and characterization of truncated triangular silver nanoplates, Nano Lett., 2002, 2, 9, 1003-1007.
[292] Geim A.K., Novoselov K.S., The rise of graphene, In: Nanoscience and Technology: A Collection of Reviews from Nature Journals, World Scientific, 2010, 11-19.
[293] Zhang S., Wang Q., Chen X., Jena P., Stable three-dimensional metallic carbon with interlocking hexagons, Proc. Nat. Acad. Sci., 2013, 110, 47, 18809-18813.
[294] Barati M.R., Porosity-dependent vibration and dynamic stability of compositionally gradient nanofilms using nonlocal strain gradient theory, Proceedings of the Institution of Mechanical Engineers, Part C: J. Mech. Eng. Sci., 2018, 232, 17, 3144-3155
[295] Barati M.R., Shahverdi H., Frequency analysis of nanoporous mass sensors based on a vibrating heterogeneous nanoplate and nonlocal strain gradient theory, Microsyst. Technol., 2018, 24, 3, 1479-1494.
[296] Nematollahi M.S., Mohammadi H., Nematollahi M.A., Thermal vibration analysis of nanoplates based on the higher-order nonlocal strain gradient theory by an analytical approach, Superlatt. Microstruct., 2017, 111, 944-959.
[297] Mehralian F., Beni Y.T., Zeverdejani M.K., Nonlocal strain gradient theory calibration using molecular dynamics simulation based on small scale vibration of nanotubes, Physica B: Condensed Matter, 2017, 514, 61-69.
[298] Mohammadi K., Mahinzare M., Ghorbani K., Ghadiri M., Cylindrical functionally graded shell model based on the first order shear deformation nonlocal strain gradient elasticity theory, Microsystem Technologies, 2018, 24, 2, 1133-1146.
[299] Barati M.R., Vibration analysis of porous FG nanoshells with even and uneven porosity distributions using nonlocal strain gradient elasticity, Acta Mechanica, 2018, 229, 3, 1183-1196.
[300] Fatahi-Vajari A., ImamA., Axial vibration of single-walled carbon nanotubes using doublet mechanics, Indian J. Phys., 2016, 90, 4, 447-455.
[301] Fatahi-Vajari A., Imam A., Torsional vibration of single-walled carbon nanotubes using doublet mechanics, Zeitschrift für angewandte Mathematik und Physik, 2016, 67, 4, 81.
[302] Fatahi-Vajari A., Imam A., Analysis of radial breathing mode of vibration of single-walled carbon nanotubes via doublet mechanics, ZAMM-J. Appl. Math. Mech./Zeitschrift für Angewandte Mathematik und Mechanik, 2016, 96, 9, 1020-1032.
[303] Fatahi-Vajari A., A new method for evaluating the natural frequency in radial breathing like mode vibration of double walled carbon nanotubes, ZAMM-J. Appl. Math. Mech./Zeitschrift für Angewandte Mathematik und Mechanik, 2018, 98, 2, 255-269.
[304] Ghadiri M., S Hosseini S.H., Nonlinear forced vibration of graphene/piezoelectric sandwich nanoplates subjected to a mechanical shock, J. Sandwich Struct. & Mater., 2019, 1099636219849647
[305] Wang Y., Li F., Shu H., Nonlocal nonlinear chaotic and homoclinic analysis of double layered forced viscoelastic nanoplates, Mech. Syst.Signal Proces., 2019, 122, 537-554.
[306] Ovesy H., Naghinejad M., Nano-Scaled Plate Free Vibration Analysis by Nonlocal Integral Elasticity Theory, AUT J. Mech. Eng., 2019, 3, 1, 77-88.
[307] Li C., Guo H., Tian X., He T., Size-dependent thermoelectromechanical responses analysis of multi-layered piezoelectric nanoplates for vibration control, Compos. Struct., 2019, 111112.
[308] Rahimi Z., Sumelka W., Ahmadi S.R., Baleanu D., Study and control of thermoelastic damping of in-plane vibration of the functionally graded nano-plate, J. Vibr. Control, 2019, 1077546319861009.
[309] Duan J., Zhang D., Wang W., Flutter and Divergence Instability of Axially-Moving Nanoplates Resting on a Viscoelastic Foundation, Appl. Sci., 2019, 9, 6, 1097.
[310] Ragb O., Mohamed M., Matbuly M., Free vibration of a piezoelectric nanobeam resting on nonlinearWinkler-Pasternak foundation by quadrature methods, Heliyon, 2019, 5, 6, e01856
[311] Al-Maliki A.F., Faleh N.M., Alasadi A.A., Finite element formulation and vibration of nonlocal refined metal foam beams with symmetric and non-symmetric porosities, Struct. Monitor. Maintenance, 2019, 6, 2, 147-159.
[312] Moshir S.K., Eipakchi H., An analytical approach for vibration analysis of laminated orthotropic beam based on nonlocal theory, Proceedings of the Institution Mech. Engineers, Part C: J. Mech. Eng. Sci., 2019, 233, 10, 3633-3648.
[313] Aria A., Friswell M., Rabczuk T., Thermal vibration analysis of cracked nanobeams embedded in an elastic matrix using finite element analysis, Compos. Struct., 2019, 212, 118-128.
[314] Ghadiri M., Hosseini S.H.S., Parametric excitation of Euler-Bernoulli nanobeams under thermo-magneto-mechanical loads: Nonlinear vibration and dynamic instability, Compos. Part B: Eng., 2019, 106928.

[315] Azarboni H.R., Rahimzadeh M., Heidari H., Keshavarzpour H., Edalatpanah S., Chaotic dynamics and primary resonance analysis of a curved carbon nanotube considering influence of thermal and magnetic fields, J. Braz. Soc. Mech. Sci. Eng., 2019, 41, 7, 294

[316] Martin O., Nonlocal effects on the dynamic analysis of a viscoelastic nanobeam using a fractional Zener model, Appl. Math. Model., 2019, 73, 637-650.

[317] Talebitooti M., A semi-analytical solution for free vibration analysis of rotating carbon nanotube with various boundary conditions based on nonlocal theory, Mater. Res. Express, 2019, 6(9), 095012.

[318] Hołubowski R., Glabisz W., Jarczewska K., Transverse vibration analysis of a single-walled carbon nanotube under a random load action, Physica E: Low-dim. Syst. Nanostruct., 2019, 109, 242-247.

[319] Arda M., Aydogdu M., Torsional dynamics of coaxial nanotubes with different lengths in viscoelastic medium, Microsyst. Technol., 2019, 1-15.

[320] Tang H., Li L., Hu Y., Meng W., Duan K., Vibration of nonlocal strain gradient beams incorporating Poisson's ratio and thickness effects, Thin-Walled Struct., 2019, 137, 377-391.

[321] Mirjavadi S.S., Afshari B.M., Barati M.R., Hamouda A., Transient response of porous inhomogeneous nanobeams due to various impulsive loads based on nonlocal strain gradient elasticity, Int. J. Mech. Mater. Design, 1-12.

[322] Rajabi K., Hosseini-Hashemi S., Nezamabadi A., Size- Dependent Forced Vibration Analysis of Three Nonlocal Strain Gradient Beam Models with Surface Effects Subjected to Moving Harmonic Loads, J. Solid Mech., 2019, 11, 1, 39-59.

[323] Jena S.K., Chakraverty S., Tornabene F., Dynamical behavior of nanobeam embedded in constant, linear, parabolic, and sinusoidal types of Winkler elastic foundation using first-Order nonlocal strain gradient model, Materials Research Express, 2019, 6, 8, 0850f2

[324] Farajpour A., Ghayesh M.H., Farokhi H., Nonlocal nonlinear mechanics of imperfect carbon nanotubes, Int. J. Eng. Sci., 2019, 142, 201-215.

[325] Allahyari E., Asgari M., Effects of in-phase and anti-phase large amplitude nonlinear models for double-layer nanostructures, SN Appl. Sci., 2019, 1, 8, 813.

[326] Fenjan R.M., Ahmed R.A., Alasadi A.A., Faleh N.M., Nonlocal strain gradient thermal vibration analysis of double-coupled metal foam plate system with uniform and non-uniform porosities, Coupled Syst. Mech., 2019, 8, 3, 247-257.

[327] Sahmani S., Fattahi A., Ahmed N., Analytical treatment on the nonlocal strain gradient vibrational response of postbuckled functionally graded porous micro-/nanoplates reinforced with GPL, Eng. Comp., 2019, 1-20.

[328] Ghorbani K., Mohammadi K., Rajabpour A., Ghadiri M., Surface and size-dependent effects on the free vibration analysis of cylindrical shell based on Gurtin-Murdoch and nonlocal strain gradient theories, J. Phys. Chem. Solids, 2019, 129, 140-150.

[329] Ghayesh M.H., Farokhi H., Farajpour A., A coupled longitudinal-transverse nonlinear NSGT model for CNTs incorporating internal energy loss, Europ. Phys. J. Plus, 2019, 134, 4, 179.

[330] Karami B., Shahsavari D., Janghorban M., On the dynamics of porous doubly-curved nanoshells, Int. J. Eng. Sci., 2019, 143, 39-55.

[331] Barretta R., Čanadija M., Marotti de Sciarra F., Modified nonlocal strain gradient elasticity for nano-rods and application to carbon nanotubes, Appl. Sci, 2019, 9, 3, 514.

[332] Gao Y., Xiao W., Zhu H., Nonlinear vibration of functionally graded nano-tubes using nonlocal strain gradient theory and a two-steps perturbation method, Struct. Eng. Mech., 2019, 69, 205-219.

[333] Mohammadian M., Abolbashari M.H., Hosseini S.M., Application of hetero junction CNTs asmass nanosensor using nonlocal strain gradient theory: An analytical solution, Appl. Math. Model., 2019

[334] Fatahi-Vajari A., Imam A., Lateral Vibrations of Single-Layered Graphene Sheets Using Doublet Mechanics, J. Solid Mech., 2016, 8, 4, 875-894.

[335] Fatahi-Vajari A., Azimzadeh Z., Analysis of nonlinear axial vibration of single-walled carbon nanotubes using Homotopy perturbation method, Ind. J. Phys., 2018, 92, 11, 1425-1438.