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A concise review of nano-plates

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ABSTRACT

Recent works done by nano-engineers and nano-sciences about mechanical behavior of nano-plates including bending, buckling and vibration response were reviewed. The authors used non-classical elasticity theories to explain these behaviors of plate structures. Some of them employed Hamilton's principle along with stain gradient theory, nonlocal theory, surface theory and couple stress theory to derive the governing equation of nanostructures. Also, the authors have used various plate theories such as classical plate theory (CPT), first-order shear deformation theory (FSDT) and higher-order shear deformation plate theory (HSDT) to explain the linear and nonlinear behavior of nano-plates. Few researchers utilized molecular dynamics or experimental tests to explain size-dependent behavior of nano-plates. Investigated nano-plates were made of homogeneous and functionally graded materials (FGM) and were under mechanical and/or thermal loads. The effect of the magnetic field was considered, in other few researches. Governing equations solved using numerical methods such as differential quadrature method (DQM). The results of recent researches were presented and discussed.

1. ‘Introduction

The behavior and mechanical properties of nanostructures can be investigated using a variety of methods. One of these methods is the principles of quantum mechanics. Quantum mechanics calculations performed by solving the Schrödinger equation are the most accurate method for studying the behavior of nanostructures. This computational approach is expensive and limited to studying small systems. Experimental techniques to determine the mechanical properties of nanostructures are widely used by atomic force microscopy to apply various mechanical loads on nanostructures and measure response. Such empirical measurements are useful for validating mathematical models but depend heavily on the accuracy of these devices as well as on the control of nanoscale objects, which is a major challenge [1].

Another method is molecular dynamics. Molecular dynamics is based on computer simulation in which atoms and molecules are allowed to interact for a period of time under the known laws of physics and to predict the motion of atoms. Since molecular systems generally contain a large number of particles, it would be time-consuming and costly to analyze them for complex and large systems. Experimental observations and molecular dynamics simulations show that the behavior of materials changes at the micro- or nano-scale, and the size effect becomes important, as interatomic and molecular forces also influence the behavior of the structural material.

In the theory of classical continuum mechanics, it is assumed that the stress at any point is a function of strain at that point. Therefore, the theory of classical continuum mechanics theory does not hold true for nanomaterials. But since classical continuum mechanics has other advantages, such as lower computational cost and so on, than other methods, so researchers have sought to modify it to include size effects. Among these theories are Eringen's theory, strain gradient, coupling stress, surface elasticity, and so on. These theories have been applied to various articles for different structures such as beams plates cylinder, etc [2-19].

2. Discussion

Karličić et al. [20] performed the free vibration analysis of the viscoelastic orthotropic multi-nanoplate system (VOMNPS) embedded in the viscoelastic medium and subjected to the in-plane magnetic field by using Eringen's nonlocal theory. The governing equations are derived based on the Kirchhoff's plate theory and solved by applying the Navier's and trigonometric method. In addition, they performed an asymptotic analysis in order to determine critical complex natural frequencies of the system.

Fernández-Sáez et al. [21] investigated the bending vibration of a nanoplate with an attached mass using the strain gradient elasticity theory for homogeneous Lamé material, under Kirchhoff assumptions. They analyzed the effect of the attached mass (as a sensor) by an exact eigenvalues method for a general

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case, and by an approximate closed-form expression for the small intensity of the mass.

Ghorbanpour Arani et *al*. [22] studied the vibration analysis of Magnetostrictive rectangular nanoplate subjected to the uniform and uni-directional magnetic field. They derived motion equations using Hamilton's principle based on Reddy's third-order shear deformation theory in conjunction with Eringen's nonlocal theory.

Using the Eringen's nonlocal theory, Atanasov et al. [23] investigated Forced transverse vibrations of an elastically connected nonlocal orthotropic double-nanoplate system subjected to an in-plane magnetic field. The governing equations are derived based on Kirchhoff–Love plate theory and are solved analytically.

Bakhshi Khaniki and Hosseini-Hashemi [24] analyzed dynamic behavior of double-layered nanoplate systems (DLNPS) with respect to a moving nanoparticle. They derived Governing equations of motion by using D'Alembert's principle, Kirchhoff-Love plate, and Eringen's nonlocal theory. They employed Galerkin's and Laplace transform methods to solve governing equations.

Despotovic [25] studied the stability and vibration of a square single-layer graphene sheet under body force by incorporating Eringen's nonlocal constitutive equation into the classical plate theory. They solved the equilibrium equations by using Galerkin's method and investigated the influence of body load and nonlocality on stability and free vibration of the nanoplate.

Ghadiri et al. [26] investigated Thermo-mechanical vibration of an orthotropic single-layer cantilever and propped cantilever nanoplate, by using Eringen's nonlocal elasticity theory. Based on classical plate theory, they derived the governing equation using Hamilton's principle and used differential quadrature method to solve the governing equation.

Ghorbanpour Arani et al. [27] carried out nonlocal vibration and dynamic qualitative analysis of embedded smart orthotropic poly-vinyli-dene fluoride (PVDF) nanoplate based nano-electromechanical sensors. The nanoplate is presumed under a moving nanoparticle on an arbitrary elliptical path. They modeled friction generated by the motion as the Coulomb model.

Ghorbanpour et al. [28] used the refined zigzag theory to study the electro-magneto buckling behavior of sandwich nanoplate resting on Pasternak foundation and subjected to external electric and magnetic potentials. The sandwich nanoplate composed of a metal core integrated by two magnetoelectroelastic (MEE) layers.

Hosseini and Jamalpoor [29] presented an analytical solution to study the influence of surface effects on the thermo-mechanical vibration of a double-FGM viscoelastic nanoplates-system which embedded between the Pasternak foundation by incorporating Eringen nonlocal theory. The governing equations of motion are derived from Hamilton's principle according to the plates Kirchhoff's plate theory. They proposed the nanoplate is coupled by an internal Kelvin–Voigt viscoelastic medium and resting to Pasternak elastic foundation.

In a similar article, according to Eringen's nonlocal theory, Hosseini et al. [30] investigated the influence of Small-scale effects on free vibrational behavior of a double FGM viscoelastic nanoplate system resting on Pasternak foundation and subjected to thermal load. They assumed nanoplate is made of functionally graded materials (FGMs). The nanoplates are bonded with each other using Kelvin-Voigt viscoelastic layer and surrounded by a Pasternak elastic foundation.

According to Kirchhoff plate theory and nonlocal elasticity of Eringen's theory, Hosseini Hashemi et al. [31] presented an analytical method for forced vibration of visco-nanoplate based on and resting on Visco-Pasternak (VP) medium. They used Kelvin Voigt model for visco-nanoplate to derive the governing equation.

Li et al. [32] performed size-dependent analysis of vibrations and stabilities in parametric resonances of axially moving viscoelastic piezoelectric nanoplate subjected to thermo-electro-mechanical loads. They used Kirchhoff plate theory and Eringen's nonlocal theory to derive the governing equations and employed Galerkin method (GM) and complex mode method (CMM) to determined Natural frequencies of nanoplate.

By exploiting the Navier's method, Liu et al. [33] presented the analytical solutions for vibration and biaxial buckling of double-viscoelastic-FGM-nanoplate systems that are connected via visco-Pasternak medium Based on the Eringen's nonlocal elastic theory and the Kelvin model.

Malikan [34] performed a study of nonlinear shear buckling of piezoelectric nanoplate based on modified couple stress theory. He considered the geometrical nonlinearity mixing the displacement field of the simplified first-order shear deformation theory (S-FSDT) with the nonlinear von-Karman relations.

Malikan [35] carried out buckling analysis of the rectangular nanoplate subjected to biaxial non-uniform compression load in the framework of the modified couple stress continuum theory. By using Hamilton's principle, they derived governing equations based on simplified first-order shear deformation theory (S-FSDT) and accounting von-Karman nonlinear strains.

Mehar et al. [36] presented free vibration analysis of a nanoplate including the Eringen nonlocal elasticity theory based on the Higher-order shear deformation theory (HSDT). They prepared the finite element method to solve the motion equation and discussed the influence scale effect and geometrical and material parameters on the frequencies.

Moradi et al. [37] investigated the vibration behavior of functional graded (FG) circular and annular nanoplate resting on the Visco-Pasternak foundation. They modeled material properties via Mori–Tanaka homogenization technique in the thickness direction and assumed the nanoplate subjected to mechanical, thermal and magnetic load. They used the modified strain gradient theory (MSGT) and the modified couple stress theory (MCST) to derive the governing equation. They also employed the differential quadrature method (DQM) and the Galerkin method (GM) to solve the governing equation.

Ponnusamy and Amuthalakshmi [38] performed dispersion analysis of double-layered nanoplate under Winkler foundation subjected to thermal and magnetic load including Eringen's nonlocal theory. They demonstrated that the thermal and magnetic load and Winkler foundation increases the natural frequencies of nanoplates.

Shahrbabaki [39] presented the three-dimensional nonlocal elasticity for vibrating simply-supported rectangular nanoplate and wave propagation in an infinite nonlocal solid by using the potential functions for Helmholtz displacement vector representation. He also presented a new approach to analyzing three-dimensional nanoplates with other boundary conditions. Their results showed when nonlocal parameter is high, the effect of boundary conditions on non-dimensional natural frequencies Disappears. Also in the nonlocal theory, the difference between two- and three-dimensional results is more significant.

By using Eringen's nonlocal theory, Wang et al. [40] reported an investigation on transverse nonlinear steady-state vibrations of double-layered nanoplate (DLNP) in the presence of 3:1 internal resonance between the first two modes by using multiple scales method. In addition, they employed the Lyapunov stability theory to determine the stability analysis of nanoplates. They assumed the van der Walls force bonding between the layers and the DLNP resting on Winkler elastic foundation.

Using Eringen's nonlocal theory, Zenkour and Sobhy [41] performed vibration analysis of piezoelectric Kelvin–Voigt viscoelastic orthotropic rectangular nanoplates under hygrothermal load and resting on visco-Pasternak's foundation. They derived the equations of motion from Hamilton's principle based on a two-variable shear deformation theory.

by employing a Hamiltonian system instead of Lagrangian system, Zhou et al. [42] determined the exact value of the in-phase and out-of-phase natural frequencies of rectangular double-layered orthotropic nanoplate embedded in an elastic medium. They used the Kirchhoff plate theory Based on Eringen's nonlocal theory and symplectic methodology. Using the Hamiltonian system, the governing equation is reduced to a set of one-order ordinary differential equations.

Barati and Shahverdi [43] analyzed the vibrational behavior of double-layered nanocrystalline silicon nanoplates resting on Winkler- Pasternak foundation. They employed modified couple stress theory to capture size-dependent effects. They obtained the governing equations via Hamilton's principle in the framework of two-variable refined plate model.

Barati and Shahverdi [44] presented new dynamic modeling and studied vibration analysis of double-layered FG nanoplates under hygrothermal environments. One side of the nanoplates elastically connected together by interlayer springs, and the other side of each nanoplate is mounted on a winkler-pasternak foundation. By incorporating the nonlocal-strain gradient elasticity theory, they derived the governing equations based on Hamilton's principle and solved via Galerkin's method.

According to the interlayer connection of the nanoplates and the elastic medium in the previous article, Barati [45] presented vibration analysis of double-layered nanoplates made of FGM in magneto-hygro-thermal environments based on higher-order refined plate theory. He employed the nonlocal-strain gradient elasticity theory by incorporating stiffness-softening and stiffness-hardening effects. In their article, He derived governing equations based on Hamilton's principle and solved via Galerkin's method.

Barati and Shahverdi [46] investigated the influence of nanoporous mass sensors based on a vibrating heterogeneous nanoplate. The Nano-pores are modeled with modified rule of mixture. By incorporating nonlocal-strain gradient theory, they derived the governing equations according to Hamilton's principle and solved via Galerkin's method.

By employing the nonlocal theory of Eringen, Ebrahimi et al. [47] performed the wave propagation analysis of a magneto-electro-elastic functionally graded (MEE-FG) nanoplate considering a refined higher-order plate theory. They studied the effect of wave number, nonlocal parameter, magnetic potential, etc. on the wave dispersion characteristics

Ebrahimi and Dabbagh [48] studied the wave propagation problem of double-layered nanoplates under a longitudinal magnetic field. Their proposed formulation was according to the nonlocal-strain gradient theory to capture scale effects and in the framework of Kirchhoff plate theory.

Ebrahimi and Barati [49] investigated flexoelectricity and surface effects on vibration characteristics of piezoelectric nanoplate resting on the Winkler-Pasternak foundation. They used Hamilton's principle and Galerkin's method to obtain the vibration frequencies.

Jalaei and Thai [50] analyzed the dynamic instability of viscoelastic porous FG nanoplates subjected to biaxially oscillating loading and longitudinal magnetic field. By using quasi-3D sinusoidal shear deformation plate theory in the framework of nonlocal-strain gradient theory, they derived the governing equations via Hamilton's principle, then solved via Navier and Bolotin's methods.

Karami et al. [51] investigated wave dispersion in FG nanoplate with porosity on Winkler–Pasternak foundation and under in-plane magnetic field. They assumed the material properties vary in the thickness direction and to be temperature-dependent. They used second-order shear deformation theory in the framework of nonlocal-strain gradient theory to drive the governing equations.

Karami .B and Karami.S [52] developed a nonlocal-strain gradient plate model for Buckling analysis of FG nanoplate in thermal environments assuming temperature-dependent material properties. They used a four-unknown refined plate to derive the governing equations and solved them via Galerkin method.

Li et al. [53] analyzed the bending of a layered two-dimensional piezoelectric quasicrystal nanoplate under a sinusoidal mechanical load and a sinusoidal electric potential load incorporating Eringen's nonlocal theory. They present exact solution utilizing pseudo-Stroh formalism and the propagator matrix.

Mohammadia and Rastgoo [54] investigated the size-dependent nonlinear vibration analysis of the composite nanoplate resting on nonlinear Pasternak foundation and based on the von Kármán type nonlinearity. They assumed that the composite nanoplate consists of three layers; the core layer having a gradient of three-direction and the other two layers are lipid face sheets based on Kelvin-Voigt model (for lipid layers). They solved the nonlinear differential equations were obtained By the Bubnov-Galerkin method and the multiple scale method.

Xu et al. [55] investigated the effects of in-plane magnetic field and size-dependent on orthotropic double-layered nanoplate system (DLNS) embedded in an elastic environment. By applying Hamilton's principle incorporating Eringen's nonlocal elasticity theory, they obtained the governing equations.

Zhang and Zhou [56] studied the chaotic motion of the nanoplate resting on a nonlinear Winkler foundation using

Melnikov's method. They showed while the parameters are chosen in the chaotic regions, chaotic behaviors may happen.

Ghorbanpour and Zamani [57] performed free vibration analysis of rectangular sandwich nanoplate resting on the elastic foundation by assuming that the core is made of functionally graded porous material and the face sheets are made of piezoelectric material. They employed Vlasov's model foundation for modeling the elastic foundation. In another article, Ghorbanpour and Zamani [58] examined the effect of the electric field on bending behavior of nanoplate with the same conditions.

Arefi and Zenkour [59] examined bending analysis of sandwich nanoplate that isotropic core embedded by two piezoelectric face sheets and subjected to Thermo-electro-mechanical loading. They derived the governing equations by employing the virtual work method in the framework of the trigonometric shear and normal deformations plate theory.

Arefi and Zenkour [60] performed vibration analysis of electro-thermo-mechanical sandwich nanoplate with viscoelastic core and viscoelastic piezoelectric face sheets. They considered Two-variable sinusoidal shear deformation plate theory incorporating Kelvin–Voigt viscoelasticity model to derive the equations of motion.

Arefi et al. [61] used Eringen's nonlocal to analyze vibration behavior of rectangular three-layered nanoplate on Pasternak foundation. The core is made of functionally graded in the thickness direction and the face sheets are made of piezomagnetic material. On the basis of the first-order shear deformation theory, they derived the equations of motion via Hamilton's principle and obtained the solution using Navier's method.

By employing Navier's solution, Arefi et al. [62] presented the analytical solution for Bending analysis of sandwich plate resting on the Pasternak foundation by assuming a porous core and two piezomagnetic face sheets in conjunction with nonlocal-strain gradient theory.

Arefi and Zenkour [63] analyzed the bending behavior of a three-layered nanoplate includes a nano-sheet integrated with a piezo-magnetic face-sheet subjected to thermo-magneto-electro-mechanical load and resting to Pasternak's foundation.

According to modified nonlocal elasticity theory Jamalpoor and Kiani [64] analyzed free vibration of double-FGM viscoelastic nanoplate including the surface effects. The nanoplates are connected together by Kelvin–Voigt visco-Pasternak medium. Based on Kirchhoff plate theory and Hamilton's principle, They employed Navier's solution to solve the governing equations.

Mechab et al. [65] developed Eringen's nonlocal theory for free vibration analysis of rectangular FG nanoplate under Winkler–Pasternak elastic foundations and taking porosities effects into account. Hamilton principle and two-variable refined plate theories are employed for derivation of the differential equations.

In a similar article, Mechab et al. [66] by using the Monte Carlo method performed Probabilistic analysis to study the influence of porosity in a rectangular FGM nanoplate under Winkler–Pasternak elastic foundations. They used the virtual displacement principle to obtain the governing equation.

Hosseini et al. [67] carried out biaxial buckling and free vibration analysis of FGM nanoplate resting on visco-Pasternak foundation. They considered the Eringen and the Gurtin-Murdoch surface elasticity theories to capture the nonlocal and surface effects, respectively.

Hosseini et al. [68] investigated the influence nanosensors on vibration analysis of FGM nanoplate resting on the Pasternak foundation by using the Mindlin plate theory in conjunction with Eringen nonlocal theory. The nanoplate subjected to external electric voltage and external magnetic potential.

According to nonlocal-strain gradient theory in the framework of Kirchhoff plate theory, Jafari et al. [69] performed free vibration analysis of a rectangular multiple nanoplate systems embedded in a visco-Pasternak medium subjected to external magnetic and electric potentials and hygrothermal effect.

Jamalpoor et al. [70] presented magneto-electro-elastic bending analysis of biaxial buckling and free vibration of a double nanoplate using Eringen nonlocal theory. They assuming that the nanoplates are connected by visco-Pasternak model.

based on Eringen nonlocal theory, Khanmirza et al. [71] studied mass nanosensor effect on the vibration of magneto-electro-elastic nanoplate resting on visco-Pasternak substrate. The nanoplate is under electric voltage and magnetic potential. They derived explicit analytical solutions to analyze the sensitivity property of nanosensor.

Kiani et al. [72] proposed a theoretical model by employing nonlocal Eringen theory and third-order shear deformation plate theory to investigate vibration response of magneto-electro-thermo-elastic nanoplate resting on the visco-Pasternak medium.

Liu et al. [73] presented analytical solutions of low-velocity transverse impact of a nanosphere on a circular nanoplate using the Kirchhoff plate theory and by considering the van der Waals interaction between the nanosphere and the nanoplate. They used Gurtin–Murdoch's theory to capture surface effects of the nanoplate.

Liu et al. [74] established a theoretical model to investigate the dynamic response of a rectangular nanoplate subjected to a low-velocity impact by a nanoparticle by assuming the van der Waals interaction between the particle and the plate. They derived the governing equations by using the surface elasticity theory and residual surface stress of the nanoplate.

Ansari et al. [75] studied large amplitude free vibrations rectangular nanoplates including stress effects for various boundary conditions and considered Gurtin-Murdoch's theory to capture the small-scale. They employed the first-order shear deformable nanoplate in conjunction with the von-Kármán's assumptions to obtain the governing equations.

based on nano-electromechanical systems (NEMS), Ebrahimi and Hosseini [76] investigated the nonlinear vibration of double-layered viscoelastic nanoplates subjected to hydrostatic and electrostatic actuations by incorporating von-Kárman geometric nonlinearity. They modeled nanoplate via Eringen's nonlocal elasticity theory and Gurtin-Murdoch theory. They also used the differential quadrature method (DQM) for computing the nonlinear frequency.

By using von Kármán deformation theory, Ebrahimi and Hosseini [77] investigated the influence of temperature change on the nonlinear vibration of double-layered viscoelastic nanoplates based-NEMS in thermal environment and subjected to hydrostatic and electrostatic actuations. To achieve the governing equation, they used Hamilton's principle incorporating Eringen's nonlocal elasticity and Gurtin–Murdoch theory.

Hosseini et al. [78] carried out vibration analysis of multi nanoplate system under Thermomechanical load including surface effects. The nanoplates are made of viscoelastic and functionally graded materials that each nanoplate is connected via Kelvin–Voigt visco-Pasternak medium to each other. To achieve the equations of motion, they employed Hamilton's principle incorporated with Eringen's nonlocal theory accounting for the size scale effect.

Lin et al. [79] the nonlinear behavior and pull-in instability of circular nanoplate under the influence of the electrostatic force, Casimir force and surface effects. They applied the hybrid differential transformation and finite difference approximation method to solve the nonlinear governing equation.

According to the Eringen's nonlocal elasticity theory, Lin et al. [80] proposed the classical plate theory for nonlinear Analysis of circular nanoplate actuator subjected to electrostatic van der Waals (vdW) forces, tensile loads and hydrostatic pressures. The nonlinearity of this problem is due to the load. They applying a combination of differential transformation and finite difference schemes to obtain the results.

Mirkalantari et al. [81] proposed a theoretical model by employing strain gradient theory and first-order shear deformation plate theory considering Gurtin-Murdoch method to investigate static pull-in instability of rectangular nanoplate under hydrostatic and electrostatic actuation. They derived the governing equation utilizing the principle of minimum potential energy, linearized by means of the step-by-step linearization method (SSLM) and solved via generalized differential quadrature (GDQ).

According to Eringen's nonlocal theory and Gurtin-Murdoch surface model, Yang et al. [82] developed an analytical model to investigate the influence of nonlocal small scale, surface elasticity modulus, and surface residual stress on the dynamic pull-in instability and bifurcation of circular nanoplate subjected to electrostatic and Casimir forces. By using the homotopy perturbation method, they solved the nonlinear governing equation.

Abbasi and Ghassemi [83] performed bending analysis of piezoelectric nanoplate under thermomechanical loading including Eringen's nonlocal theory and surface effect. The nanoplate modeled according to the two-variable refined plate theory.

The surface stress and nonlocal small scale effects on uniaxial and biaxial buckling analysis of rectangular piezoelectric nanoplate investigated by Fathi and Ghassemi [84] considering the two variable-refined plate theory. They utilized finite difference method to solve the governing equations were extracted via the virtual work principle.

Jamali and Ghassemi [85] studied the vibration behavior of piezoelectric nanoplates subjected to mechanical and electrical in-plane forces including surface layer effects. They extracted the governing equation by using two variable refined plate theory and solved via finite difference method.

Karimi et al. [86] investigated and compared the value of the surface layers on the out-of-phase and in-phase vibration behavior of a double-layer magneto–electro–thermo-elastic nanoplates considering surface layer. They simulated the nanoplates are coupled by van der Waals forces and each of the nanoplate surrounding elastic medium by Winkler and shear moduli.

Karimi and Shahidi [87] studied the influence of surface layers on the in-phase and out-of-phase natural frequencies of skew double-layer magneto–electro–thermo-elastic (DLMETE) nanoplates based on nonlocal elasticity, surface energy, and refined plate theory. They considered van der Waals interactions of the layers and proposed each layer surrounded via the Pasternak model. Equilibrium equations were extracted via Hamilton's principle and were solved via the Galerkin method. Also, Navier's method was implemented for the validation of the results.

Hosseini et al. [88] developed an analytical model to studied the influence of the magnetic field and the small-scale parameter on vibration behavior of rotating FG circular nanoplate including porosity. They employed the first-order shear deformation theory and the modified couple stress theory to achieve the governing equations.

Mahinzare et al. [89] used modified couple stress theory to investigate the vibration behavior of bi-directional FG piezoelectric rotating circular nanoplate composed of two different materials with continuously varying along the thickness and radius based on the power-law model. In the framework of the first shear deformation theory, they derived and solved the governing equations, via Hamilton's principle and differential quadrature method (DQM), respectively.

Jamali et al. [90] presented buckling analysis of the nanoplate and nanocomposite plate with a central square cutout resting on the Winkler foundation. To improve mechanical properties, the nanoplate reinforced via carbon nanotubes (CNTs) with the uniformly distributed. They applied the classical plate theory (CPT) by incorporating the Eringen's nonlocal theory to simulate the plate and they obtained the critical buckling load via Rayleigh-Ritz energy method.

Utilizing the third-order shear deformation theory incorporating with nonlocal-strain gradient theory, a dynamic analysis was carried out by Ghahnavieh et al. [91] for the vibration response of a magneto-electro-elastic nanoplate-based mass nanosensors resting on Pasternak foundation. They assumed the effective properties of nanoplate change continuously along the thickness according to the power-law function.

By using the introduced effective elastic moduli, Bochkarev [92] developed the theory of the large deflection of a plate with accounting surface stresses based on the von Karman hypothesis and strain-consistent model of surface elasticity. He examined the presented theory for solving the compressive buckling of a rectangular nanoplate under the different flexural boundary conditions.

Bochkarev and Grekov [93] formulated the system of von Karman equations on the basis of Gurtin-Murdoch surface elasticity for a nanoplate Assuming plate stress. The then solved a modified Kirsch problem for an infinite nanoplate with a circular hole including plane stress in respect of effective.

Li and Pan [94] proposed a surface piezoelectricity model to investigate the surface effect on bending behavior of a piezoelectric nanoplate subjected to uniform mechanical and electric loading in framework of the sinusoidal shear theory. They assumed the piezoelectric nanoplate consists of a bulk core integrated by two surface layers.

Guo et al. [95] studied the size-dependent and flexoelectric effect on the bending behavior of laminated piezoelectric nanoplate subjected to inhomogeneous electric loads. For this purpose, they introduced a stress function based Ritz-type solution procedure and imposing the flexoelectric effect to it for the first time. They showed that flexoelectricity has a significantly effect on small-scale dielectrics and stress distributions.

Wang et al. [96] presented the influence of the flexoelectric effect on the static bending analysis of Cantilevered Piezoelectric Nanoplate under mechanical and electrical loads. They supposed the Kirchhoff plate theory and the extended linear piezoelectric theory to achieve governing equations and used finite difference method (FDM) to obtain the results. By employing Eringen's nonlocal theory in the framework of a refined exponential shear deformation plate theory, Sahmani and Fattahi [97] developed a nonlocal plate model to predict the axial instability characteristics of zirconia nanosheets under buckling load. They used perturbation technique solve the governing equation. They used molecular dynamics simulation to calibrate Nonlocal parameter.

Ho et al [98] Proved numerically and theoretically that for some metal nanoplates under finite strain, the Poisson's ratio becomes negative. this Materials called auxetics. They studied the influence of Poisson's ratios on auxetic metal nanoplates.

Shahsavari et al. [99] investigated dynamic responses of nanoplate embedded within visco-Pasternak foundation under moving load and hygrothermal environment. To incorporate the scaling effects, they considered Eringen's nonlocal theory based on the classical plate theory.

Liu and Chen [100] studied dynamic responses of the finite periodic nanoplate by employing Mindlin plate theory and Eringen's nonlocal theory. They investigated the effects of nanoplate width and thickness and boundary conditions.

Jamshidian et al. [101] investigated the influence of surface energy on nanoplates by using gradient continuum theory and molecular dynamics simulations. They showed good agreement between molecular dynamics simulation and continuum theory.

Jalali et al. [102] investigated vibrational analysis of single layered graphene sheets with out-of-plane defects using two methods of molecular dynamics and Eringen's nonlocal elasticity. They modeled defects by employing Stone-Wales defect model and their results are indicated the defects increase the frequency.

Jalali et al. [103] carried out the nonlinear frequency analysis of single layered graphene sheets (SLGSs) with an attached ultrafine nanoparticles (NPs) incorporating nonlocal elasticity. They performed molecular dynamics (MD) simulation to obtain the proper value of nonlocal parameter.

Mohammadimehr et al. [104] performed complete mechanical analysis of microcomposite circular-annular sandwich plate subjected to hydro-thermo-magneto-mechanical loads based on modified strain gradient theory in the framework of first order shear deformation theory (FSDT). The sandwich nanoplate composed of isotropic homogeneous core with integrated by CNT reinforced composite facesheets.

3. Conclusion

The results of this research will play an important role in the future life of humans and bring about great changes. Reviewing recent articles indicate that nanotechnology enables engineers and scientists to achieve promising, unique properties for materials. These special properties were investigated in the areas of mechanical, thermal, electrical and magnetic properties. The results of these researches show the properties of the material in the nano-scale can be very different from those on the macro-scale. The development of computers has contributed to molecular dynamics calculations and scientists find out the properties of nanomaterials without doing too many expensive experiments.

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