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Magnetic field and surface elasticity effects on thermal vibration properties of nanoplates

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ABSTRACT

Thermal vibration properties of nanoplates are studied in the present work. The governing equations of motion for the nanoplate are derived from the fundamental principles with the consideration of Eringen's nonlocal elasticity theory. The effects of magnetic field and surface elasticity are also considered in the analysis. Different surface layers are considered over the nanoplate on upper and lower sides. From the present analysis, it is found that the presence of surface layers on nanoplate increases the natural frequency and stiffens the structure, whereas the magnetic field softens the nanoplate and reduces the natural frequency. Further the effects of nonlocal scale, mode number, surface layer strength, surface residual stress, inplane load parameter and thickness of the nanoplate are studied with respect to temperature parameter. The results presented in this manuscript can provide a useful guidance for the study and design of next generation of nanodevices that make use of the thermal vibration properties of a monolayer graphene as the primary element.

1. Introduction and literature works

The energy of the bulk nano-structures is different from that of the surface layers. In the recent years, a numerous investigations have been done to study the behaviour of nanostructures like nanorods, nanobeams, nanoplates and nanoshells. Understanding the static and dynamic behaviour of such nano-structures under the influence of surface effects is very important to design nanoscale devices. The present work is devoted towards the study of the dynamics of a nanoplate under surface, thermal and magnetic field effects. Hashemi et al. [1] studied the buckling and transverse vibration behaviour of Levy type rectangular nanoplates based on Reddy third order shear deformation theory with the use of nonlocal elasticity theory. They presented all analytical close from expressions in explicit for both the buckling and vibration problems. They observed that as aspect ratio increases, the buckling load and the natural frequency of nanoplates decreases for all type of boundary conditions except for simply supported-free-simply supported-free case. Hosseini and Jamalpoor [2] studied the dynamic characteristics of a double functionally graded viscoelastic nanoplates. They also considered the effects of the surface elasticity. The coupling between the nanoplates was considered as Kelvin-Voigt model. They identified that the natural frequency of these nanoplates is highly affected by the surface elasticity modulus and residual stress. Analooei et al. [3] formulated the solution for the buckling and vibration analysis of nonlocal orthotropic nanoplates using the B3-spline finite strip method. They analysed the buckling behaviour of the nanoplates under both the biaxial compression and pure shear loading. They brought the effect of nonlocal scale parameter on the buckling and vibration characteristics of nanoplates clearly. Karlicic et al. [4] studied the vibration and buckling analysis of multi-nanoplate systems embedded in elastic medium with use of the nonlocal Eringens theory. They proposed the exact solutions for both the vibration and buckling analysis for the multi-nanoplate system with the use of Naviers and trigonometric methods. Babaei and Shahidi [5] carried out the free vibration analysis of nonlocal monolayer quadrilateral graphene sheets. The nonlocal governing equations of motion were derived with the use of principle of virtual work and the Galerkin method is used for the solution. The vibration analysis of skew, rhombic, trapezoidal and rectangular nanoplates were inverstigated in detail.

Liang Ke et al. [6] investigated the nonlocal vibration characteristics of a magneto-electro-elastic (MEE) nanoplates. They

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modelled the nanoplates with the use of the Kirchoffs plate theory. Analytical solution for the nonlocal governing equations of motion were presented. They identified that the natural frequency if the MEE nanoplates was insensitive to the thermal effects as compared to that of mechanical, electric and magnetic loadings. Lu et al. [7] derived the nonlocal governing equations of motion for a bare nanoplate with the use of Kirchhoff and the Mindlin plate theories. They studied both the bending and the vibration problems related to the nonlocal plate theories. Exact nonlocal solutions were presented for both cases. They found that the impact of the nonlocal effects on mechanical properties are highly considerable for very small sized plates.

Thermal effects on the vibration properties of a double-layer nanoplates system was studied by Wan et al. [8] with the consideration of nonlocal elasticity. They identified that the small scale effects are significant for the larger half wavenumbers. The influences of thermal effects, size and half wavenumbers on the vibration modes (I and II) of the nanoplates system were discussed. Wang et al. [9] investigated the mechanical properties of nanostructures under the effects of the surface tension and surface residual stress. They formulated the surface elasticity in both the Eulerian and Legrangian descriptions. They showed that the surface tension significantly affects the effective Youngs modulus of nanowires. Ansari et al. [10] investigated the vibrational behaviour of single layer graphene sheets via nonlocal elasticity and Mindlin plate theory. By using generalized differential quadrature method, the natural frequencies of the nanoplates were obtained. Later, the molecular dynamics simulations (MDS) were performed on simply-supported and clamped graphene sheets for its vibrational behaviour. They found the values of nonlocal scale parameter for both armchair and zigzag graphene sheets. They further proved that the nonlocal scale parameter is independent of the geometric properties of a nano-system. Kang et al. [11] presented the molecular dynamic simulations on graphene nanoribbon resonators under the static and dynamic conditions. Under the static condition the tension and strain energy variations are considered. Under the dynamic condition the effect of tensile loading on the resonance frequency change are captured. They concluded that for ultra-high frequency devices, the graphene nanoribbon resonators can be tuned by tensile loading. Ahmad Fazelzaden and Ghavanloo [12] studied the thermal effects on a graphene based nanoscale mass sensor. A monolayer graphene sheet with multiple attached nanoparticles is considered as nanoscale mass sensor. Based on the nonlocal elasticity, the governing equations of motion were formulated and closed-form relations were obtained for natural frequencies and relative frequency shifts for the nanoscale mass sensor. They found that the frequency shift of the nanoscale mass sensor increases with increasing temperature difference.

Shen et al. [13] investigated the nonlinear vibration behaviour of a simply supported orthotropic graphene nanoplates under thermal environments. The von-Karman type of nonlinearity was considered in the formulation. All the temperature dependent material properties were obtained from MDS. They obtained a nonlocal scale parameter values of the above said problem by matching the vibration results of MDS and nonlocal continuum formulation. Shen et al. [14] investigated the nonlinear vibration characteristics of double-layer graphene sheets under thermal environment by using MDS and nonlocal continuum plate theories. Similar material properties were used as per Ref. [13] They found that the aspect ratio of the graphene nanoplate has moderate effect on the nonlinear vibration response of the double-layer nanoplate system whereas the stacking sequence has small effect. Pradhan and Padhikar [15] formulated the classical and first order shear deformation theories via nonlocal elasticity theory for analysing the dynamic behaviour of nanoplates. The formulated nonlocal governing equations of motion were solved analytically by using Naviers approach. Further they extended the theory to analyse the dynamic behaviour of double nanoplates-system. The effects of nonlocal scale parameter, length and stiffness of Winkler foundation were discussed.

Assadi [16] studied the forced vibration analysis of rectangular nanoplates under general external loading. Surface elasticity effects were also considered in the formulations. He concluded that there exists a neutral ellipse on the surface of nanoplate for which a concentrated load was applied. This means that, if a harmonic concentrated load is applied on any point of this ellipse, then the surface effects do not change the time response of the nanoplate. He also proved that the higher the excitation frequency, the surface property effect diminishes and it can be ignored at near resonance excitations. It was further noted that for square nanoplates the ellipse becomes a circle (neutral circle). Mouloodi et al. [17] implemented a finite element formulation for the vibration analysis of multi crystalline nanoplates with the consideration of surface effects. They also simulated the vibration behaviour of the multi crystalline nanoplates by using ANSYS software and obtained a remarkable correlation between the ANSYS results and their finite element code. They concluded that the prediction of the vibration behaviour (modal analysis) of multi-crystalline nanoplates was not straight forward, and therefore involves numerical procedures.

Ansari et al. [18] studied the thermal effects on the vibration and buckling behaviour of a functionally graded nanoplates with the consideration of surface elasticity theory. The Gurtin Murdoch elasticity theory was employed for surface effects to formulate the governing equations of the classical plate model. The importance of the surface effect was clearly brought out in the results and discussion along with the material gradation index. Ansari and Gholami [19] presented the nonlinear post buckling and free vibration behaviour of nanoplates. They modelled the nanoplates with the third order shear deformation theory with consideration of nonlocal scale effects and surface elasticity. The Gurtin–Murdoch surface elasticity and von-Karman type nonlinearities were considered in the mathematical formulations. The nonlocal governing equations were solved using generalized differential quadrature method and pseudo-arc length continuation were used to obtain the post-buckling load–deflection curves of nanoplates. They concluded that neglecting the surface elasticity effects results in underestimated critical buckling load and stability of nanoplates in the post-buckling domain. Sahmani et al. [20] studied the free vibration behaviour of the post bucked circular nanoplates. They modelled the circular nanoplates with higher order shear deformable plate theory along with nonlocal elasticity and geometrical nonlinearity. They found that the surface density effect was negligible on the buckling point of nanoplates. But for pre- and post-buckling domains, the increase in surface density reduces the natural frequencies. Ansari et al. [21] studied the vibrational behaviour of circular nanoplates under surface stress effects and nonlocal elasticity theory. Ansari and Sahmani [22] formulated the classical and first order shear deformation plate theories with the consideration of surface elasticity and nonlocal elasticity theories for studying the free vibration behaviour of nanoplates. Closed-form solutions were derived for both the plate theories. They found that the sign and magnitudes of the surface elasticity constants play a major role in vibration properties of a nano-system.

Prasanna Kumar et al. [23] presented the thermal vibration analysis of a monolayer graphene sheet embedded in polymer elastic medium. They modelled the graphene with plate theory and nonlocal continuum mechanics and the elastic medium was modelled with Pasternak type model. They also considered the thermal effects caused by the axial stress in the formulations. Closed form analytical solutions using Naviers method were presented to study the thermal vibration behaviour of a graphene embedded in elastic medium. The influences of nonlocal scale, temperature (low, nil