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Mini Review

A Review on Dynamics of Multi-Layered Nano and Microstructures

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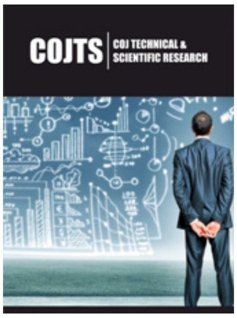
Abstract

Multi-layered small-scale structures have engrossed a great deal of attention in the past few years. Nano/micro-structures are found as multi-layered in nature which shows the importance of studying them considering the layer interactions. To this end, in this paper, a brief review on the highlighted previous investigations on modelling small-scale structures considering layer interactions is presented in the framework of dynamic analysis. The importance of correctly modelling the size-dependence mechanical formulation and layer interaction is discussed in detail for both nano and micro scale structures.

Keywords: Multi-layered; Nanobeam; Microbeam; Nanoplate; Microplate; Dynamics; Vibration



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Submission: May 19, 2020

Published: July 21, 2020

Volume 3 - Issue 1

How to cite this article: Khaniki HB, Ghayesh MH. A Review on Dynamics of Multi-Layered Nano and Microstructures. COJ Technical & Scientific Research. 3(1). COJTS. 000553. 2020.

Introduction

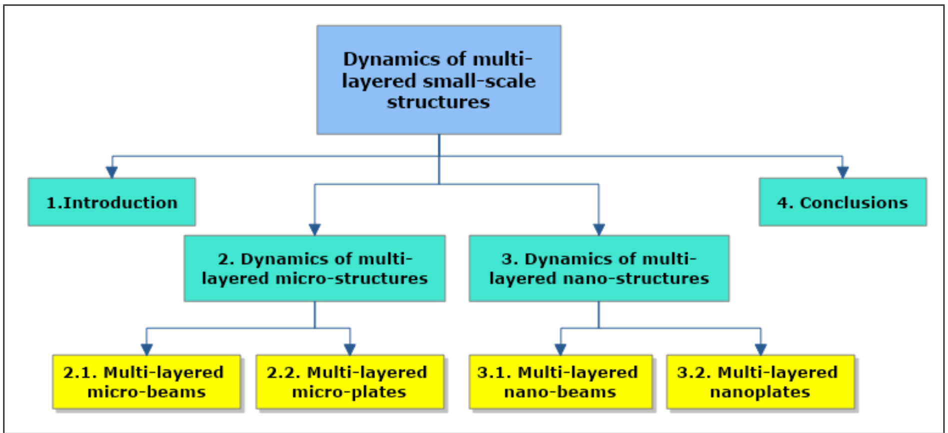

Figure 1: Flowchart of the structure of this mini review paper.

A well-known class of small-scale are multi-layered size-dependent structures which may be fabricated using different fabrication processes such as roll-to-roll process, nano-transfer printing, etc. [1,2]. Due to the very small geometric size of such structures, molecular interactions and van der Waals forces become considerable and therefore the continuum classical models are incapable of modelling such structures; hence, it is important to use an appropriate accurate model to study such structures. Since experimentally studying such structures require high-tech laboratories and investigating considerable budget, it is more logical and convenient to find an accurate way of modelling the mechanical behavior using theoretical formulations. To this end, this review paper presents the previous investigations on multi-layered small-scale structures to show the importance of considering the layer interactions and size- dependency effects; however, the previous studies on single-layered small-scale structures could be found in [3-13] for micro structures and [14-22] for nano-structures which is out of the scope of this review. Accordingly, as shown in (Figure 1), this review paper is divided into four main sections; in the first section, an introduction is given on layered small-scale structures emphasizing on the importance of modelling these structures. In Section 2, highlighted research studies on dynamics of micro-scale layered structures are presented which is divided into two subsections discussing nano-beam structures and nano-plate structures. Similarly, Section 3 presents the highlighted literature on the dynamics of nanoscale layered structures which is also divided into nano-beams and nano-plates as subsections.

Dynamics of Multi-Layered Micro-Structures

As mentioned previously, in small-scale structures, the classical continuum theories are invalid, and a proper type of modelling needs to be used. Modified couple stress theory (MCST) [23-28] and its derivation strain gradient theory (SGT) [29-31] have been used by researchers over past few years to model and analyze micro-scale structures. Accordingly, in this section, the dynamics of multi-layered micro-scale structures are investigated which have great potential applications in MEMS.

Multi-layered micro-beams

For the case of dynamic analysis of multi-layered micro-scale structures, Ghayesh et al. [32] investigated the nonlinear dynamic response of three-layered micro-beams via the MCST; higher-order shear deformable beam theory was used to model the micro-beams considering imperfection in the structures. Frequency-responses of the layered micro-beams was presented and both hardening and softening behavior were observed. Newton-Raphson method was used by Farokhi et al. [33] to comprehend the mechanical response of clamped layered micro-beams. Farokhi et al. [34] examined the nonlinear vibration behavior of extensible micro-beams using Timoshenko beam theory and MCST; it was shown that the longitudinal, transverse, and rotational motions show hardening effect in the nonlinear frequency-response. Nonlinear resonance [35-38] of layered micro-beams with cantilevered boundary condition has also been studied by Ghayesh et al. [39] using Bernoulli-Euler beam theory. The effects of the excitation amplitude and the MCST small-scale parameter were discussed in detail. Khaniki [40] investigated the forced dynamic response of multi-layered micro-beams under the action of moving nanoparticle. Euler-Bernoulli beam theory in conjunction with MCST was used to model the micro-beam system resting on a Winkler elastic medium; it was shown that increasing the MCST parameter leads to lower dynamic deformations. Curved micro-structures have also been examined by researchers in the past few years. Ghayesh et al. [41] studied the complex motion of small-size arches. Timoshenko beam theory together with von-Karman nonlinearity and MCST was used to model the structure and solved using a well-optimized numerical technique.

Multi-layered micro-plates

For the case of plate analysis, Ghayesh [42] investigated the nonlinear oscillation behavior of three-layered microplates; the MCST in conjunction with von-Karman nonlinearity, Kirchhoff plate theory and Hamilton's principle [43-52] were used to model the microstructure accurately it was shown that the general behavior of such micro structures is hardening type. Moreover, Yang [53] examined the linear vibration response of multi-layered micro-plates using a revised MCST; it was shown that the size-dependent term has a considerable effect in varying the natural frequency parameters.

Dynamics of Multi-Layered Nanostructures

For nano-scale structures, as for micro-scale structures, the classical continuum theories are invalid, and a proper type of modelling needs to be used. Nonlocal continuum theory is used by researchers to study the nano-scale structures which have been presented in differential [54,55], integral [56] and two-phase [57,58] forms. Accordingly, in this section, multi-layered nano-scale structures are discussed which have broad applications in NEMS.

Multi-layered nano-beams

Layered nano-beams have received a great deal of attention in the past years. For the sake of free vibration analysis, Karličić et al. [59] examined the free vibration response of multi-layered nano-beams. The Euler-Bernoulli beam theory, Winkler elastic model and differential form of the nonlocal theory were used to model the nano-system; it was shown that increasing the number of layers have a considerable effect in changing the natural frequency term of each layer. Khaniki [60,61] presented the dynamic response of double- layered isotropic and functionally graded nano-beams using the two-phase local/nonlocal model. Natural frequencies were observed for different boundary conditions and the ill-posed issue overcame. Dynamic response of multi-layered nano-beams acting upon a moving mass or force was studied lately by researchers. Hashemi [62,63] examined the forced deformation of layered nano-beams with elastic and viscoelastic [64-66] interactions. Nonlocal elastic theory, the Euler-Bernoulli beam theory and the Kelvin-Voigt viscoelastic models were used; it was shown that the size-effect has a considerable effect on the enhancement of the forced deformations.

Multi-layered nano-plates

Similarly, layered nano-plates have been investigated by researchers in the past years. Karličić et al. [67,68] investigated the free vibration response of multi-layered nano-plate systems. Kelvin-Voigt viscoelastic model [69] was used to model the layer interactions and Kirchhoff-Love plate theory was used in conjunction with nonlocal theory to model the nano- plates; the influence of different parameters on the vibration response was discussed, showing the importance of considering size-effects. Mahmoudpour [70] studied the nonlinear vibration of multi-layered nano-plates with simply supported boundary conditions. Mindlin plate theory and von-Karman large deformation model were used to model the plates with van der Waals interactions between layers. Scale effect was modeled using a combination of nonlocal theory with SGT; it was shown that the amplitude of the response decreases by increasing the number of layers. Khaniki [71] examined the dynamic deformation of double-layered orthotropic nano-plates acted upon moving nanoparticle. Plates were assumed to be bi- axially loaded and the nanoparticle was modelled with linear and circular motions; it was shown that increasing the nonlocal parameter increases the deformation in both layers of the system. By using the Reissner-Mindlin plate theory, Ansari [72] investigated the vibration behavior of layered nano-plates with van der Waals interlayer forces. It was shown that the presence of the elastic foundation has a significant effect on increasing the natural frequencies.

Conclusion

Over the past few decades, the importance of having an accurate model for analyzing the multi-layered small-scale structures has been a challenging task regarding the size-dependence effect and the layer interactions. In this review paper, efforts made by researchers in the past few years in modelling and analyzing multi-layered small-scale structures are discussed by presenting highlighted works in this field. The size-dependency terms in modelling micro-scale structures (using MCST and STG) and nano-scale structures (using nonlocal theory) play a dominant role in modifying the classical continuum models for macro-structures. In summary, by analyzing previous literature on the dynamic behavior of layered small- scale structures, it can be seen that although there have been several studies on both nano and micro-structures, the topic is still novel and requires more investigations to accurately model the dynamics, especially for large deformations and forced vibrations.

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