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Size Dependent Buckling Analysis of Hybrid Organic/Inorganic Nano-Sized I-Beam

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Abstract

In the paper, the size dependent buckling analysis of hybrid organic/inorganic nanobeam with I cross section is investigated. Eringen's nonlocal elasticity theory is used to take the size effect into consideration. Comparative buckling loads of nanobeams for first ten modes is plotted in figure using Euler-Bernoulli theory and Eringen's nonlocal elasticity theory. Two different size parameter is used. It is clearly demonstrated that the size effect can be neglected for first modes while it is unneglectable for higher modes. Simply supported case in investigated. The advantages of I-cross section are discussed.

Keywords: Nonlocal elasticity theory, Euler-Bernoulli, Hybrid nanobeam, Nano-sized I-beam.

1. Introduction

Nano sized materials attracted much attention because of their out of the common properties. The starting point of the rise of these materials is the discovery of Carbon Nanotubes (CNTs) by Iijima in 1991 [1]. CNTs are graphene based materials. The discovery of graphene happened 13 years later of CNTs [2]. Many methods of obtaining CNTs from graphene sheets was developed (layer separation, chemical separation, chemical vapor deposition etc.). The key point of attracting much attention is the material was performing outstanding mechanical strength, electronical conductivity, physicochemical properties compared to any known material [3]. Working experimentally with CNTs need advanced level of laboratory equipment together with very high experiment cost. Also, researchers have fronted to working theoretically instead of experiments because of time. A researcher can obtain results for thousands of alternative variant in seconds while working theoretically using accurate models [4]. As nanotubes dimensions are in nanometer level, classical theories were insufficient to perform theoretic analysis [5]. In past years, researchers developed and proved the accuracy of new size-dependent theories such as nonlocal elasticity [6, 7], strain gradient [8, 9], modified couple stress [10], surface elasticity [11-13] theories to perform modal [14-25], bending [26-28], buckling [29-35] analyzes accurately. In more detail some other outstanding properties of these materials can be stated as high energy absorption, very high strength, superior electrical conductivity, flexibility, high maximum current density, high thermal conductivity, reduced skin and proximity effect, extreme lightweight, fatigue resistance etc. CNTs are performing very well in supercapasitors which are widely applied in portable devices, electric vehicles [36], drug delivery [37], high-strength polymer compounds, water-gas shift and production of H_2 [38]. Lately, with the rise of popularity and extremely widened usage area CNTs and functionally graded materials (FGMs) are composed to create a novel type of composite material [39-50]. The novel composed material is named functionally graded carbon nanotube-reinforced composites (FG-CNTRC) [51]. FG-CNTR has both advantages of CNTs and FGMs [52-55]. However, CNTs are not performing drastic mechanical strength or electrical or thermal conductivities for many applications [56]. The load capacity of CNTs and its composites started to be insufficient for some specific area. Therefore, scientists aimed to develop the classical tubular CNT structure [57]. Elmoselhy [58] presented a molecular form of I-shaped like beam CNT. The web resists shear forces applied to nanostructure, while the flanges resist most of the bending moment. The I shaped structure have advantages in carrying both bending and shear loads in the plane of the web while having the disadvantage of reduced capacity in the transverse direction, and carrying torsional loads. In present work, the buckling analysis of I-shaped hybrid nanobeam is investigated. In order to take the size effect into consideration, Eringen's nonlocal elasticity theory is used.

2. Hybrid Organic/Inorganic Nano-Sized I-Beam

The classical method of obtaining conventional nanotubes with tubular cross section is demonstrated in Fig. 1. As it can be seen clearly from Fig. 1, the graphene-like flat structure composed of Carbon atoms, Silicon and Carbon atoms, Boron and Nitrogen atoms bonded to each other for obtaining CNTs, silicon carbide nanotubes (SiCNTs), and boron nitride nanotubes (BNNTs) respectively by simply rolling it to form the tubular structure [59].

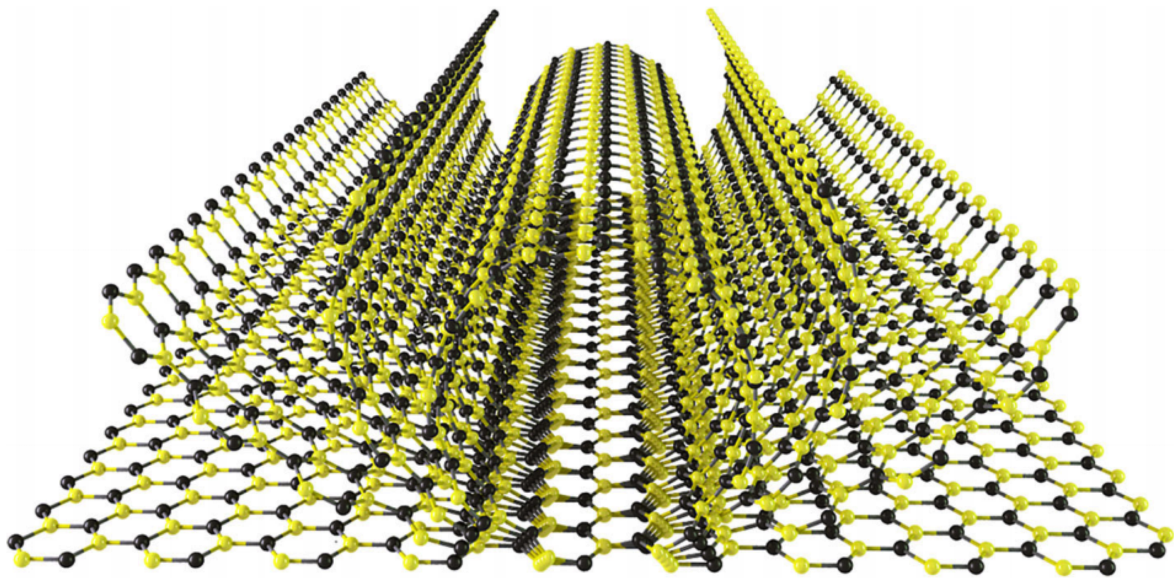

Fig. 1. Obtaining nanotube from graphene-like structure [60]

The discovery and usage of inorganic nanotubes is later than organic nanotubes. Inorganic nanotubes are synthesized of group III-Nitrides, metal oxides, or other inorganic elements. Inorganic nanotubes have the advantages in case of ease in synthesis, high crystallinity, uniformity, high impact-resistance, high chemical stability under acidic and basic conditions [61]. Obtaining nanobeam with I shaped cross section was described by Elmoselhy [58]. Unlike the conventional techniques, a hybrid growth method was used. In the method, perpendicular growing technique of nanorods was combined with a tangential growing technique of a ribbon of multi nanorods. Five phases of of growing were used to form a nanoribbon which compose the flange of the single walled nano-sized I-beam. Discrete catalytic nanoparticle (Inorganic Fe_2O_3) was placed on substrate, then chemical vapor deposition method was used to obtain hybrid organic/inorganic nano-sized I-Beam. It is also demonstrated that different I cross-sectioned alternative nanobeams can be obtained according to the need in usage area. Alternative structures are single walled hollow, single walled solid, multi-walled hollow, multi-walled solid nano-I-beams. In Fig. 2, the obtained nano-sized beam with I cross section is demonstrated. Selected nano I-beam is single walled solid nanobeam.

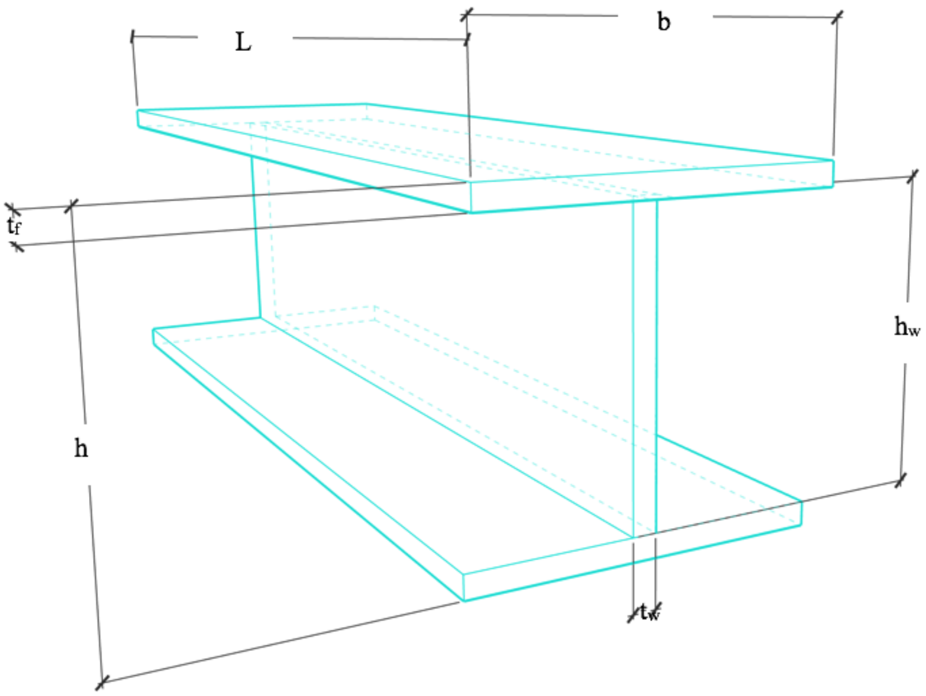

Fig. 2. Nano-sized I-Beam

Previous works shown that the Young's modulus of hybrid or inorganic nano structures can be lower than conventional CNTs which effect directly the stability potential of material [61, 62]. On the other hand, the great advantage of having I-like cross section can pass over the disadvantage of Young's modulus. I-cross section is widely used in civil engineering due to it's high moment of inertia of cross section. The web resists shear forces while the flanges resist most of the bending moment. The I shaped structure have advantages in carrying both bending and shear loads in the plane of the web while having the disadvantage of reduced capacity in the transverse direction, and carrying torsional loads. Also, used material in I-cross section is minimized to needed area. Minimizing the production material is also a great advantage when it comes to work with high-cost nanomaterials.

3. Size Dependent Buckling Analysis

In present paper, the size effective stability analysis of simply supported, I-shaped hybrid nanobeam. Deriving the size effective buckling equation based on Eringen's nonlocal elasticity theory [63] is given in detail in literature [60, 64].

$$P(n)=\frac{(\overline{EI}-k_p\mu)\left(\frac{n\pi}{L}\right)^4+(k_w\mu+k_p)\left(\frac{n\pi}{L}\right)^2+k_w}{\mu\left(\frac{n\pi}{L}\right)^4+\left(\frac{n\pi}{L}\right)^2} \tag{1}$$

Herein, *"E"* and *"I"* represent the Young's Modulus and moment of inertia respectively. μ is the nonlocal parameter. k_w and k_p stand for the Winkler modulus and Pasternak modulus of the elastic foundation which will be neglected in present paper as the nanobeam is modeled without foundation. Young's modulus of hybrid inorganic/organic can vary. Selected Young's modulus for this paper is equal to spinel structured C_3N_4 834 GPa to represent an average hybrid nanobeam [65]. Also, selected size of I-shaped nanobeam is 15nm wide flanges with 2nm thickness while having 20 nm web with 2 nm thickness and 500 nm length. The moment of inertia can be calculated analytically using following formulas;

$$I_{I-shape}=\frac{bh^3-bh_w^3+t_wh_w^3}{12} \tag{2}$$

Nonlocal parameter is;

$$\mu=(1-e_0a)^2 \tag{3}$$

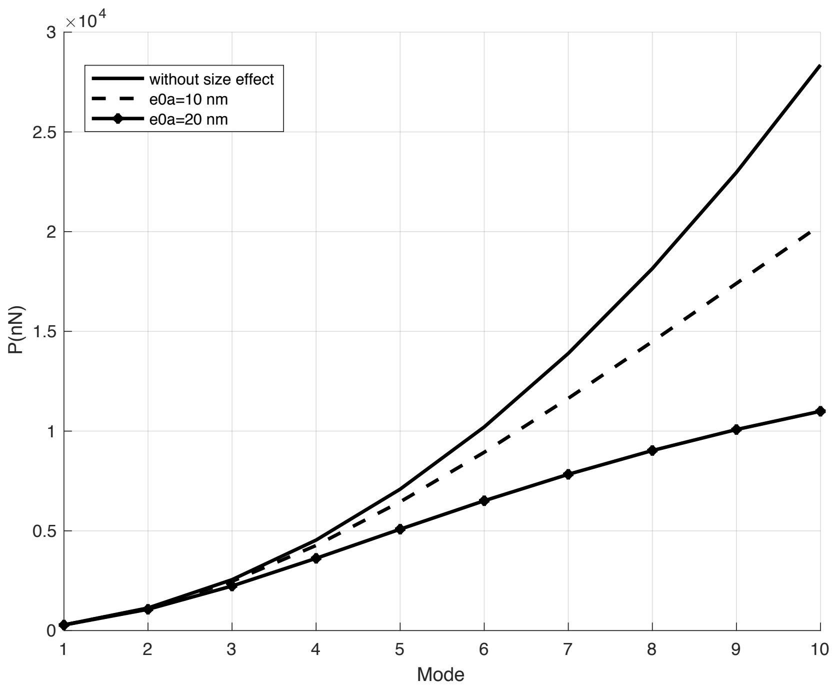

Fig. 3. The variation of buckling load versus mode number

As it can be clearly seen from Fig. 3, the buckling load difference between size effective results and classical theory become dramatic with the rise in mode number. The effect of size dependent theory can be neglected for first modes while it is impossible for higher mode modes. On the other hand, the advantage of high moment of inertia results with higher buckling loads comparing to conventional tubular nanobeams. Together with the rise in moment of inertia the advantage of lower cross-sectional area results with lower production and material cost.

4. Conclusions

In this work, the buckling analysis of hybrid organic/inorganic nanobeam with I cross section is investigated by taking the size effect into consideration. Eringen's nonlocal elasticity theory is used. Buckling loads of hybrid inorganic/organic nanobeam for first ten modes is demonstrated in figure using classical theory and Eringen's nonlocal elasticity theory. It is clearly demonstrated that the size effect can be neglected for first modes while it is unneglectable for higher modes. The nanobeam is modeled simply supported without foundation. Further researches can be comparing conventional nanotubes with I cross-sectioned nanobeams using different size effective theory. Comparative results can guide the usage of nanobeams in nano-structures.

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