BUCKLING ANALYSIS OF SWCNT REINFORCED COMPOSITE PLATE

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ABSTRACT

This work presents the buckling analysis of functionally graded single walled carbon nano tubes reinforced composite plates under in-plane mechanical loads. The effective material properties of uniformly distributed carbon nano tubes are obtained using Mori–Tanaka approach and extended rule of mixtures. The buckling load has been obtained numerically with the help of commercial finite element package ANSYS using ANSYS parametric design language code. The convergence behaviour of the developed model has been checked and validated by comparing the responses with that available literature. Effect of different geometrical parameters such as aspect ratio and side to thickness ratio have been studies and discussed in details.

Keywords: *SWCNT, FEM, ANSYS, Laminated composite, buckling.*

INTRODUCTION

Carbon Nano tubes (CNTs) are carbon allotropes whose structure resembles that of a cylinder. The length to diameter ratio of CNT's can be in excess of thousands. It is well known from various experiments conducted by the researcher and claimed that the aspect ratio (l/d) exceed 1.32×10^8 to 1. These carbon atoms which are cylindrical in shape have very unusual properties which find application in electronics, optics, nanotechnology and other areas of science and engineering. These tubes possess extremely high thermal conductivity and electrical and mechanical properties and find application in material science and engineering. Nanotubes are used in tiny quantities and in microscopic proportions for common items like golf balls and in military application like gun barrels.

The basic structure of a nanotube resembles that of a fullerene, it is like long hollow walls which are formed by layers of carbon one atom thick which is called grapheme. These tubes vary in properties depending upon the angle of rolling and the rolling radius. The angle of rolling assumes prime importance in determining the properties of the CNT and is called as chiral angle. Nanotubes are mainly classified as single walled and multi walled nanotubes (SWCNT/MWCNT). All nanotube molecules are held together by covalent forces which are also known as Vander Walls forces. Quantum chemistry and orbital hybridization can be used to describe the chemical structure of CNT's and it is composed of completely sp^2 bonds, like graphite.

There are numerous applications of CNT's which vary from use in miniscule applications involving nanotechnology to providing strength to gigantic structures. Breakthroughs carried out by Ray H. Baughman at the Nano Tech Institute have proposed that MWCNT and SWCNT can yield substances with great toughness which has been previously unheard of. Many researchers have carried out experiments to reinforce composites of CNT's. Generally mechanical, thermal and electrical properties of composite structures greatly depend on the added reinforcement, and the elasticity and tension strength of CNTs may give strong and stiff composite structures, such as shells, beams and plates.

Buckling of structural parts and equipment is a common failure mode. Buckling is a geometrical instability, which leads to a catastrophic failures. Buckling is characterized by a sudden failure of a structural member subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Numerous studies have been conducted to study and describe the buckling behaviour of composites. Many studies have been reported in literature to predict the buckling strength of functionally graded carbon nanotube (FGCNT) under mechanical loading.

LITERATURE SURVEY

It focuses on study of developing a new nanocomposite material using carbon nanotubes because of its excellent mechanical properties, buckling, vibration, bending, analysis of SWCNTS and MWCNTs reinforced composite. It was found that the technique which was used for calculating the effective material properties of composite and method is used to find the mechanical behaviours.

Lei et al. [1] presented the buckling analysis of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) plates under various in-plane mechanical loads using first order shear deformation theory (FSDT) and calculate effective mechanical properties of nano composite using rule of mixture or Eshelby-Mori-Tanaka approach, optimised the variation in the buckling strength on composite plate with volume fraction, aspect ratio, loading conditions, width-to-thickness ratio and environment temperature. Han and Elliott [2] employed molecular dynamics (MD) and energy minimization simulation methods to examine the elastic properties of the CNT composites materials. Mehrabadi et al. [3] studied the mechanical buckling behaviour of a FG-CNTRCs rectangular plate using FSDT mid-plane kinematics. The authors utilized MD, Eshelby-Mori-Tanaka approach and the extended rule of mixture to evaluate the effect material properties of SWCNT. Zhu et al. [4] presented the vibration and bending analyses of FG-CNTRCs using finite element method based on FSDT. Shen and Zhang [5] examined the thermal buckling and postbuckling behaviour of FG-CNTRC using a micromechanical model. Shen [6] investigated the nonlinear bending of simply-supported FG-CNTRCs under thermo-mechanical loading using higher order shear deformation theory (HSDT) with von Karman nonlinearity. Alibeigloo and Liew [7] employed three dimensional theory of elasticity to obtain the bending responses of simply supported FG-CNTRCs rectangular plate subjected to thermo-mechanical loads. Fazzolari et al. [8] presented the buckling response of composite plate assemblies using HSDT and dynamic stiffness method. Ansari [9] studied the buckling behaviour of single-walled silicon carbide nanotubes using density functional theory. Neves et al. [10]

investigated stability behaviour of isotropic and functionally graded sandwich plates in the framework of HSDT by using a messless technique. Murmu and Pradhan [11] examined the buckling behaviour of SWCNTs embedded in elastic medium using Eringen"s nonlocal elasticity theory and the Timoshenko beam theory. Popov et al. [12] evaluated the elastic properties of triangular close-packed crystal lattices of SWCNTs using analytical expressions based on a force-constant lattice dynamical model. Yas and Samadi [13] analysed the free vibrations and the buckling behaviour of FG-SWCNT resting on an elastic foundation using Timoshenko beam theory. Ayatollahi et al. [14] estimated the nonlinear mechanical properties of the zigzag and armchair SWNTs under axial, bending and torsional loading conditions using finite element based molecular mechanics steps. Chen and Liu [15] obtained effective mechanical properties of carbon nanotube based composite using a square representative volume element (RVE) based on continuum mechanics. Odegard et al. [16] developed a constitutive model for polymer composite systems reinforced with SWCNTs. Shen and Xiang [17] investigated the postbuckling of SWCNTs reinforced nanocomposite cylindrical shells under thermo-mechanical loading. The model has been developed based on HSDT shell theories with a von Karman type of nonlinearity kinematics. Thai [18] employed a nonlocal shear deformation beam theory to investigate the buckling, bending, and vibration of nanobeams. Guo et al. [19] employed an atomic scale finite element method (FEM) to analyse bending and buckling behaviour of SWCNTs. Zhang et al. [20] studied the buckling responses of CNTs using FEM. Mohammadimehr et al. [21] presented the buckling behaviour of double-walled carbon nanotubes embedded in an elastic medium under axial compression using non-local elasticity theory. Sears et al. [22] presented buckling of MWNTs and SWNTs, correspondingly under the axial compressive loads have been studied by MDs, and results compared with those from the analysis of equivalent continuum structures using the finite element method and Euler buckling theory. Vodenitcharova and Zhang [23] presented buckling and bending analysis of nano composite beam reinforced by SWCNTs, analysed the matrix deformation using Airy stress function method. Also it has been found that adding quantity of CNTs reinforced in matrix increased load carrying capacity of structure. Sun and Liew [24] studied a bending buckling behaviour test of SWCNTs using higher order gradient continuum and mesh free method. It also studied about various types of CNTs and the buckling mechanism.

Shima [27] presented a nonlinear mechanical bending and buckling response of CNTs based composite and studied the behaviour of CNTs under different load condition as compression, bending, tension torsion, and their combination. Lei et al. [28] investigated the vibration analysis of FG-SWCNT, using the element-free kp-Ritz method. SWCNT was reinforced into a matrix with various types of distribution. The material properties of FG-CNTRCs were assumed to be graded through the thickness direction according to several linear distributions of the volume fraction of carbon nanotubes and FSDT was used for governing equation. Rangel et al. [29] presented an analytical procedure to find out the elastic properties of SWCNTs of armchair type using finite element approach for mechanical modelling of a SWCNTs and it was found that mechanical properties of CNTs was outstanding. Simsek [30] presented forced vibration analysis of simply supported SWCNTs under the action of a moving harmonic load based on nonlocal elasticity theory. Grace [31] studied different types of CNTs like SWCNTs and MWCNTs and geometrical arrangement of carbon atom as armchair, chiral and zig-zag because of physical and mechanical properties of CNTs depending on its atomic arrangement. Lu, X., and Hu, Z.,

[32] studied computational simulation for predicting the mechanical properties of carbon nanotubes. It have been adopted as a powerful tool relative to the experimental difficulty. Based on molecular mechanics, an improved 3D finite element model for armchair, zigzag and chiral SWCNTs has been developed. Yu et al. [33] investigated the properties of carbon nanotubes based composite by precursor infiltration and pyrolysis process (PIP). The fiber and matrix interface coating has been arranged through chemical vapormdeposition (CVD) process using methyltrichlorosilane (MTS). An effect of the CNTs on mechanical and thermal properties of the composite has been estimated by three-point single edge notched beam test, bending test, and laser flash method. Yeetsorn [34] studied about the carbon nanotubes as an advanced composite material in the form of CNTs like armchair and zigzag. They found out CNTs have excellent mechanical, thermal, and electrical properties. CNT was developed through different technique like laser ablation, arc discharge and chemical vapour deposition. Formica et al. [35] studied of the vibrational property of CNTRC by using an equivalent continuum model based on the Eshelby–Mori–Tanaka method. Odegard et al. [36] discussed representative volume element (RVE) based on continuum mechanism for developing structural properties relationship of nano structure material. Volcov et al. [37] discussed effect of bending and buckling analysis of carbon CNTs on thermal conductivity of carbon nanotubes materials was studied in mesoscopic and atomistic simulations.

Based on the above literature, it is clear that many attempts have been made to study the mechanical buckling behaviour of FG-CNTRC but the studies with temperature dependent material properties were very rare. Hence, the authors‟ aim is to analyse the mechanical buckling of uniformly distributed (UD) and FG-CNTRC with temperature dependent material properties. A simulation model is developed using ANSYS parametric design language (APDL) in ANSYS environment.

RESULT AND DISCUSSION

In this section, the FGCNT model of uniformly distributed (UD) composite plate has been developed using APDL code in ANSYS. As discussed a plate having dimensions $a = b = 20$ mm and $h = 2$ mm and the effective modulus of elasticity of matrix (Em) = 2.1□10^9 N/mm^2 have been developed and presented in Fig.

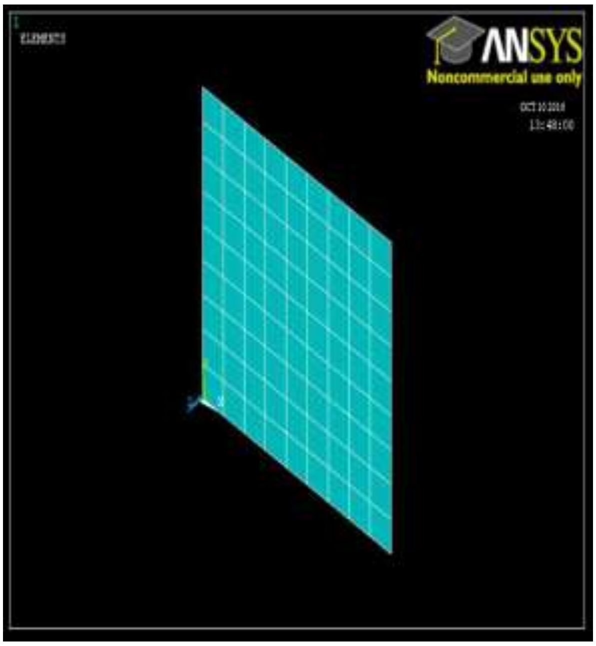


Fig. 1. FGCNT plate model

The following simply supported boundary conditions are used for the analysis:

$v_0 \square w_0 \square \square_y \square 0$ at x = 0 and x = a

$u_0 \square w_0 \square \square_x \square 0$ at y = 0 and y = b

Convergence and Comparison Study

In order to check the convergence behaviour of the present model, the present model has been developed in ANSYS and presented in Fig.4. It is clearly observed that the present results are converging well with mesh refinement. In continuation to that, the nondimensional critical buckling load parameters are computed using the present APDL code and the comparison study has been presented in Table 1. The material and geometrical parameters are same as the reference. The ANSYS model is showing very good agreement with that of the reference.

Table 1. Comparison of critical buckling load

Mode No.	Present $\bar{N}_{cr}$	Reference [9]	Percentage of difference
1	27.44	28.4768	3.78
2	27.46	28.8410	5.03
3	27.64	29.5768	7.01
4	28.94	30.1219	4.08

Numerical Illustration

Some new results are computed for FGCNT composite plate for thickness ratio and aspect ratio and presented in Fig. 5 and 6, respectively. It is observed that the buckling load parameters increase as the thickness ratio increases and the decreases with aspect ratio. In addition to that four different buckling mode shapes are presented in Fig. respectively.

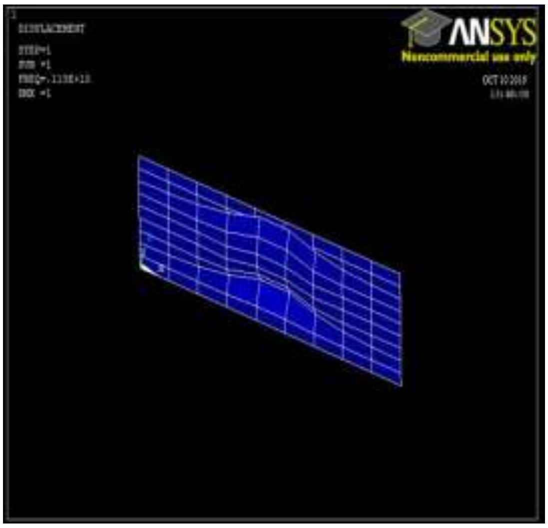


Fig. (a). 1st Mode

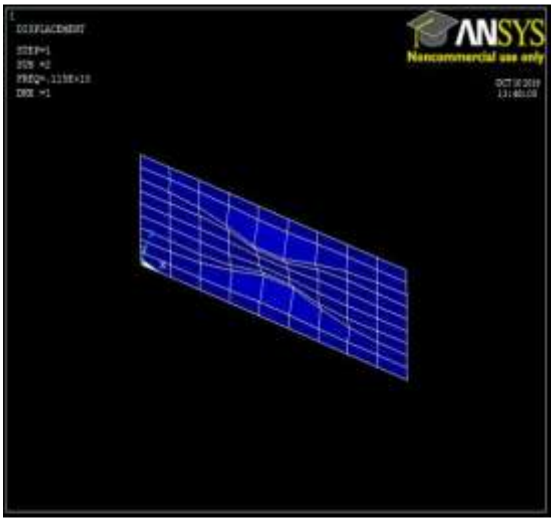


Fig. (b). 2nd Mode

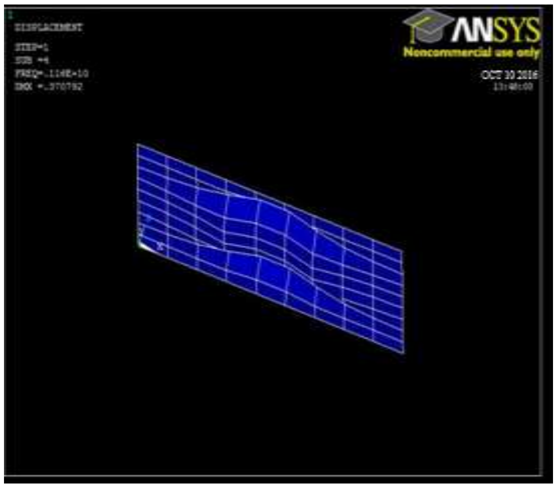
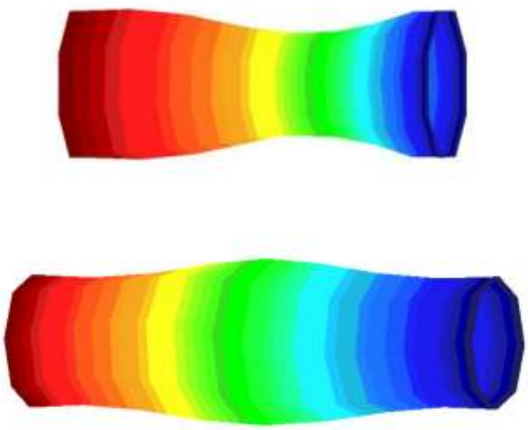


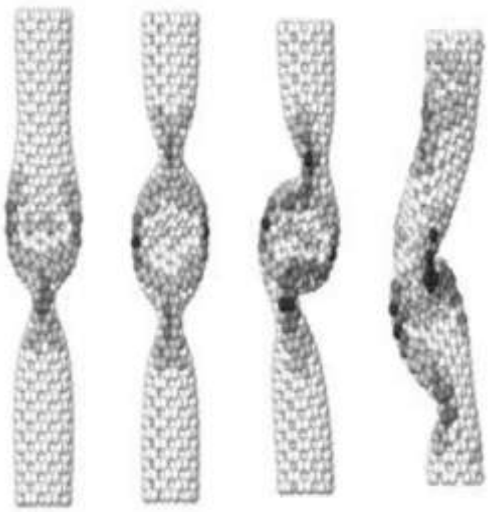
Fig. (d). 1st Mode

Cylindrical shell model: buckling

For one end fixed cylindrical shell, two types of buckling modes have been observed in this research, as shown in Fig. Yakobson et al. (1996) adopted molecular dynamics method to simulate buckling of SWCNTs under axial compression, and provided the simulations as shown in Figure. Our cylindrical shell in this research is able to capture the first two buckling patterns.



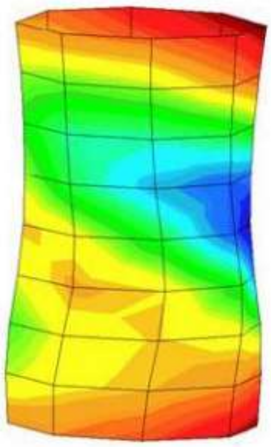
Two buckling patterns of SWCNTs under axial compression



Simulations of buckling patterns of SWCNTs under axial compression

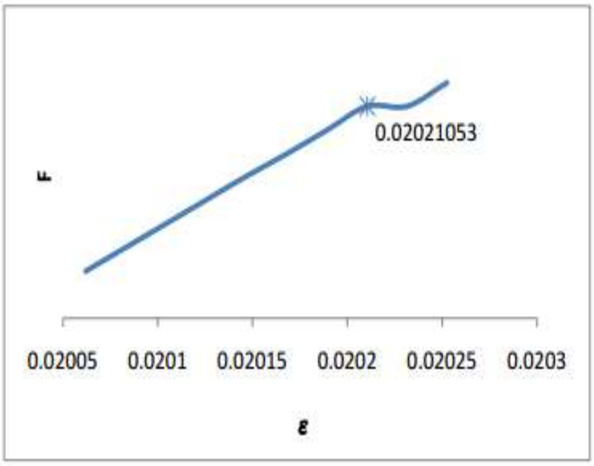
For a cylindrical shell with applied compression at both ends, the buckling deformation is as shown in Figure

Sketch of cylindrical shell model under stretching

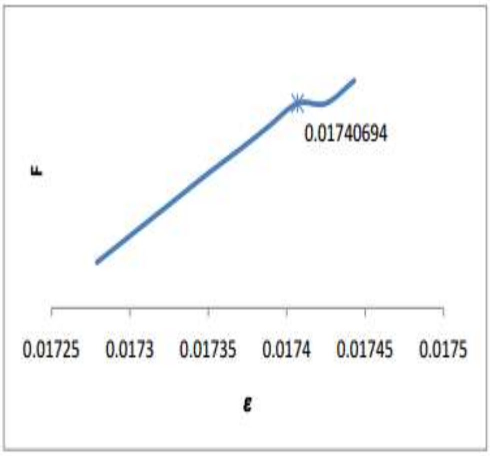


Deformation of cylindrical shell under compression (D=4.266nm; L=8nm)

Zigzag SWCNTs are studied, with the tube length fixed to L=16nm, and the tube diameter ranging from 0.939nm to 3.757nm. The critical bucking strain is captured via a force-strain relationship as shown in Figure. The same method is applied to capture the critical strains for SWCNTs with length L=16nm as listed in Table and plotted out in Figure. It is shown that the critical buckling strain decreases when the tube diameter increases for a fixed length, but the differences are not significant.



Force-strain relationship of cylindrical shell under compression (D=3.288nm; L=16nm)

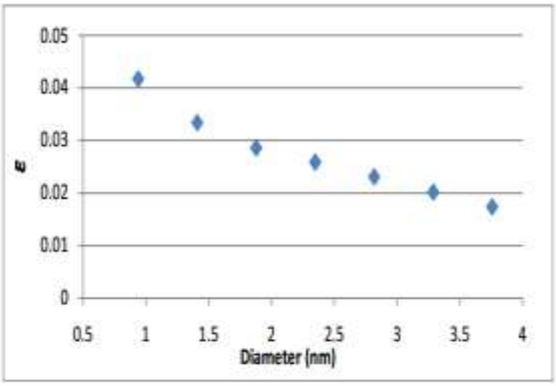


Force-strain relationship of cylindrical shell under compression (D=3.757nm; L=16nm)

Force-strain relationship of cylindrical shell under compression with various tube diameters

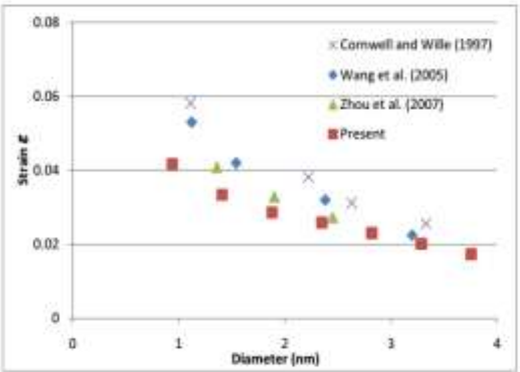
Critical strains for zigzag SWCNTs with different tube diameters

Diameter (nm)	0.939	1.409	1.879	2.348	2.818	3.288	3.757
Critical strain	0.0417	0.0334	0.0286	0.0259	0.0231	0.0202	0.0174



Critical strains of zigzag SWCNTs under compression with fixed length

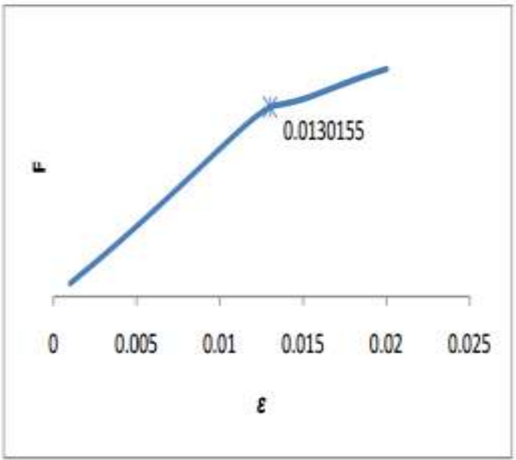
Variations of critical strain with respect to tube diameter are compared in Figure 4 with results from three other authors all of which gained from atomistic simulations. While Wang et al. (2005) fixed the tube length to 10.1 nm, Zhou et al. (2007) fixed the tube length to 11.0 nm. Their specimens were also studied with different chiralities. Differences in tube lengths and chiralities may be the cause of the differences in critical strains.



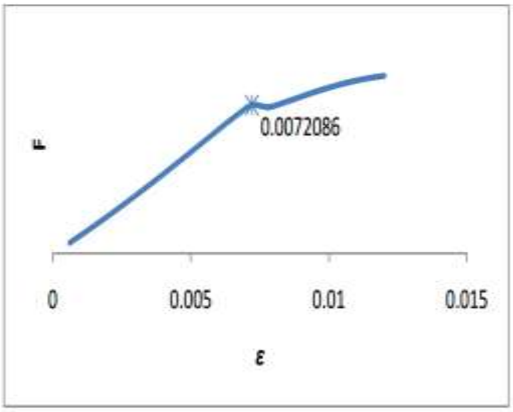
Comparison of variation of critical strains with respect to tube diameter

Second sets of zigzag SWCNTs are studied with respect to the aspect ratio L/D, by fixing the tube diameter to D=1.409nm with the tube length ranging from 8nm to 40nm.

The critical bucking strain is captured from the force strain relationship as shown in Figure. It is shown that the curve of the force-strain relationship here varies from what is shown in Figure, where the aspect ratio is relatively small. Apparently after a certain aspect ratio, the force-strain relationship decreases beyond the critical strain, i.e. the tube is less stiff. Critical strains for SWCNTs with diameter D=1.409nm are listed in Table



Force-strain relationship of cylindrical shell under compression (D=1.409nm; L=32nm)



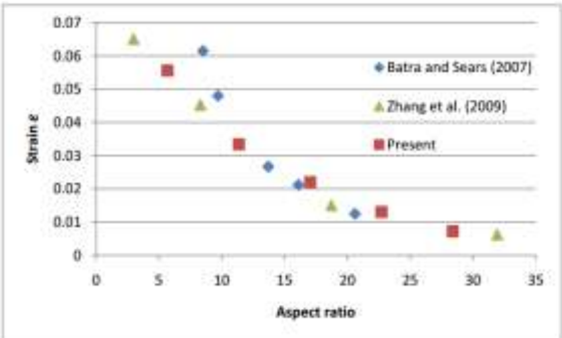
Force-strain relationship of cylindrical shell under compression (D=1.409nm; L=40nm)

Force-strain relationship of cylindrical shell under compression with various tube lengths

Critical strains for zigzag SWCNTs with different aspect ratio

Tube length (nm)	8	16	24	32	40
Aspect ratio	5.68	11.36	17.03	22.71	28.39
Critical strain	0.0556	0.0334	0.0220	0.0130	0.0072

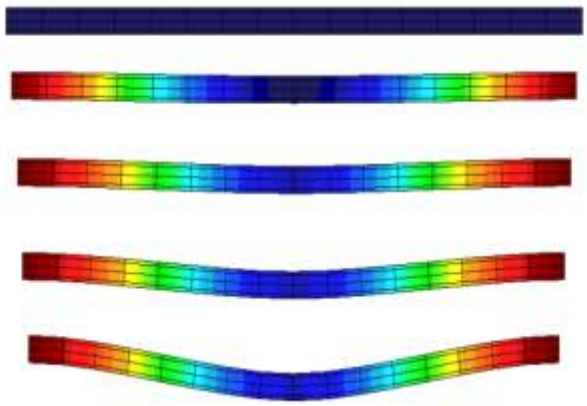
Batra and Sears (2007) applied molecular mechanics to predict critical buckling strains for zigzag SWCNTs with tube diameter D=1.19nm, and the tube lengths changing from 10.12 nm to 24.51nm. Zhang et al. (2009) assessed nonlocal beam and shell models in predicting buckling strains of SWCNTs with tube diameter D=0.94nm, and tube lengths changing from 2.8 nm to 30nm. The results for critical buckling strains with respect to aspect ratios of SWCNTs together with comparisons with results from two authors mentioned above are presented in Figure 4.41. The results obtained here are in good agreements with the literature, and it is shown that the critical buckling strain decreases when the tube length increases with a fixed tube diameter for SWCNTs



Comparison of variation of critical strains with respect to aspect ratio

It is observed that when the tube aspect ratio becomes larger, modelled SWCNT buckles sideways under axial compression rather than the buckling pattern in Figure. Buckling deformations for slender SWCNTs are simulated as shown in Figure, which shows the bending deformations.

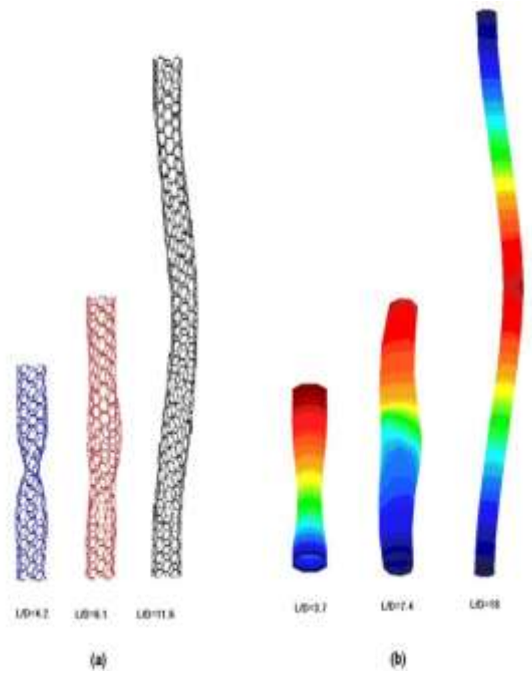
Liew et al. (2006) performed molecular dynamics approach and simulated the deformations for SWCNT bundle under axial compression as shown in Figure, as well as proved in this research that buckling under compression should present bending deformations for slender SWCNTs.



Deformation of cylindrical shell under compression (D=1.409nm; L=40nm)

Bending deformations of SWCNT bundle under axial compression

Zhang et al. (2009) applied molecular dynamics (MD) and simulated three types of buckling modes depending on the aspect ratios of SWCNTs, as shown in Figure 4.44 (a). In this research three similar results are obtained with similar aspect ratios for SWCNTs, as shown in Figure 4.44 (b). The results present a shell-like buckling mode when the aspect ratio L/D is small, a beam-like bending buckling mode when aspect ratio is large, and a shell-beam mixed buckling mode when the aspect ratios are in between certain range. Our results are in good agreements with results from Zhang et al. (2009).



Three types of buckling modes of SWCNTs under axial compression depending on the aspect ratios (a) results from Zhang et al. (2009) (b) present results

CONCLUSIONS

In this study, the non-dimensional buckling load parameter has been obtained numerically. The model has been developed in ANSYS using APDL code. The convergence and comparison behaviour of the developed model has been checked. Some new results are computed for thickness ratio and aspect ratio. The results are following the expected line. The buckling behaviour of SWCNT composite plate has been investigated. The effective material properties of FG-CNTRC are evaluated by using rule of mixture for different distribution type (UD, FG-X and FG-V). Finite element solutions are obtained in ANSYS 13.0 environment. The present model is validated through the comparison with those available in the literature. Some new numerical experimentation for different volume fractions, boundary conditions, temperature and loading conditions are illustrated Based on the parametric study on the buckling behaviour of SWCNT composite plate. SWCNTs under compression are simulated. Critical buckling strains have been captured by reading the force and strain relationship. The results show that, for a fixed tube length, critical buckling strain decreases with the tube diameter increasing. And for a fixed tube diameter, critical buckling strain decreases when the tube length increases. Results are in good agreement with the literature. Twisting deformations of SWCNTs are also simulated, and a non-linear behaviour after twisting angle of 100°is captured. As the number of support constraints increase, the buckling load parameter increases. The effect of loading conditions on buckling behaviour of SWCNT composite plate is found critical i.e., plate under biaxial compression and tension is having maximum buckling load parameter whereas plate under biaxial compression exhibits minimum buckling load parameter.

FUTURE WORK

- Buckling analysis of functionally graded multi-walled carbon nanotubes plates can be performed.
- The effective material properties of CNT based composite material can be evaluated through different material modal such as Mori-Tanaka approach, molecular dynamics simulation, etc.
- An experimental study can be performed on CNT based composite plates for buckling analysis.

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