Analysis of Functionally Graded Carbon Nanotube Reinforced Composite Cylindrical Shells

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Abstract:

In this paper, a two-step perturbation method is used to study the nonlinear behavior of functionally graded carbon-nanotube-reinforced composite cylindrical shells with different filler distributions. It is further compared with traditional carbon fibers, carbon nanotubes (CNTs) that have remarkable mechanical properties. For this reason, there has been a considerable amount of attention paid to the use of CNTs as reinforcements for polymer composites by the researchers, and thus to obtain lightweight structural materials with improved thermo-mechanical characteristics. In this work, we have considered two different types of CNT distribution namely uniformly distributed and FG-distributed reinforcements in CNTRC cylindrical shells. In this study, Central deflection, contact force measurements of the impact response for the different types of CNTRC cylindrical shells, the nonlinear low-velocity Impactor response of carbon-nano tube-reinforced composite cylindrical shells that have different CNT distributions. The effect of a variety of parameters such as CNT volume fraction, initial impactor velocity on the impactor response of our functionally graded Shells is examined.

Keywords: carbon nanotubes, Impactor analysis, Graded shells, carbonnanotube-reinforced composite, cylindrical shells, Central deflection.

1. Introduction

Recently, carbon nanotubes (CNTs) have attracted researchers' attention because of their exceedingly favorable properties. Composite shell structures are very important structural components as they support applied external forces efficiently by virtue of their special geometrical shape. Such structures are widely used in numerous fields such as civil, architectural, aeronautical and marine engineering and are frequently subjected to dynamic loads that cause vibrations. So the study of vibration is an important facet in the successful application of this structures.CNTs have remarkable mechanical properties in comparison with traditional carbon fibers [1]. These properties have drawn considerable attention in using CNTs as reinforcement in polymer composites to get lightweight structural materials with improved thermo-mechanical characteristics [2, 3]. Adding less than 1 wt % CNT to poly(vinyl alcohol)-based composites has been shown to increase Young's modulus, tensile strength, and toughness of 3.7, 4.3, and 1.7 times, respectively [4]. The remarkable mechanical properties of carbon nanotubes, such as high elastic modulus and tensile strength, make them the most ideal and promising reinforcements in substantially enhancing the mechanical properties of resulting polymer/carbon nanotube composites [5].

In order to facilitate the development of reinforced polymer composites and the design of the materials, the bulk mechanical properties of the materials must be determined. Although some experiments have been conducted on material properties of CNT reinforced composites. Dong-Li Shi et al. [6] obtained the elastic properties of a CNT-reinforced composite for aligned and randomly oriented CNT by micromechanics method to account for nanotube waviness and agglomeration. The waviness and agglomeration result in reduction of the stiffness of the material. Wuite and Adali [7] examined the deflection and stress of nano composite-reinforced beams using a multiscale analysis. They found that a small percentage of nanotube reinforcement leads to significant improvements in beam stiffness. Recently, carbon nanotubes (CNTs) have attracted researchers' attention because of their exceedingly favorable properties. CNTs have remarkable mechanical properties in comparison with traditional carbon fibers [1]. These properties have drawn considerable attention in using CNTs as reinforcement in polymer composites to get lightweight structural materials with improved thermo mechanical characteristics [2, 3]. Recently, carbon nanotubes (CNTs) have attracted researcher's attention because of their exceedingly favorable properties. CNTs have remarkable mechanical properties in comparison with traditional carbon fibers [1]. These properties have drawn considerable attention in using CNTs as reinforcement in polymer composites to get lightweight structural materials with improved thermo-mechanical characteristics [2, 3].

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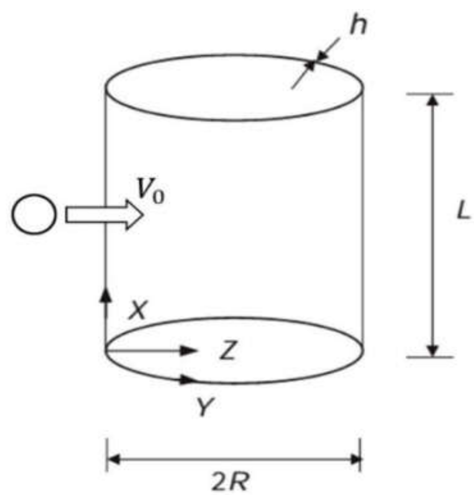
2. Nonlinear Dynamics of CNTRC Cylindrical Shells

We supposed that a CNTRC layer consist of a mixture of SWCNTs and isotropic matrix. Geometry and coordinate system of the cylindrical shell analysis was studied in this paper are shown in Figure. 1. It shows the geometry and coordinate system of a carbon nanotube-reinforced composite (CNTRC) cylindrical shell that is being subjected to a low-velocity impact. V0: Initial impact of velocity. L, R, and h represent the shell length, radius, and thickness, respectively, Y, and Z: Coordinate axes.



Figureure 1. The geometry and coordinate system of a carbonnanotube-reinforced composite (CNTRC) cylindrical shell

The length, mean radius and total thickness of the cylindrical shell are denominated as L, R, and h, respectively. The nanotube reinforcement in the shell may be either uniformly-distributed (UD) or FG in the shell thickness direction. The shell is exposed to elevated temperature and is subjected to transverse low-velocity impact included with initial edge loads, if any. The axial, circumferential and inward normal to the middle surface directions are assumed as X, Y, and Z directions of the coordinate system, respectively.

3. Nonlinear Dynamics of Impactor

The vibration of impactor is neglected in this study. Until the maximum indentation and corresponding maximum force, the overall contact force P_C during the loading phase is related to local contact indentation δ(t) and defined by a nonlinear relation as follows [15, 16].

$$T_z(t) = K_C[\delta(t)]^r \quad (1)$$

The contact between two homogeneous isotropic solids, according to the Hertzian law, r - 15 is considered. In addition, for laminated composite targets it has been proved that r is also equal to 1.5. K_C is the contact stiffness which is defined as,

$$T_C = \frac{4}{3} E^* \sqrt{R^*} \quad (2)$$

$$E^* = \left(\frac{1-v^{i2}}{E^i} + \frac{1-v_{12}^2}{E_{22}^S} \right) \quad (3)$$

$$\frac{1}{R^*} = \frac{1}{R^i} + \frac{1}{2R^c} \quad (4)$$

where E^i, v^i and R^i are Young's moduli, Poisson's ratio and radius of impactor, respectively; and E_{22}^S and R^c are the transverse Young's moduli of the surface of the shell and radius of the shell, respectively.

4. Numerical Results and Discussion

In this section, numerical results are done and presented for the CNTRC cylindrical shell subjected to lateral low-velocity impact in thermal environments. First of all, the effective material properties of CNTRCs have to be determined. The variation in CNT volume distribution across the shell thickness (t) for the uniformly distributed (UD) and functionally graded (FG) CNTRC shells are also being analyzed.

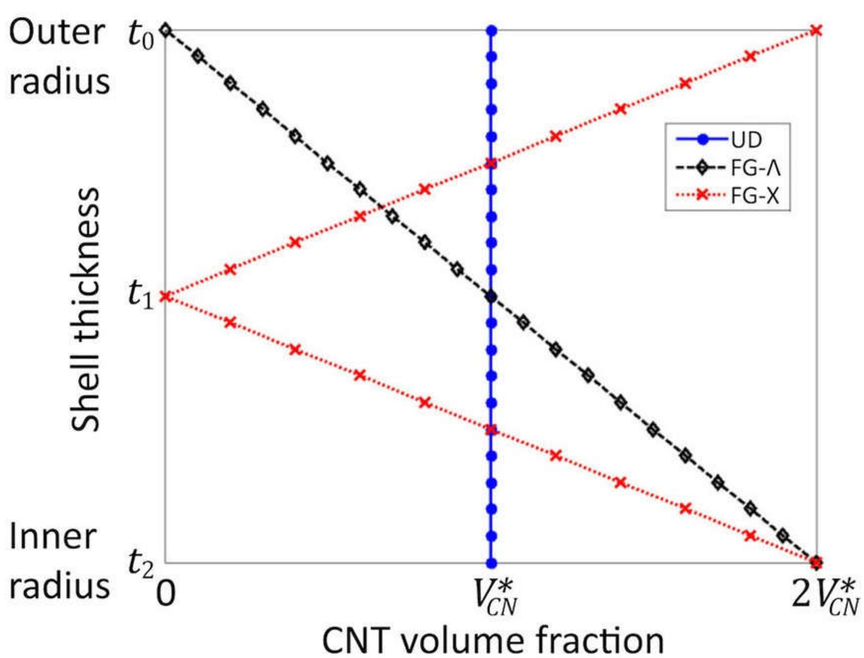


Figure 2. The variation in CNT volume distribution across the shell thickness for the uniformly distributed (UD) and functionally graded CNTRC shells.

To estimate the material properties, micromechanical models are used in the simulation study. The equations of motion that are employed were based on higher-order shear deformation theory, and we used a two-step perturbation technique to solve these equations. Furthermore, we assumed that the material properties of the CNTRC shells were temperature-dependent. To verify the accuracy of our micromechanical model calculations, we conducted a series of measurements on our CNTRC samples as part of a low-velocity impact study. We resolved this plate by letting the radius of the cylinder reach infinity. The histories of impactor displacement and contact force that are measured in this research are presented in Figure.3 and 4. We find a good agreement between our results and those of previous studies that are available in the literature, which shows that our model is accurate. The small differences between our results and the previous data may arise because of the different methodologies used by various researchers.

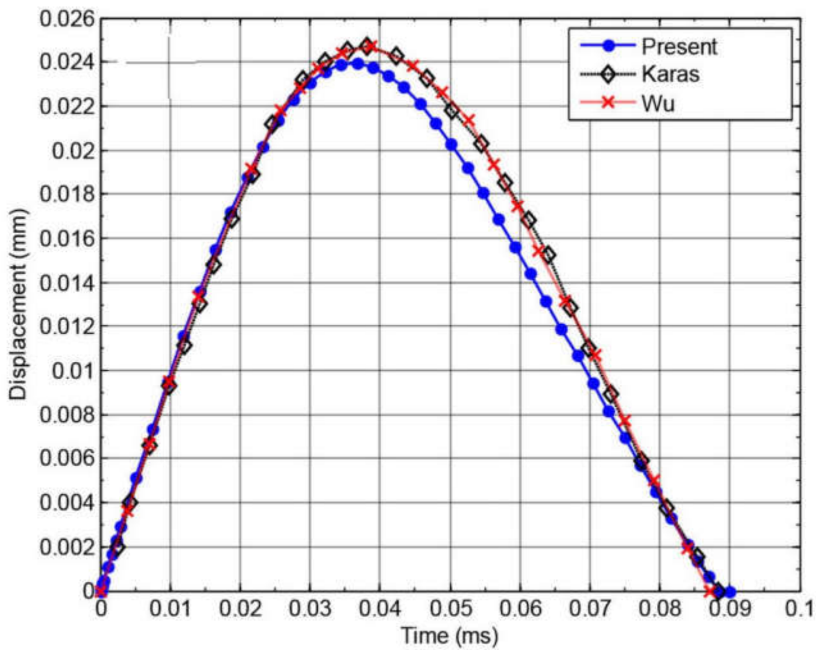


Figure 3. The impactor displacement of an isotropic plate that was subjected to a low-velocity impact.

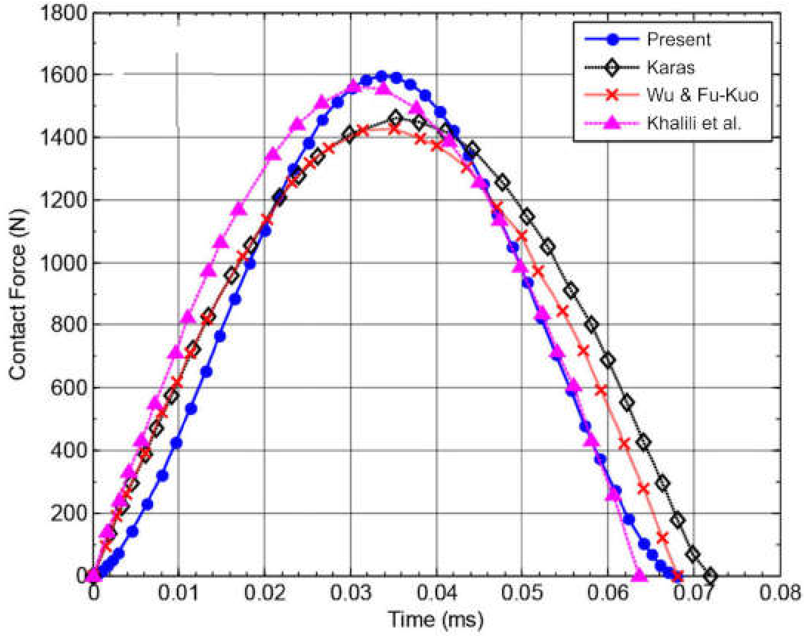


Figure 4. Contact force histories of an isotropic plate that was subjected to a low-velocity impact

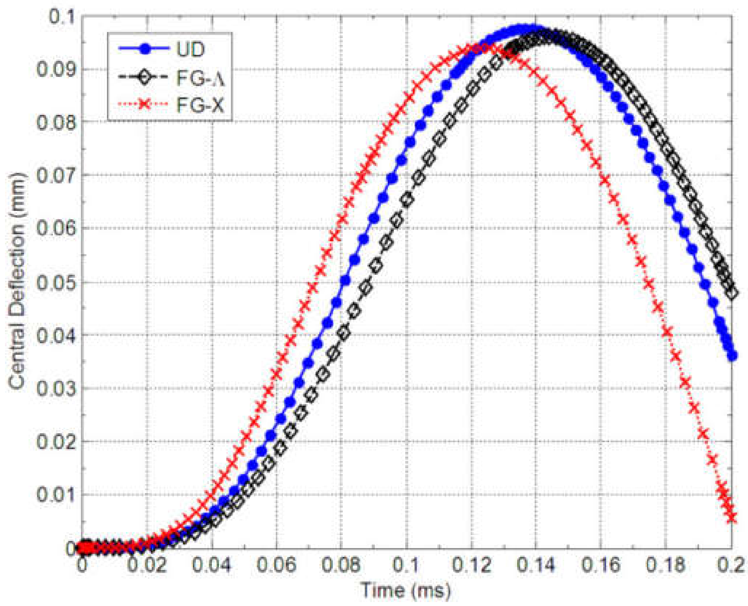


Figure 5. Central defection of the impact response for the three types of CNTRC cylindrical shells.

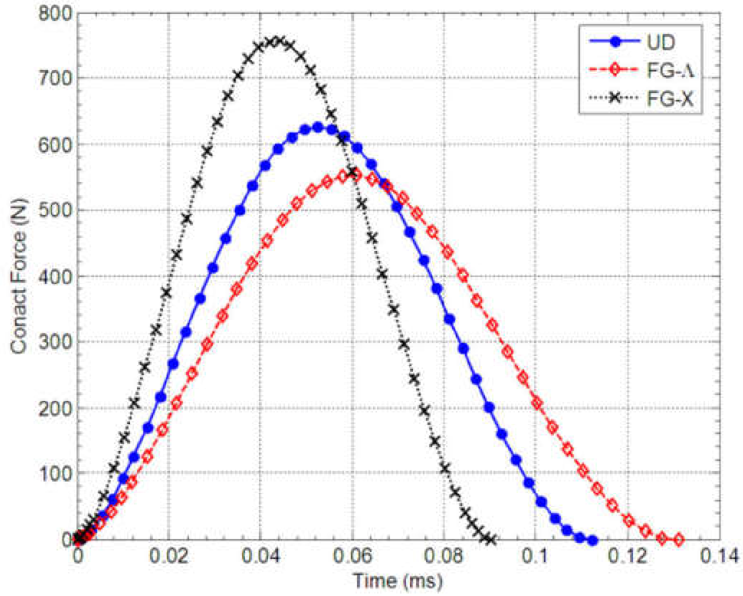
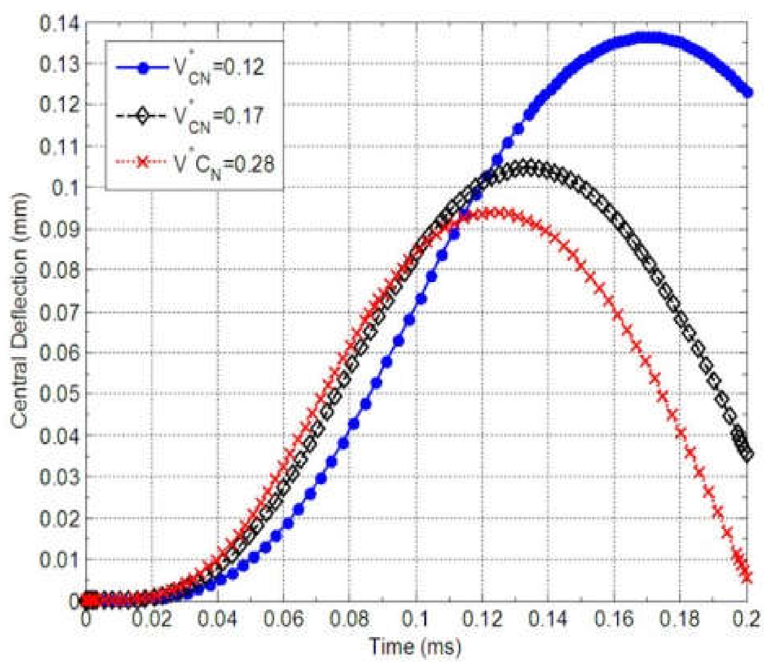


Figure 6. Contact force measurements of the impact response for the three types of CNTRC cylindrical shells.

We also estimated the impact response of our two types of FG-CNTRC shells namely type A and type X as shown in Figure 5 and 6. We found that the type X FG-CNTRC shell had the lowest deflection from the impact, with the shortest contact duration compared to type –A FG-CNTRC shell. In addition, the type, FG-CNTRC shell has the lowest contact force among the three samples because of its low transverse Young's modulus value.



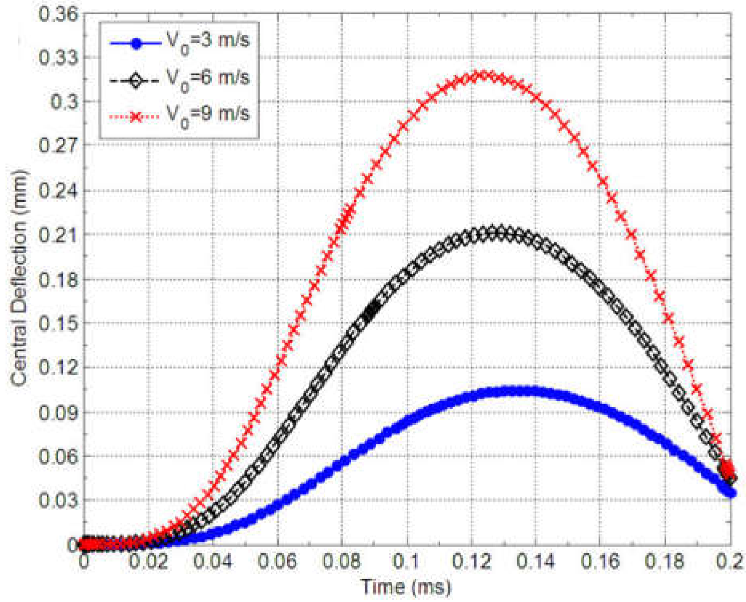
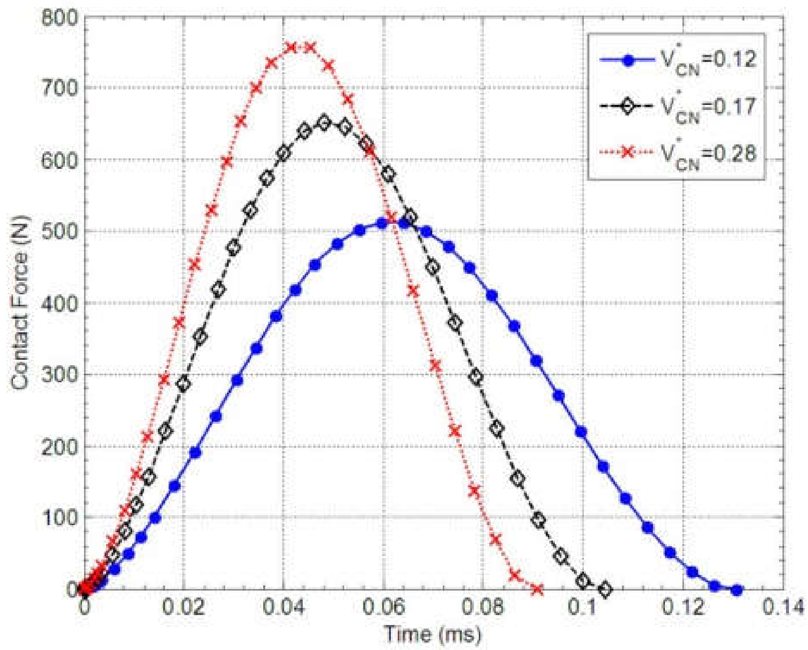


Figure 7. Central deflection that illustrate how changing and the initial impactor velocity cylindrical shell.



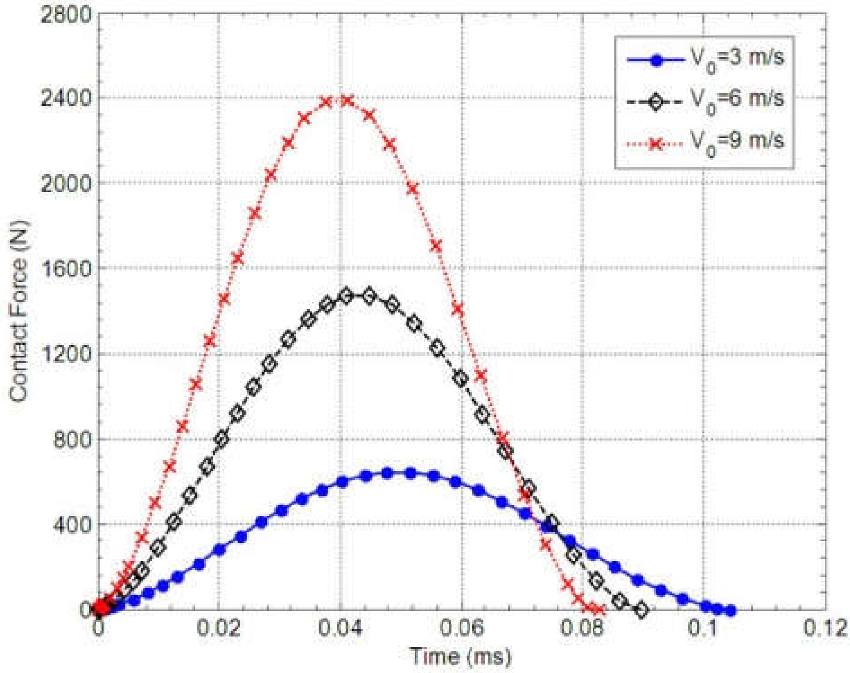


Figure 8. Contact force illustrate how changing and the initial impactor velocity cylindrical shell.

In addition, we have considered how the v_{CN}^{*} affects the impact response of CNTRC cylindrical shells and is analyzed with reference values as values of 0.12, 0.17, and 0.28. The results shown in Figure 7 and Figure 8 indicates that with an increased CNT volume fraction, both the central deflection and the contact duration decrease. Also, we examined the effect of the impactor's initial velocity on the impact response of the type X FG-CNTRC cylindrical shell. For these measurements, we considered three different initial velocities for the impactor of 3, 6 and 9 m/s. from the results shown in Figure 7 and Figure 8 it is clear that as the initial velocity increases, both the central deflection and the contact force increase.

5. Conclusion

We have presented the nonlinear low-velocity impact response of carbon-nanotube-reinforced composite cylindrical shells that have different CNT distributions. We have examined the effect of a variety of parameters (i.e., CNT volume fraction, initial impactor velocity, and temperature) on the impact response of our functionally graded shells. Our results show that the linear FG-CNT reinforcement has a significant effect on the nonlinear impact response of CNTRC cylindrical shells. In addition, our parametric numerical results illustrate that the initial velocity of the impact and the initial CNT load have a substantial influence on the impact behavior.

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