Thermal Stress Analysis of the Carbon Nanotube Reinforced Composite Cylindrical Shells

Hamed Aminivida, Hassan Shokrollah*, Reza Beigpour

Department of Mechanical Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran

ABSTRACT

This paper presents an analytical and computational approach for investigating the behavior of a simply supported carbon nanotube-reinforced composite shell that has been exposed to temperature variations. The equations are solved using the Ritz energy method for the analytical solution and ABAQUS finite element software for numerical solution. The displacement field is the first-order shear deformation theory, and the linear equations were solved using the rule of mixture to determine the mechanical properties of carbon nanotube-reinforced composites. A uniform distribution of temperature with no heat flux in the shell and nanotubes in five distinct shapes classified as V, A, X, and O have been considered in this study. The support conditions are the same in all cases, but the temperature, thermal boundary conditions, and carbon nanotube volume function values vary. The findings are illustrated in a detailed manner in the form of diagrams, which perfectly demonstrate the differences between both of the carbon nanotube distribution material models. Validation of the results shows great compatibility in energy solution and finite element methods. The results show that increasing the volume function of the carbon nanotubes increases the stress values and thermal gradients, and on the other hand, reduces the displacement, and by increasing the temperature the number of stress increases.

KEYWORDS

Cylindrical shell, composite, carbon nanotube, thermal stress, Ritz method.

* Corresponding Author: Email: hshokrollahi@khu.ac.ir

1. Introduction

The carbon nanotubes have attracted the interest of scientists and engineers from a variety of fields. This is mostly owing to its superior physical and chemical characteristics, which include high strength, stiffness, and aspect ratio while having a low density. Carbon nanotubes may be used as an ideal reinforcement for polymer composites because of their remarkable characteristics, which can considerably improve the mechanical, electrical, and thermal properties of the resultant nanocomposites [1]. Carbon nanotube-reinforced composites have been studied experimentally and numerically, and it has been found that uniformly dispersing carbon nanotubes as reinforcements in the matrix may only provide a minor increase in mechanical characteristics [2]. This is owing to a weak contact between the carbon nanotubes and the matrix, where there is a substantial material property mismatch. Shen and Xiang [3] investigated the compressive and thermal post buckling strength of carbon nanotube-reinforced composites plates when the nanotube volume percentage was low. They discovered that a carbon nanotube-reinforced composites plate with an intermediate carbon nanotube volume percentage does not always have an intermediate buckling temperature or first thermal post buckling strength. In 2006, a study on the properties of carbon nanotube-reinforced composite material was performed using a micro-mechanical model, which resulted in a general concept for estimating the modulus of elasticity [4]. The aim of the present study is to provide results that can be used in the design of composite structures reinforced by carbon nanotubes. In this paper, using analytical and numerical solutions, the behavior of a cylindrical shell made of carbon nanotube-reinforced composite material under thermal conditions has been investigated.

2. Methodology

In this study, the energy solution approach was utilized to solve the problem. The strain and stress components are computed by supplying a displacement field that satisfies the boundary conditions. These terms can be constituted of basic or trigonometric functions, but they should not contain too many phrases because as the number of sentences increases, the complexity of the calculations increases, and the accuracy of the findings does not improve substantially, and in some circumstances, it decreases. The energy technique is utilized to acquire an unknown coefficient in a few trigonometric phrases used in this study. This procedure starts with the presentation of conjectural assertions regarding the displacement field. Followed by the strain components being derived by inserting this displacement field in the strain-displacement relations, and then the same relations are inserted in the moment and force components.

3. Results and discussion

The A (FG-A) distribution model of carbon nanotubes was utilized to validate the energy dissolution approach employed in this study. All issues are solved and compared using both energy and finite element methods in the parametric findings section. The findings of thermal gradient distribution, thermal stresses, and radial displacement are shown in Figure 1.

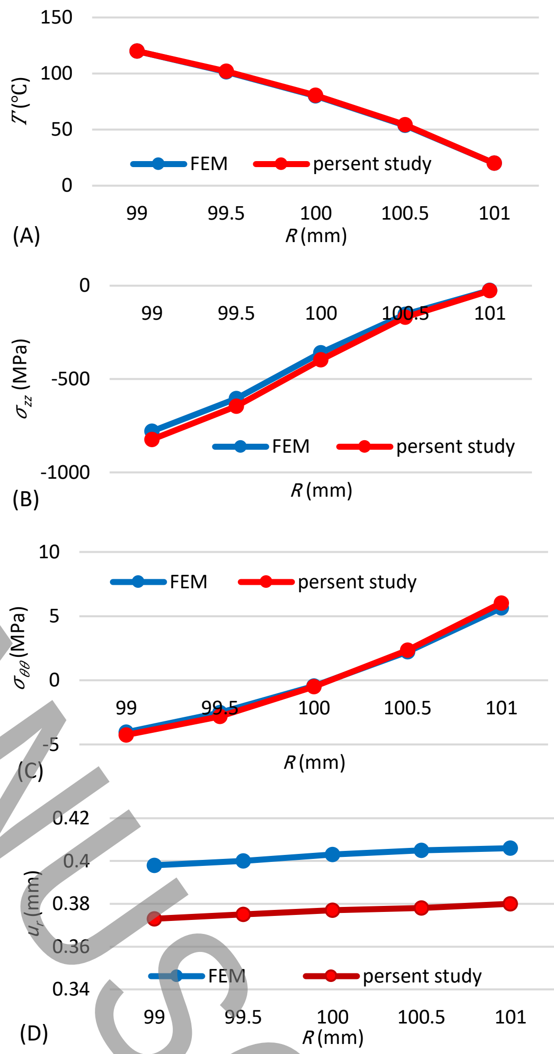

Figure 1. Validation results; (A) thermal gradient, (B) longitudinal stress, (C) circumferential stress, (D) radial displacement

Figure 1 (A) shows that the differences in the distribution of temperature gradients, are quite low, with the highest difference reaching less than 2%. The results for the thermal stress distribution differ by less than 10% in Figure 1 (B), whereas the results for the inner radius differ by 5%. The discrepancy between the two solution approaches of 5 to 10% is attributable to a difference in the two solution methods. The difference between the two solution techniques is less than 10% in Figure 1 (C) and (D). According to the assumptions examined in the technique described in this work, the difference between the two methods is acceptable in general.

Since the nanotube volume function does not depend on the radial variable in the UD state, the characteristics of the heat transfer coefficient remain constant throughout the thickness, the unidirectional thermal gradient changes linearly. Furthermore, the difference between the two solution approaches is negligible, with a value of less than 1%. Temperature variations seem nonlinear in various states of nanotube dispersion. Because the volume function determines the material's characteristics, the qualities of the material vary as the thickness range changes, and the results change as well. The FG-A type produces the greatest temperature inside the thickness, while the FG-V type produces the lowest. The values of longitudinal stress have increased with growing temperature, according to the results obtained in all three issues and a comparison of these data, but the most noteworthy issue is the percentage increase in these values. The values of longitudinal stress results increase in proportion to the increase in temperature.

According to the findings, when the volume function of carbon nanotubes increases, the values of longitudinal stress rise as well. The difference between the results of the state of the volume function of 0.17 and the state of the volume function of 0.11 is between 33 and 53 percent, and the rise in the values of the volume function of 0.14 compared to the volume function of 0.11 is between 19.2 and 28 percent. The influence that the volume function of carbon nanotubes has on the characteristics of the composite material is the major reason for raising the stress with increasing the volume function of nanotubes because the elastic modulus of the composite material rises with increasing the volume function.

4. Conclusions

In this research, a cylindrical shell made of reinforced composite material has been analyzed for thermal stress. The composite material consists of a polymer matrix and carbon nanotubes. Distribution types of these carbon nanotubes have five types of uniform distribution, A (FG-A), V (FG-V), X (FG-X) O (FG-O) distribution. The basic theory for defining the displacement field is the first-order shear deformation theory, which is used to form the strain energy and unknown coefficients of the displacement functions using the Ritz method. The finite element solution of Abaqus software has been used to validate the energy solution method. The assumed boundary conditions in this analysis is simply supported and the internal and external radius is subjected to a certain temperature. The results of this study are summarized as follows:

- The energy solution method provided in this work is well compatible with the finite element solution method in different outcomes. The longitudinal stress is considerably larger than the circumferential stress, and the values of stress and displacement increased proportionately with increasing temperature.
- The displacement in the radial direction decreased as the volume function of carbon nanotubes grew; in contrast to the nonlinear results of the graded functional types, the results for the unidirectional distribution types are practically linear.
- In the FG-V and FG-O types, longitudinal stress results are lower than in the FG-A and FG-X types, and unidirectional distribution results are the average of the FG-V and FG-A distributions.
- The circumferential stresses of the FG-A and FG-X types are lower than the FG-V and FG-O types, and the unidirectional distribution has an average value when compared to the other outputs. In FG-V and FG-O distributions radial displacement is less than FG-A and FG-X types. Unidirectional distribution has an average value relative to other outputs.
- The temperature difference between various places is reduced by the distribution of thermal gradients at every point where the dispersion of nanotubes is denser.

5. References

[1] K.M. Liew, Z.X. Lei, L.W. Zhang, Mechanical analysis of functionally graded carbon nanotube reinforced composites: a review, Composite Structures, 120 (2015) 90-97.
[2] G.D. Seidel, D.C. Lagoudas, Micromechanical analysis of the effective elastic properties of carbon nanotube reinforced composites, Mechanics of Materials, 38(8-10) (2006) 884-907.
[3] H.S. Shen, Y. Xiang, Thermal postbuckling of nanotube-reinforced composite cylindrical panels resting on elastic foundations, Composite Structures, 123 (2015) 383-392.
[4] V. Anumandla, R.F. Gibson, A comprehensive closed form micromechanics model for estimating the elastic modulus of nanotube-reinforced composites, Composites Part A: Applied Science and Manufacturing, 37(12) (2006) 2178-2185.