VIBRATION ANALYSIS OF FUNCTIONALLY GRADED NANO COMPOSITE AIRFOIL STRUCTURE

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ABSTRACT

The present work deals with the free vibration analysis and buckling behavior of functionally graded Nano composite conical shell structures reinforced with carbon nanotubes. The effective material properties of the functionally graded Nano composite shell structures are obtained using the extended rule of mixture by using UD and some functionally graded distribution of single-walled carbon nanotubes (SWCNTs) in the thickness direction of the shell. In this study the Nano composite is forming by mixing SWCNTs as reinforced phase with the polymer as matrix phase and makes a superior quality Nano composite material at Nano scale level with some extraordinary material properties which provides advanced performance and service level. A suitable finite element model of functionally graded conical shell structure is developed using the ANSYS parametric design language (APDL) code in ANSYS environment. The model has been discretized using an eight nodded shell element. The solution is obtained for fundamental natural frequencies and deformation of the composite shell. The effects of various geometric parameters, CNT volume fraction, boundary conditions and material properties are presented and discussed.

Keywords*— Conical shell structures, CNTs based polymer Nano composite, various CNT distributions, functionally graded material (FGM), free vibration, buckling analysis.*

INTRODUCTION

Composite Materials

Historical examples of composites are available in the various literatures. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500 B.C.), and laminated metals in forging swords (A.D. 1800). In the 20th century, high structural strength and glass fiber reinforced composites were developed in the early 1930s and the technology of modern composite materials has progressed significantly since then. Aircraft and boats were built out of these glass fiber composites which are commonly known as fiber-glass. The application of composite materials has extensively increased since the 1970s because of the development of new fibers like boron, carbon, and aramids and some other new composite structures with the matrices made from metals, polymer and ceramics.

In recent years the applications of the composite materials have increased extensively in different fields of engineering because of its great strength and light weight. Composite structures belong to the category of such engineering materials in which two or more materials mixed with each other at a macroscopic level with some significant changes in physical and chemical properties and forms a new material with better material properties than those of the individual components used alone. They are continuously used in various engineering fields because of its better properties than other conventional materials like higher strength, higher stiffness, low weight, design flexibility, wear resistance, corrosion resistance, good thermal properties and better fatigue life. Because of these properties there are a wide range of application of composite materials like in aircraft/military industry, construction industry, automobile/transportation sector, marine applications, chemical industry, electrical and electronics applications, nuclear industry etc.

Basically a composite material is a combination of two constituents one is called reinforcing phase (or embedded phase) and the other in which this reinforcing phase is embedded known as matrix. The matrix phase materials are generally continuous and the reinforcing phase are discontinuous or dispersed phase. The reinforcing phase serves to strengthen the composite materials; this phase may be in the form of particles, fibers or flakes. Various varieties of reinforcing materials used in composite structures are glass fiber, graphite (carbon), asbestos, jute, sisal, boron kevlar 49 and whiskers, as well as chopped paper and synthetic fibers. There are three basic types of matrix materials polymers, metals or ceramics. The two chief purposes of the matrix are binding the reinforcement phases (embedded phase) in place and deforming to distribute the stresses between the constituent reinforcement materials under some applied forces. Examples of composite materials include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc.

An increasing number of engineering structural designs, especially in the automobile, aerospace and civil engineering structures are extensively utilizing various types of fiber composite laminated structures such as beams, plates and shells. The laminated orthotropic shell structures belong to the category of composite shell. In recent years the use of laminated composite shell structures is increased for high performance structures such as wind turbine blades, fuselages of aircraft, ship and boat hulls etc. The main important factor in the analysis of the laminated shell structures is its individual layer properties, which may be made of orthotropic, isotropic or anisotropic materials. The primary function of a laminated shell is to transfer the loads from the edges of one layer to another. A thin shell is defined as a shell which has very small thickness as compared to its diameter, about 20 times smaller than its diameter. Laminated shells are widely used in various engineering fields because of its light weight and high strength like in structural engineering, power and chemical engineering, architecture and building, vehicle body structures, composite construction, armour, submarines etc.

LITERATURE SURVEY

A composite material of FGM based shell

structure performs a superior service which can be used in high temperature applications and high loading conditions. In recent years, functionally graded materials (FGMs) have received a great attention for the applications in high loading and high temperature conditions. Various literatures, studies and journals are available for the study of functionally graded material based nanocomposite shell structures.

Lei et al. [6] investigated the buckling behavior of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) plates under the effects of different mechanical loadings by using element-free kp-Ritz method. The buckling analysis is carried out for functionally graded single-walled carbon nanotubes (SWCNTs) reinforced plates by using first-order shear deformation plate theory and mesh free method. The effective material properties for single-walled carbon nanotubes reinforced plate materials is based on a micromechanical model, either the extended rule of mixture or the Eshelby Mori Tanaka method. Chakraborty et al. [7] modeled a new beam element to analyze the thermoelastic behavior of FGMs based beam structures. The element considered first order shear deformation theory and the thermal and elastic properties are varying in the thickness direction. Wave propagation, static and free vibration problems are considered to examine the variation in thermoelastic behavior of functionally graded material (FGM) beam with pure ceramic beams or pure metal. Azadi [8] presents finite element method (FEM) based forced and free vibration analysis of functionally graded material based beams by considering the temperature dependent material properties. In this work, material properties were graded in the thickness direction of beams by considering simple power law distribution of constituent's volume fractions. Finally the dynamic analysis has been done for the damped and undamped systems. Yas and Heshmati [9] presented the vibrational study of functionally graded nanocomposite beams under the effect of moving loads which is reinforced by randomly oriented straight single walled carbon nanotubes (SWCNTs) by considering the Timoshenko and Euler-Bernoulli beam theories. Dastjerdi et al. [10] investigated dynamic analysis of functionally graded materials based nanocomposite cylindrical structures reinforced by single walled carbon nanotubes subjected to an impact load by a mesh free method. Stress wave propagation study and free vibration analysis of single- walled carbon nanotube reinforced composite (SWCTNRC) cylinders are studied in this work. Woo et al. [11] presented an analytical solution for the postbuckling behavior of functionally graded shallow cylindrical shells and plates under the effect of compressive loads and thermomechanical effects. The material properties for functionally graded (FG) shell structures are assumed to vary in the thickness direction of the shell by applying power law distribution of the constituent's volume fraction. This work shows the effects of thermomechanical coupling and different boundary conditions on the response of the FG shells and plates under the action of compressive loads. Shen [12] developed thermal buckling and postbuckling analysis of functionally graded nanocomposite cylindrical shell structures reinforced by single-walled carbon nanotubes (SWCNTs) under the action of temperature effects. Functionally graded and uniformly distributed reinforcements types of carbon nanotube (CNT) reinforced composite shells are considered. The governing equation is based on higher order shear deformation theory (HSDT) and von Karman equation to analyze the buckling behavior of functionally graded carbon nanotube reinforced composite (FG-CNTRC) cylindrical shell structures. Xiang [13] developed a computational model for the forced and free vibration analysis of functionally graded materials (FGMs) based laminated beam of variable thickness under the action of temperature field by considering the Timoshenko beam theory. Wali et al [14] investigated free vibration analysis of functionally graded material (FGM) based shell structures by using 3d shell model based on a discrete double directors shell elements. The material properties of the shell structures are assumed to vary in the direction of shell thickness according to the power law distributions of the constituents and the fundamental frequencies are derived from the virtual work principle.

Bhangale et al. [15] presented the effect of vibration behavior and thermal buckling of FGM based truncated conical shells in the environment of large temperature condition. The analysis for the free vibration and the thermal buckling has been done by considering the temperature dependent material properties. Haddadpour et al. [16] presented the analysis of free vibration for simply supported functionally graded cylindrical shell structures under the effect of temperature. The equations of motions are based on von Karman Donnell and shell theory of Love's equations. Kadoli and Ganesan [17] investigated the free vibration analysis and the effect of buckling load on the functionally graded cylindrical shell structures with the clamped-clamped boundary condition under the effect of temperature. For the modeling of functionally graded material (FGM) based shell structure, first order shear deformation theory (FSDT) andFourier series expansion of the displacement variables are used. Heydarpour et al. [18] presented the effects of coriolis and centrifugal forces on the free vibration behavior of rotating functionally graded carbon nanotubes reinforced composite (FG-CNTRC) truncated conical shell structures. The governing equations are based on the FSDT of shell structures by considering the Hamilton's principle. The differential quadrature method (DQM) is used to solve the equations of motion and applied boundary conditions. Jam et al. [19] presented the free vibration analysis of carbon nanotube reinforced functionally graded cylindrical panels under the simply supported boundary conditions. The material properties of FG carbon nanotube reinforced nanocomposite cylindrical panels are obtained by using the extended rule of mixture which varies in the radial direction. Viola and Tornabene [20] presented free vibration analysis of homogeneous and isotropic conical shell structures using the numerical technique method known as Generalized Differential Quadrature (GDQ) method. Tornabene investigated the dynamic behavior and free vibration analysis of thick functionally graded material based cylindrical shells, conical shells and annular plates with a four parameter power law distribution based on the first-order shear deformation theory (FSDT). Tornabene et al.

MATHEMATICAL MODELING

Consider a truncated conical shell made of carbon nanotube reinforced composites (CNTRCs) in which the distribution of carbon nanotubes (CNTs) is graded along the thickness direction of FG-CNTRCs. Four different types of distributions of CNTs are considered along the shell thickness directions which are shown in Figure 1. In the first case of distribution, the CNTs has a uniformly distribution through the direction of shell thickness, which is referred to UD type as shown in Figure 1(a). In the second case of distribution, the distribution of CNTs have a mid-plane symmetry and both the inner and the outer surfaces are rich CNTs, which is referred to FG-X type as shown in Figure 1(b). In the third type of distribution, the outer surfaces have lean CNTs and has rich matrix, whereas the inner surface is CNTs-rich. This type of distribution is known as *FG* □□□ type distribution as shown in Figure 1(c). In the last case of distribution, the distribution of CNTs are opposite of third type, in which the inner surface is matrix-rich and the outer surface is CNTs-rich and known as FG-V type of distribution as shown in Figure 1(d).

The material properties of the FG-CNTRC conical shells vary smoothly and continuously in the direction of the shell thickness. Similarly, in order to evaluate the various CNT distributions effects on the free vibration characteristics of a FG-CNTRC conical shell, different types of material profiles through the shell thickness are considered. In this present work, we are assuming only linear distribution of the CNT volume fraction for the various types of the FG-CNTRC conical shell that can easily be achieved in practice and given by

UD: $V_{CNT} = V^{*}_{CNT}$

FG-V: $V_{CNT} = V^{*}_{CNT}\left(1 - \frac{2z}{h}\right)$

$FG-\Lambda$: $V_{CNT} = V^{*}_{CNT}\left(1 + \frac{2z}{h}\right)$

FG-X $V_{CNT} = V^{*}_{CNT}\left(\frac{4|z|}{h}\right)$

Similarly, Poisson's ratio υ and mass density ρ can be determined by:

RESULT AND DISCUSSION

Material Modeling

Based on the above formulation the free vibration analysis and buckling behavior of functionally graded nano composite conical shell is carried out by using ANSYS (APDL code) and some of the results are presented here. The material properties of matrix material are □ ^{M} = 0.34, □ ^{M} = 1150 kg/m^3 and E^{M} = 2.5Gpa at environment temperature (300^{o}K). The material properties of single walled carbon nano tube (SWCNTs) are E_{11}^{CNT} = 5.6466 TPa E_{22}^{CNT} = 7.0800 TPa, G_{12}^{CNT} = 1.9445 TPa, □^{CNT} = 1440 kg/m^3 and □ ^{CNT} =.175 mixes with the polymer at 12%, 17% and 28% distributions of CNTs.

Table 1: CNT efficiency parameters for different CNT volume fraction

V_{cnt}	CNT efficiency parameters		
	η_1	η_2	η_3
0.12	0.137	1.022	0.715
0.17	0.142	1.626	1.138
0.28	0.141	1.585	1.109

To analyze the vibration and buckling effects on the FG nano composite conical shell structures, two types of boundary conditions are considered, namely simply supported boundary condition and clamped-clamped boundary condition.

4.2 Numerical illustrations

The numerical results for the current work by considering the above material properties and boundary conditions under the effect of compression load are given below. From the above solution we get the effects of buckling parameter on the functionally graded nano composite conical shell at different distributions of the CNTs (V_{CNT}^{*} = 12%, 17% and 28%) under the simply supported and clamped-clamped boundary conditions. It is observed from the results obtained from the table that with increase in the CNTs volume fraction the buckling load parameter also increases. From the table it is note that the frequency of vibration is found maximum in case of *FG* □□□ type CNTRC conical shell and minimum for the case FG-V type CNTRC conical shell.

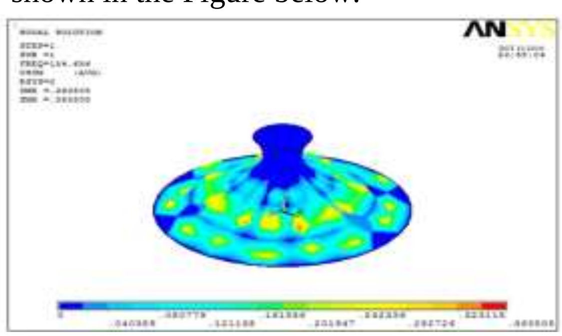
Table 2 and 4 shows the variation of buckling parameter for different CNT distribution and volume fraction for conical and catenoidal shell. Both the Tables shows that there is a prominent effect of FG-V and *FG* □□□ type CNT distribution on the buckling parameter. Table 3 and 5 shows variation of first 10 fundamental frequencies of conical and catenoidal shell respectively and it clear from both Tables that as the CNT volume fraction increases the fundamental frequency also increases which results in increase in the stiffness of the structure.

Table: The first 10 fundamental frequencies for doubly curved (catenoidal) shell.

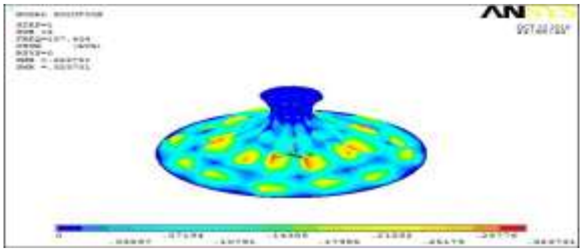
f_1	154.656
f_2	154.656
f_3	157.434
f4	157.613
f5	157.954
f6	157.954
f7	158.460
f_8	159.000
f_9	161.226
f10	161.488

Frequencies (in Hz)

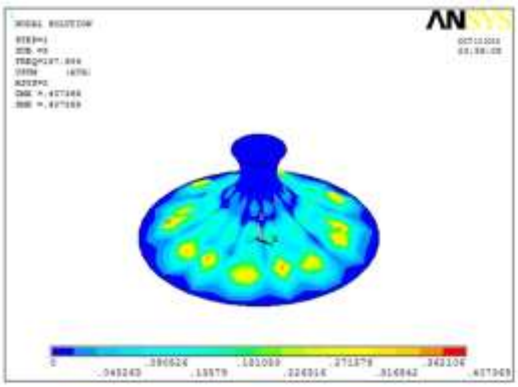
Figure shows the mode shapes for the conical shell structure and for doubly curved (catenoidal) shell structure respectively. From the table 3 and 5 it is noticed that the fundamental frequencies are coming almost same for pair of two frequencies which are shown in the Figure below.



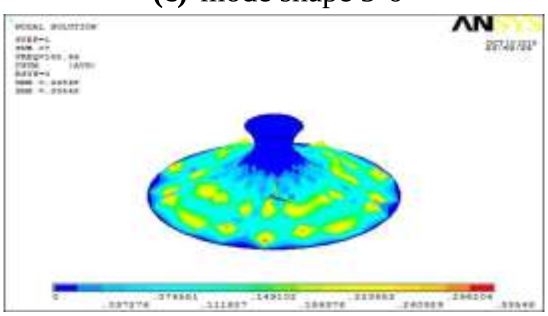
(a) mode shape 1-2



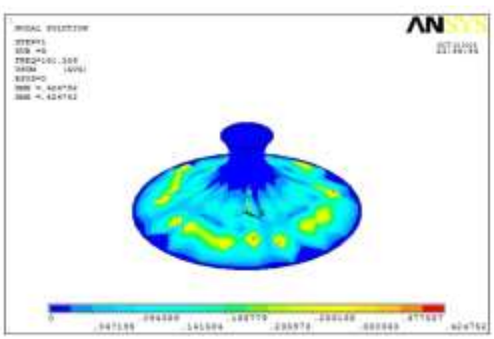
(b) mode shape 3-4



(c) mode shape 5-6



(d) mode shape 7-8



(e) Mode shape 9-10

Figure - Mode shapes for doubly curved (catenoidal) shell.

CONCLUSION

From the above solutions, the present work has been investigated. The vibration behavior and buckling analysis for the functionally graded carbon nanotube reinforced conical shell and for doubly curved (catenoidal) shell has been carried out by using the extended rule of mixture for the FG-CNTRC shell structures and considering the different types of distributions of CNTs. From the results, it is found that the buckling load parameter is maximum for the *FG* □□□ and minimum in the case of FG-V type of CNT distribution. The buckling behavior and fundamental frequencies has been obtained by using the ANSYS parametric design language (APDL) code in the ANSYS software. The fundamental frequencies have been carried out by using the Block-Lanco's method in ANSYS environment.

It is noticed that the fundamental frequencies and buckling load parameter increases with the increase of carbon nano tube volume fraction which implies that there is increase of stiffness of the FG-CNTRC shell structures with decrease in deflection.

SCOPE OF FUTURE WORK

The present work is based on the analysis of free vibration and buckling behavior of functionally graded material based carbon nanotube reinforced nanocomposite shell structures under the effect of compression load. Moreover, on the basis of some other vital parameters the present work can be extended for further research as follows:

i. To analyze the vibrational behavior and buckling analysis, the present work can be extended on the basis of temperature dependent material properties and thermomechanical loading conditions.

ii. The present work can be extended to

evaluate the forced vibration for nanocomposite functionally graded carbon nanotube reinforced shell structures.

iii. The present work has been done by using a single walled carbon nanotube (SWCNT) which can be further extended on the basis of multi-walled carbon nanotube (MWCNT) and other different types of CNT to analyze the vibrational behavior.

iv. On the basis of this work, we can investigate the vibrational behavior for different geometric shell structures such as plate, spherical, hyperboloid, cylinder etc.

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