Flexural Behaviour of Functionally Graded Nanotube Reinforced Sandwich Spherical Panel

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Abstract: In the current work, flexural behavior of functional graded the sandwich spherical panel were examined under thermal environment. Face sheet of sandwich structure are reinforced by carbon nanotube material categorized by functional and core face is composed of homogeneous isotropic content. Physical properties of both fiber and matrix are assumed to be temperature-dependent. First-order shear deformation theory of sandwich panel model developed in the structure and governing equations of motion derived by using variational principle. For the discretization purpose a suitable shell element has been employed from the ANSYS library and the responses are computed using a parametric design language (APDL) coding. The performance and accuracy of the developed model has been established through the convergence and validation by comparing the obtained results with previously published results. Finally, the influence of different geometrical parameters and material properties on the flexural behaviour of the sandwich spherical panel in thermal environment has been investigated through various numerical illustrations and discussed in details.

1. Introduction

Conventional laminated composites consist of various layers of lamina that are homogenous and are held together to achieve enhanced mechanical properties. Thus, they are light in weight and at the same time possess higher strength/stiffness to weight ratio. However, since the content in between the different layers of the lamina properties, sudden changes in stress-induced high laminar differences are those due to delamination failure of the structure. When these structures under severe thermal load service failure is more common. To resolve this issue, functionally graded materials (FGMs), which content functional properties are used, where, properties are variety in thickness direction. In General, FGMs contain, ceramic and metal, thus component with the property amounts to plate thickness by a fraction of the contents are varied during manufacturing. Due to excellent thermal resistance property FGMs widely used in high-performance engineering structures/ aerospace structural components, automotive, marine and nuclear industry.

Recently, the family of advanced materials, carbon nanotubes (CNT) with excellent mechanical properties, it very much thermal and mechanical properties as compared to the other existing properties due to advanced content. Functionally graded carbon nanotube (FGCNT) reinforced composite plates, beams or shells, preferably used as in advanced structural components. Due to their excellent properties also sandwich type geometry became more attractive. Therefore, this application for their superior design in real life FGCNT mechanical behavior of sandwich structures is highly essential and understanding. Many researchers have been attempts to check the of linear and nonlinear behavior of sandwich plates and reinforced FGCNT shells numerically/ analytically, using principles of various existing and sophisticated. In this regard, first order shear deformation theory (FSDT) and higher order shear deformation theory (HSDT) are more popular due to the sophisticated simplicity in construction/

intelligent than the layer wise theories [1]. Zenkour [2] calculated under bending analysis of simply supported FG sandwich plates using the sinusoidal loading sinusoidal, third-order, first-order shear deformation classical theories. Shen [3] used the thermal environment, obtain the nonlinear bending behavior of FGCNT reinforced composite plate with HSDT and von Karman nonlinear kinematics. Ke et al. explored the nonlinear free vibration [4] and dynamic solidness [5] conduct of FGCNTRC bars in the system of the Timoshenko shaft hypothesis and von-Karman sort strains. Systematic answers for the nonlinear bowing and free vibration reactions of basically bolstered CNTRC [6] and sandwich plates [7] in warm environment are introduced by Wang and Shen utilizing the HSDT and general von-Karman sort conditions and considering temperature subordinate material properties. Zhu et al. [8] introduced the static and free vibration examination of CNTRC plates utilizing the FSDT and limited component strategy (FEM). Lei et al. [9] concentrated the nonlinear diversion conduct of FGCNTRC plates utilizing the component free kp-Ritz strategy. The detailing depends on the FSDT mid-plane kinematics and von-Karman nonlinearity. Zhang et al. [10] concentrated the flexural quality of FGCNTRC tube-shaped boards in the system of the FSDT. The static and element reactions of sandwich plates with CNT strengthened face sheets have been researched by Natarajan et al. [11] utilizing the HSDT mid-plane kinematics. Mehar et al. [12] inspected the nonlinear free vibration of CNTRC level board under uniform warm environment utilizing the HSDT and Green-Lagrange geometrical nonlinearity.

It is clear from the brief survey that, numerous endeavors have as of now been made in past on the hypothetical improvements for the numerical or explanatory arrangements of straight/nonlinear flexural conduct of FG-CNTRC sandwich structures. To the best of the creators' learning, no work has been accounted for in the open writing on flexural conduct of FGCNT fortified sandwich round board. The point of the present examination is to concentrate the twisting conduct of sandwich round boards with FGCNT confront sheets. Keeping in mind the end goal to do as such, a recreation show for the FG sandwich board has been produced utilizing APDL code and discretized utilizing Shell 281 component from ANSYS essential library. Numerical outlines are introduced to demonstrate the impact of different parameters on the flexural reaction of FGCNT fortified sandwich round board and talked about in detail.

2. Methodology

In the present study, two types of CNT reinforced sandwich panels have been considered with length "*a*", width "*b*", thickness "*h*" and principal radius of curvature *"R"*, as shown in Figure 1 (a) and (b). The notations UD and FG stands for uniform distribution and functionally graded distribution of the carbon nanotubes along the thickness direction of the sandwich panel. Due to convenience, the Mori-Tanaka scheme [8] is employed to estimate the material properties of two-phase nano-composites (mixture of CNTs and isotropic polymer) by using CNT efficiency parameter. Thus, the material properties can be written as

$$E_{11} = \eta_1 V_{CNT} E_{11}^{CNT} + V_m E^m \tag{1}$$

$$\frac{\eta_2}{E_{22}} = \frac{V_{CNT}}{E_{22}^{CNT}} + \frac{V_m}{E^m} \tag{2}$$

$$\frac{\eta_3}{G_{12}} = \frac{V_{CNT}}{G_{12}^{CNT}} + \frac{V_m}{G^m} \tag{3}$$

where, E_{11}^{CNT}, E_{22}^{CNT} and G_{12}^{CNT} represents the Young's moduli and shear modulus of single walled CNTs, respectively and E^m and G^m indicate the corresponding properties of the isotropic matrix.

The UD and FG carbon nanotubes reinforcement composite are related as follows:

$$V_{CNT} = V_{CNT}^{*} \quad \text{(UD)} \tag{4}$$

$$V_{CNT}(z) = 2\left(\frac{2|z|}{h}\right)V_{CNT}^{*} \qquad \text{(FG)}$$

(5)

where, $$V_{CNT}^{*} = \frac{W_{CNT}}{W_{CNT} + (\rho^{CNT}/\rho^{m}) - (\rho^{CNT}/\rho^{m})W_{CNT}}$$

(6)

W_{CNT} = mass fraction of the carbon nanotube in the composite panel

ρ^{m} = density of matrix

ρ^{CNT} = density of carbon nanotube

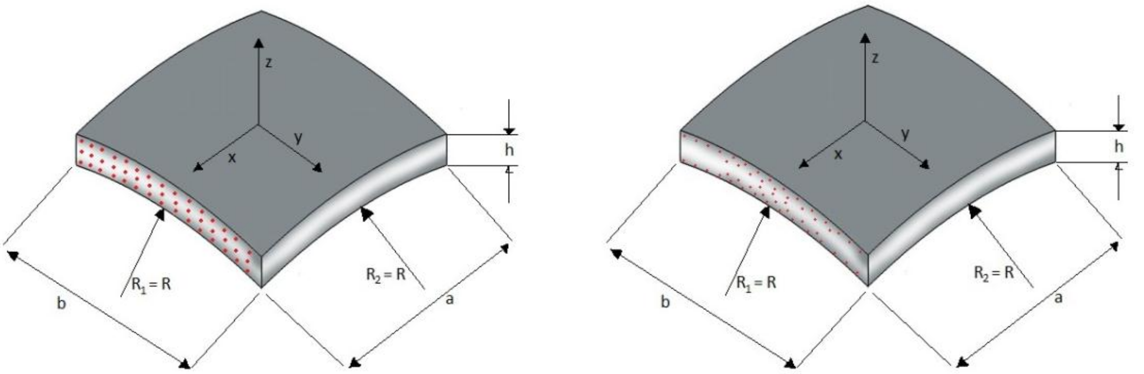


Figure 1. Configuration and gradation of FGCNT sandwich spherical panel **(a)** UD **(b)** FG

With a specific end goal to process the fancied reactions, a reproduction demonstrates for the sandwich circular board has been created utilizing APDL code in ANSYS 15.0 environment. In ANSYS mechanical APDL, different component sorts are accessible for demonstrating of layered structures. For the present examination, Shell 281 component has been taken. Shell 281 is known for its heartiness and appropriateness for the investigation of thin to marginally thick shell structures. The considered component has added up to eight hubs having six degrees of flexibility for every hub say, interpretation along x, y, and z-axis, and pivot about x, y, and z-axes. This component gives palatable outcomes for direct, extensive pivot, or potentially expansive strain nonlinear arrangements. It likewise represents stack firmness impacts of circulated weight. Its systems and convey the arrangements in light of the FSDT and logarithmic strain and genuine anxiety measures. In this manner, the translation anytime in the board u, v and w along x, y and z-axis, individually can be spoken to:

$$u(x,y,z) = u^{0}(x,y) + z\theta_{X}(x,y)$$
$$v(x,y,z) = v^{0}(x,y) + z\theta_{y}(x,y)$$
$$w(x,y,z) = w^{0}(x,y) + z\theta_{z}(x,y)$$

(7)

where, u^0, v^0 and w^0 are the displacements of any point in the mid-plane along x, y and z directions, respectively and θ_x, θ_y and θ_z are the shear rotations. Figure 2 represents the geometrical parameters such as node location and element coordinate system for this element. The element is defined by shell section information and by eight nodes (I, J, K, L, M, N, O and P).

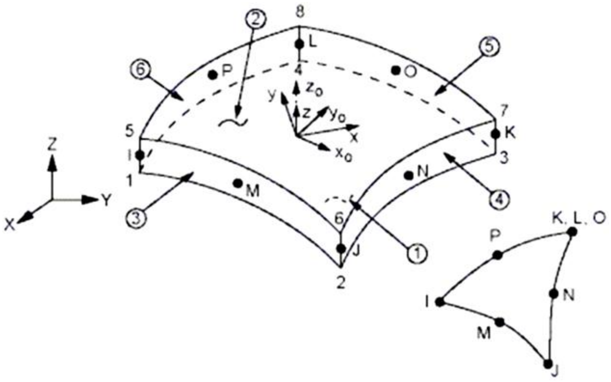


Figure 2. SHELL281 geometry (ANSYS15.0)

3. Results and Discussions

In this area, the flexural reactions of FGCNT sandwich circular board under warm environment have been examined utilizing the present demonstrate model. The material properties utilized for the calculation reason have been given in Table 1. For the calculation reason PMMA and the single-walled carbon nanotube (SWCNT) are considered as the framework material and the support stage, individually. The successful properties and the viable parameters for the PMMA and SWCNT can be seen in [12]. The capacity and adequacy of the present model has been built up through the joining and approval examines. Accordingly, different parametric reviews have been given to draw out their noteworthiness. If not expressed something else, consistently circulated mechanical load (1MPa) and temperature (300K) is expected all through for the present review. To confine the unbending body movement and to lessen the quantity of questions for finding the arrangement, the different limit conditions utilized as a part of the present examination are given as:

1. All sides simply supported (SSSS)

$v^0 = w^0 = \theta_y = \theta_z = 0$ at x = 0 and a; $u^0 = w^0 = \theta_x = \theta_z = 0$ at y = 0 and b.

2. All sides clamped (CCCC)

$u^0 = v^0 = w^0 = \theta_x = \theta_y = \theta_z = 0$ at both x = 0 and a; y = 0 and b.

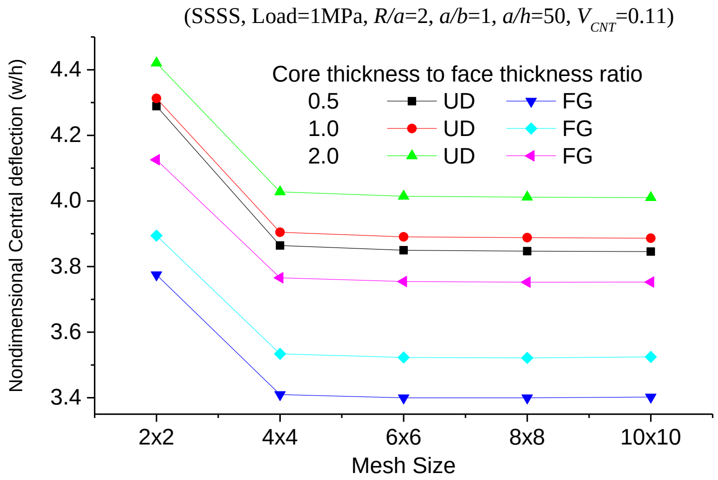
3. All sides free (FFFF)

$u^0 \neq v^0 \neq w^0 \neq \theta_x \neq \theta_y \neq \theta_z \neq 0$ at both x = 0 and a; y = 0 and b.

The transverse central deflection of the FGCNT sandwich spherical panel in nondimensional form is expressed using the formula as: $w_{\text{nondimensional}} = w_{\text{central}}/h$.

3.1 Convergence Study

The convergence study of the present reenactment demonstrate has been tried in this illustration. So as to do as such, FGCNT strengthened square (a/b=1) sandwich circular boards (h=2mm a/h =50 and R/a=2, VCNT=0.11) subjected to consistently dispersed load (=1MPa) with both UD and FG reviewing condition and diverse center to face thickness proportions (0.5, 1 and 2) are considered. The nondimensional focal redirections values processed over different work refinements under SSSS and CCCC conditions are plotted in Figure 3 (a) and (b), separately. It is obviously watched that the reactions figured utilizing the present recreation model are uniting admirably with work refinement. In view of the joining study, a 10×10 work has been decided for deciding the reactions assist all through the present review.



(a)

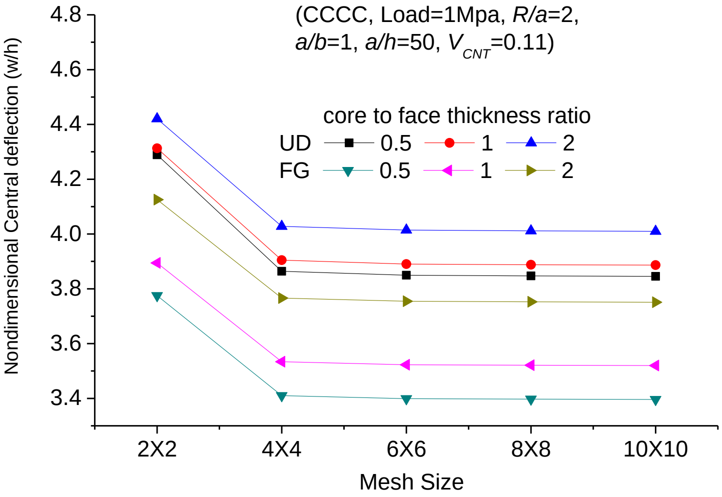


Figure 3. Convergence behaviour of nondimensional central deflection (w/h) of FGCNT reinforced sandwich spherical panel subjected to uniformly distributed load under **(a)** SSSS and **(b)** CCCC boundary condition.

3.2 Comparison Study

With a specific end goal to approve the presently created model, the FGCNT fortified composite level boards as in [8] have been considered. This is on the grounds that only plate model is accessible in the concerned space and the flat panel is thought to be the least difficult type of the shell boards. The reactions are processed for consistently disseminated pressure (0.1MPa), various volume division of CNT (VCNT = 0.11, 0.14 and 0.17), SSSS and CCCC limit conditions and considering both UD and FG angle. For calculation, the geometry, material properties, support conditions and nondimensional equation for the most extreme avoidance utilized are same as considered reference [8]. The examination of results displayed in Figure 4 delineates that the reactions processed utilizing the present model are comparable to the reference values.

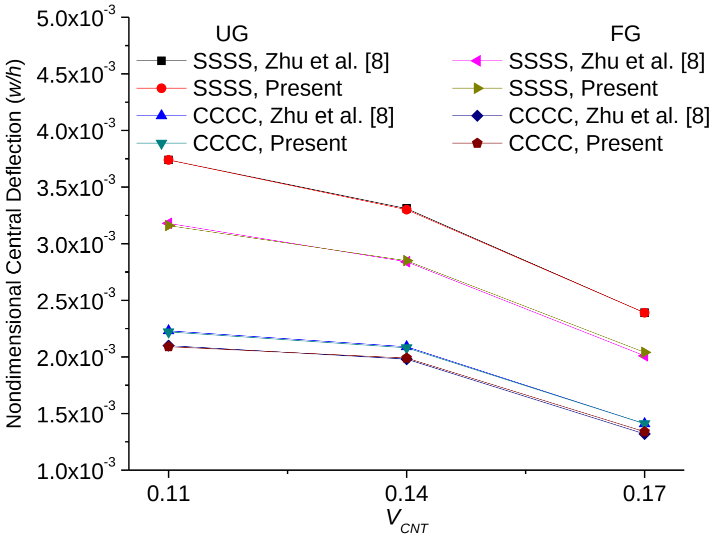


Figure 4. Comparison of nondimensional central deflection of FGCNT reinforced composite flat panel under uniform distributed load.

3.3 Numerical Illustrations

The steadiness and precision of the instantly created show has been affirmed in the meeting and the examination study. In this area, some more numerical examinations have been done to exhibit the relevance of the proposed demonstrate and to draw out the impact of parameters (shape proportion, thickness proportion, limit conditions and centre thickness to face thickness proportion) on the flexural conduct of FGCNT strengthened sandwich circular board under warm environment.

3.3.1 Effect of curvature ratio (R/a) and temperature

Membrane quality of the board structure extraordinarily relies on upon its ebb and flow. The impact of ebb and flow proportion on the twisting conduct of FGCNT strengthened sandwich circular board in the warm environment is examined in this case. Reactions are registered for various curvature proportions (R/a = 5, 20, 50 and 100) with both UD and FG slope synthesis independently for volume faction of CNT (VCNT = 0.11) and temperature (T=300K, 500K and 700K). The geometrical parameters and bolster condition considered as: a/b= 1, a/h= 10, center thickness to face thickness proportion = 0.5, SSSS limit condition and the outcomes are exhibited in Table 1. It is watched that the focal redirection values increment with curvature ratio and whereas decrease with expanding volume portion of CNT. It is additionally qualified to note that as the temperature builds the most extreme diversion esteem likewise increments.

Table 1. Effect of curvature ratio and temperature on nondimensional central deflection of FGCNT reinforced sandwich spherical panel.

Temperature		300K		500K		700K	
V_{CNT}	*R/a*	UD	FG	UD	FG	UD	FG
0.11	5	36.6750 x 10^{-3}	31.6410 x 10^{-3}	36.994 x 10^{-3}	31.882 x 10^{-3}	37.154 x 10^{-3}	32.003 x 10^{-3}
	20	37.8450 x 10^{-3}	32.5160 x 10^{-3}	38.184 x 10^{-3}	32.771 x 10^{-3}	38.353 x 10^{-3}	32.898 x 10^{-3}
	50	37.9085 x 10^{-3}	32.5635 x 10^{-3}	38.248 x 10^{-3}	32.819 x 10^{-3}	38.418 x 10^{-3}	32.947 x 10^{-3}
	100	37.9175 x 10^{-3}	32.5705 x 10^{-3}	38.257 x 10^{-3}	32.826 x 10^{-3}	38.428 x 10^{-3}	32.954 x 10^{-3}

3.3.2 Effect of thickness ratio (a/h)

It is notable that the thickness proportion of the curved structures contributes altogether their quality and firmness. Keeping in mind the end goal to concentrate the impact of thickness proportion on the flexural strength of FGCNT reinforced sandwich round panel under uniform disseminated stack, all sides clasped square sandwich circular boards (R/a = 10, center thickness to face thickness proportion = 1) with various volume division (VCNT = 0.11, 0.14 and 0.17) are considered. The reactions are registered for different thickness proportion (a/h = 10, 20, 40 and 80) and exhibited in Figure 5. It is watched that the nondimensional focal redirection increments with increment in thickness proportion. It is, for the most part, expected as the solidness of the structure diminish as the board has a tendency to end up distinctly thin. It is additionally noticed that the most extreme redirection diminishes with expanding volume portion of the CNT.

3.3.3 Effect of support conditions

Strength and stiffness behavior of any structure/basic segment to a great extent relies on upon the support conditions which thus influences their flexural reactions. In this illustration, the impacts of different support conditions (SSSS, CCCC, CSCS and CFCF) on the nondimensional most extreme diversion of FGCNTRC sandwich round board have been explored. For calculation, the geometrical parameters are taken as: R/a = 10, center thickness to face thickness proportion = 1.5, a/b = 1 and a/h= 10. Results are processed for both UD and FG inclination with three distinctive CNT volume divisions (VCNT = 0.11, 0.14 and 0.17) and appeared in Figure 6. It is seen that the transverse central deflection values increment as the quantity of requirements at the support diminish.

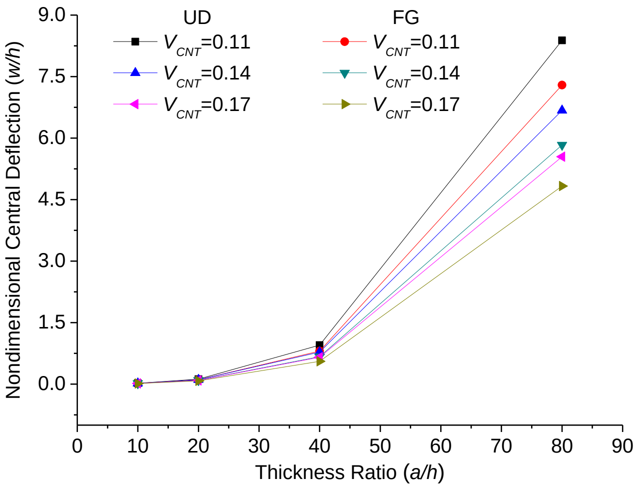


Figure 5. Effect of thickness ratio on nondimensional central deflection of functionally graded nanotube reinforced sandwich spherical panel

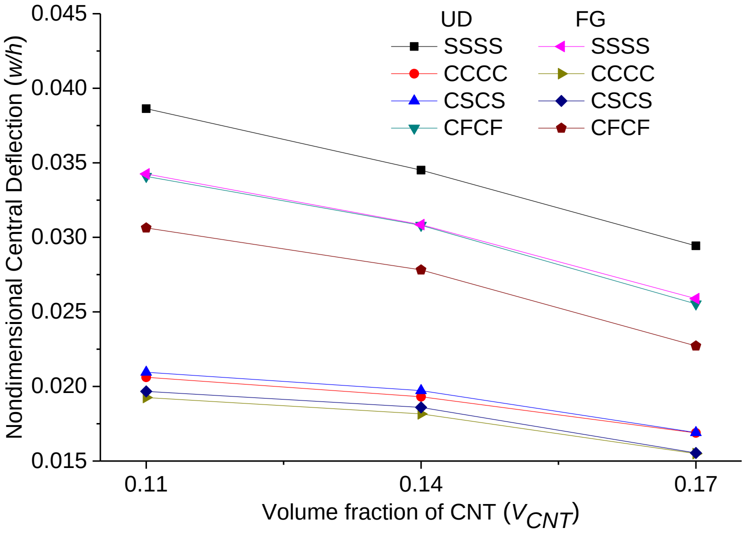


Figure 6. Nondimensional maximum deflection FGCNT sandwich spherical panel subjected to uniformly distributed load for various support conditions.

3.3.4 Effect of core to face thickness ratio

In this example the flexural behavior of FGCNT reinforced sandwich spherical panel (R/a= 40, a/h= 10, a/b= 1 and under CSCS support condition) due to variation of the core thickness to face thickness ratio has been investigated. The nondimensional central deflection values are computed for four different core to face thickness ratio (0, 0.5, 1, 1.5 and 2), three different CNT volume fractions (V_{CNT} = 0.11, 0.14 and 0.17) and for UD and FG gradient separately. The results plotted in Figure 7 depict that in both UD and FG gradient the transverse central deflection values increase with increase in core to face thickness ratio, which is within the expected line.

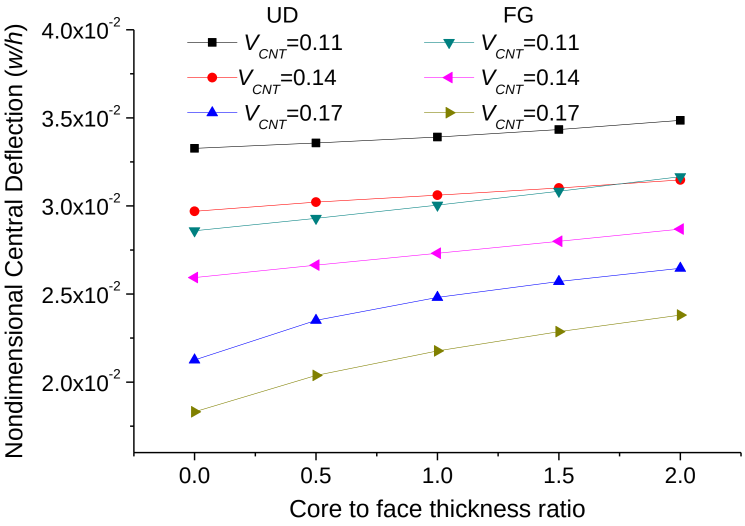


Figure 8. Effect of core thickness to face thickness ratio on nondimensional central deflection of functionally graded nanotube reinforced sandwich spherical panel.

4. Conclusion

In this article, the flexural strength of FGCNTRC sandwich round board of two different grading (UD and FG) under consistently appropriated stack and the warm environment has been examined. The sandwich board is made of FGCNT fortified face sheets and isotropic homogeneous center material. The properties of the panel structure are considered to change in the thickness bearing in light of the volume part of the CNT and are administered by Mori-Tanaka method. What's more, the properties of the CNT is likewise thought to be temperature subordinate. For the calculation of the reactions of the FGCNT sandwich panel has been created in ANSYS 15.0 utilizing APDL code. The convergence and approval contemplate demonstrating the viability of the present model as far as execution and exactness to acquire the final reactions. A couple of new cases are fathomed to research the impact of different parameters on the flexural conduct of the FGCNT fortified sandwich circular board. In view of the parametric reviews, it is watched that the focal avoidance values diminish with increment in volume portion of CNT. It is qualified to note that the solidness of the round sandwich board diminishes with increment in temperature. For a specific estimation of CNT volume portion, the FG review indicates lesser avoidance values when contrasted with UG review. It is additionally observed that the transverse central deflection values diminish as the values of imperatives at the support increase.

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