Structural Analysis of Functionally Graded Carbon Nanotube Reinforced Composite Plates

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By

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“I would like to dedicate
this thesis to
my Parents, who instilled
in me the virtue
of perseverance and commitment,
and relentlessly encouraged me
to strive for excellence…”

Chapter 5
Conclusions

5.1. Concluding Remarks

In the present work, the structural analysis of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation is carried out using different non-polynomial shear deformation theories based on secant and inverse hyperbolic sine function. A closed form analytical solution based on Navier's method is presented for the first time to carry out the static, buckling and dynamic analysis of functionally graded carbon nanotube reinforced composite plate resting on Pasternak's elastic foundation. Further, a generalized FE formulation is also developed to carry out the bending, buckling, and free vibration analysis of functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation. A detailed analytical and FE investigations is carried out for the structural analysis of functionally graded carbon nanotube reinforced composite plate structures with and without Pasternak's elastic foundation which includes the effect of various geometrical, material and elastic foundation features. The conclusions based on the present study are affirmed below:

- The non-polynomial shear deformation theories based on secant function and inverse hyperbolic sine function are used here contains non-polynomial shear strain function to introduce the non-linearity of transverse shear stresses through thickness at the cost of less number of field variables with respect to the HSDT's available in the literature which are generally of polynomial nature. FSDT does not have the required deformation modes to model thick CNTs reinforced composite and sandwich plates and is usually preferred to study the thin ones where shear deformation is not dominant. While the higher-order deformation modes (membrane and bending) are present in the polynomial based HSDT's, yet their inclusion is only possible with a large number of higher-order terms which increases computational costs. In non-polynomial shear deformation theory, the non-linearity of shear deformation is accommodated with the aid of a single non-polynomial function 'secant function' or 'inverse hyperbolic sine function' in the kinematic field. Hence, efficient results are obtained at the cost of lesser computational efforts. Further, the non-polynomial shear deformation theories based on secant and inverse hyperbolic sine functions are inherently satisfying the traction free conditions of transverse shear stresses at the top and bottom surfaces of the plate while in most of the polynomial based HSDT's, this conditions are generally not taken into consideration and in some cases, these conditions are artificially enforced.

- The structural responses of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation obtained using the present models is found to be in good agreement with the available results in literature. The results obtained using FEM are in close agreement with the present analytical results for both the theories selected for the analysis.
- The natural frequencies and the higher-modes of vibration are largely affected by the material and the geometrical features of the functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation like density, core-thickness, aspect-ratio, volume fraction of the carbon nanotubes, distribution of carbon nanotubes, and modular ratio.

- The foundation stiffness has a significant impact on the structural responses of functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation. The magnitudes deflection and stresses have significantly reduced due to the Winkler and the shear stiffness of the elastic foundations.
- The stiffness of the foundation also has a significant impact on the fundamental frequencies of the functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation tend to increase due to the stiffness of the foundations.
- The stiffness of the foundation also has a significant impact on the critical buckling load under uni-axial and bi-axial loading condition of the functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation tend to increase due to the stiffness of the foundations.
- Functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation produce improved structural responses as compared to the uniformly graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation.
- The flexural rigidity due to the carbon nanotubes distribution near the edge is more compared to reinforcement near the mid plane in the functionally graded carbon nanotube reinforced composite plate structures.
- The overall responses of the structure are enhanced as the volume fraction of the carbon nanotubes are increasing in the functionally graded carbon nanotube reinforced composite plate structures.

- The combined Winkler and shear stiffness in the Pasternak's foundation model has a greater impact on the structural responses of the functionally graded carbon nanotube reinforced composite plate structures resting on Pasternak's elastic foundation than the Winkler's foundation model as it accounts for the shear interactions among the points in the elastic soil in addition to the proportional interaction between the pressure and deflection of any point on the surface of the soil.

- The ascending order of the resistance to the transverse deflection of functionally graded carbon nanotube reinforced composite plate structures for a particular volume fraction of carbon nanotubes and span thickness ratio is FG-X followed by UD, FG-V and FG-O distributions.

- The descending order of the plate stiffness of the functionally graded carbon nanotube reinforced composite plate structures for a particular volume fraction of carbon nanotube and span thickness ratio is FG-X followed by UD, FG-V and FG-O distributions.

5.2. Contribution of the thesis

New analytical and FE models are derived for the structural responses of functionally graded carbon nanotube reinforced composite plate structures resting on an elastic foundation. The developed models can produce accurate responses for functionally graded carbon nanotube reinforced sandwich plate structures with less computational effort. The bending responses which include the transverse deflection, normal stresses, in-plane shear stresses, transverse shear stresses of the functionally graded carbon nanotube reinforced composite plate structures resting on an elastic foundation can be accurately estimated. The accurate estimation of the natural frequency and critical buckling load of functionally graded carbon nanotube reinforced composite plate structures resting on an elastic foundation can be carried out using present analytical and FE models. The present analytical and FE models gives the clear understanding of the effects of the different parametric conditions on the structural response of the functionally graded carbon nanotube reinforced composite plate structures with and without an elastic foundation. The analytical and FE models for the structural responses of functionally graded carbon nanotube reinforced composite plate structures resting on an elastic foundation reviles the best possible arrangement for the reinforcement distribution that will produce the improved structural responses for the functionally graded carbon nanotube reinforced composite plate structures resting on an elastic foundation.

5.3. Scope for the Future Research

In this section, some of the possible areas of research which can be carried out in the future are presented below:

- Shell structures are more economical than those of plate structures due to their shape which helps to transfer the load through axial as well bending stiffness. The present work can be extended for determining the static and dynamic responses of functionally graded carbon nanotube reinforced composite shell structures.
- Analytical solutions are considered as the best solutions of any problem and are often useful to test new numerical methods. However, the analytical solutions based on Navier’s scheme are restricted to simply supported boundary conditions. Therefore, solutions for other boundary conditions are required to be obtained analytically.

- The environmental conditions like variation of temperature and moisture often degrade the strength of structures. The present work can be extended to study the static and dynamic deformation responses of functionally graded carbon nanotube reinforced composite plate structures subjected to hygro-thermo-mechanical loads.
- The present work can be extended to study the dynamic time-dependent loading responses of functionally graded carbon nanotube reinforced composite plate structures.
- The present formulation is developed in the framework of linear elasticity. The incorporation of material and geometrical non-linearity in the formulation is essential to study the non-linear effects on the deformation responses of functionally graded carbon nanotube reinforced composite plate structures.