Review Paper on Modal Analysis of FGM Plate Using First Order Shear Deformation Theory

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Abstract — Functionally graded material due to their excellent strength to weigh ratio and stiffness to weigh ratio makes them perfect choice for aircraft and other mechanical applications. Modal analysis of FGM plate is carried out using first order shear deformation theory in Ansys 18.0. Mechanical properties of FGM plate are varying above and below the reference plane i.e., center of the plate in accordance with the simple power law distribution. The aim of our work is to study the effect of various boundary conditions, aspect ratio, thickness ratio, power law index etc. on frequency parameter.

Keywords: Free Vibration, FGM, FSDT

I. INTRODUCTION

In many aerospace and mechanical applications ceramic coatings on metal are considered to be an effective material where their heat resistance properties are required in addition with strength of metals. However, their different thermal expansion coefficient can lead to delamination problems. This problem can be overcome by the introduction of functionally graded material (FGM), in which there is gradual transition of material from metal to ceramic.

Engineering applications requiring properties of opposite nature such as hardness and ductility at the same time can not be satisfied by any material in its pure form. These properties of opposite nature can be fulfilled by composite material as they are comprised of two or more physically and chemically distinct materials. Functionally graded materials belongs to category of advanced composite material as they are manufactured by continuously varying mechanical and thermal properties in a certain direction. The major difference between composite material and functionally graded material is abrupt change and gradual change in their mechanical properties respectively.

FGMs generally used are combination of metal and ceramic which have high strength and excellent heat resistance properties respectively, makes them suitable for civil, mechanical, aerospace engineering and nuclear reactor and shipbuilding sector applications. Conventional or laminated composite presents the problem of stress and delamination between fiber and composite which can be encounter by FGMs.

II. LITERATURE REVIEW

According to V Kumar, SJ Singh, VH Saran, and SP Harsha objective of the current study is to determine the vibration response of FGM plate with variable thickness, for which the governing equation of the plate is derived using Hamilton's principle in conjunction with the Galerkin-Vlasov's method. Power, Exponential, and Sigmoid law distribution in terms of volume fractions of the constituent materials is selected to obtain the effective properties of the FGM plate. The comparison studies have been carried out to establish the accuracy of the present semi-analytical formulation. The benchmark results are presented for a tapered plate with taper ratio 0.25, 0.50, and 1. Furthermore, the parametric studies have been conducted based on the various parameters as aspect ratio, span ratio, volume fraction exponent, taper ratio, and boundary conditions.[1]

E.F. Erdurcan Y. Cunedioglu investigate the free vibration of an aluminum beam coated with imperfect and damaged functionally graded material. The imperfections consist of porosities, while 4 evenly distributed cracks represent the damage profile. A polynomial function is used to vary the density and elasticity through the thickness of the coating, while the effective elastic modulus and density are found with classical lamination theory. To achieve a truthful modeling, the gradually changing mechanical properties of the coating are modeled with 25 layers of material. The individual layers are isotropic and homogeneous. Numerical solutions are found with the finite element method using Timoshenko beam elements. MATLAB is used to write a finite element code, and the beam natural frequencies are found. To show the influences of porosity, crack depth, coating thickness and the polynomial function index (n) on the natural beam frequencies, a parametric study is conducted. It was found that the natural frequency values were significantly affected by the studied parameters.[2]

According to Mohammad Talha, B.N. Singh the mechanical properties of the plate are assumed to vary continuously in the thickness direction by a simple power-law distribution in terms of the volume fractions of the constituents. Convergence tests and comparison studies have been carried out to demonstrate the efficiency of the present model. Numerical results for different thickness ratios, aspect ratios and volume fraction index with different boundary conditions have been presented. It is observed that the natural frequency parameter increases for plate aspect ratio, lower volume fraction index n and smaller thickness ratios. It is also observed that the effect of thickness ratio on the frequency of a plate is independent of the volume fraction index. For a given thickness ratio non-dimensional deflection increases as the volume fraction index increases. It is concluded that the gradient in the material properties plays a vital role in determining the response of the FGM plates.[3]

Omer Civalek, Ali Kemal Baltacioglu used two different numerical approaches for frequency response of annular sector and sector plates with functionally graded materials and laminated composite cases. First-order shear deformation (FSDT) and Love's conical shell theories are used for obtaining the annular sector plate equations via some suitable angles and geometric parameters. The method of harmonic differential quadrature (HDQ) and discrete singular convolution (DSC) have been used for numerical solution of the resulting governing equations for modal analysis. Simple power-law and four-parameter power law distributions in terms of the volume fractions of constituents have been used for FGM composites. Comparison and convergence study for the present numeral methods have been made via existing results available in the literature for sector and annular sector plates. Frequencies values for annular sector/sector plates have been obtained for different material and geometric parameters, boundary conditions and sector angles.[4]

Vyacheslav N. Burlayenko, Tomasz Sadowski presents a three-dimensional modelling of free vibrations and static response of functionally graded material (FGM) sandwich plates. Natural frequencies and associated mode shapes as well as displacements and stresses are determined by using the finite element method within the ABAQUS code. The three-dimensional (3-D) brick graded finite element is programmed and incorporated into the code via the user-defined material subroutine UMAT. The results of modal and static analyses are demonstrated for square metal-ceramic functionally graded simply supported plates with a power-law through-the-thickness variation of the volume fraction of the ceramic constituent. The through-the-thickness distribution of effective material properties at a point are defined based on the Mori-Tanaka scheme. First, exact values of displacements, stresses and natural frequencies available for FGM sandwich plates in the literature are used to verify the performance and estimate the accuracy of the developed 3-D graded finite element. Then, parametric studies are carried out for the frequency analysis by varying the volume fraction profile and value of the ceramic volume fraction.[5]

According to Deepak S.A., Rajesh A. Shetty Functionally graded materials are the non-homogeneous composite materials whose material properties vary along thickness from one surface to another surface. Within FGM, there are different layers of two or more materials having different functionality which will enhance the overall properties. When compared to individual metals or ceramics, FGM proves to be a better class of material. In this work, finite element analysis is carried out, in order to assess the static behaviour of functionally graded plates and free vibration analysis to ascertain the natural frequencies. Simply supported (SSSS) and clamped (CCCC) plates are considered for the analysis. A rectangular plate is made up of a ceramic material at the top and a metallic surface at the bottom. Static and free vibration analysis shows that for a length to thickness ratio of above 20, the deflection of plates was lower compared to the lower thickness ratios.[6]

M.N.A. Gulshan Taj, Anupam Chakrabarti, Abdul Hamid Sheikh addresses a static analysis of functionally graded material (FGM) plates using higher order shear deformation theory. In the theory the transverse shear stresses are represented as quadratic through the thickness and hence it requires no shear correction factor. The material property gradient is assumed to vary in the thickness direction. Mori and Tanaka theory (1973) is used to represent the material property of FGM plate at any point. The thermal gradient across the plate thickness is represented accurately by utilizing the thermal properties of the constituent materials. Results have been obtained by employing a continuous isoparametric Lagrangian finite element with seven degrees of freedom for each node. The convergence and comparison studies are presented and effects of the different material composition and the plate geometry (side-thickness, side–side) on deflection and temperature are investigated. Effect of skew angle on deflection and axial stress of the plate is also studied. Effects of material constant n on deflection and the temperature distribution are also discussed in detail.[7]

Nam-II Kim, Jaehong Lee present the exact solutions for coupled analysis for bending and torsional case thin-walled functionally graded (FG) beams with non-symmetric single- and double-cells are presented for the first time. For this purpose, an accurate and efficient method is proposed to obtain the FG member stiffness matrix based on the series expansions of displacement components. Three types of material distributions are considered and the beam mechanical properties are graded along the wall thickness according to a power law of the volume fraction. The present beam model is on the basis of the Euler-Bernoulli beam theory and the Vlasov one for bending and torsional problems, respectively. The explicit expressions for displacement parameters are derived using the power series approach from the four coupled equilibrium equations. Finally, the FG member stiffness matrix is determined from the seven force-displacement relations. In order to show the accuracy and super convergence of the thin-walled FG beam element developed by this study, the numerical solutions are presented and compared with results obtained from the finite beam element based on the approximate interpolation polynomials and other available results. Especially, the effects of various structural parameters such as material distribution type, volume fraction index, boundary condition, and material ratio on the spatially coupled responses of FG box beams with non-symmetric single- and double-cells are parametrically investigated.[8]

P. Malekzadeh works on the three-dimensional (3D) free vibration analyses of functionally graded (FG) plates are limited to plates with simply supported boundary conditions and without elastic foundations. Hence, the free vibration analysis of thick FG plates supported on two-parameter elastic foundation is presented. The formulations are based on the three-dimensional elasticity theory. Plates with two opposite edges simply supported and arbitrary boundary conditions at other edges are considered. A semi analytical approach composed of differential quadrature method (DQM) and series solution is adopted to solve the equations of motions. The material properties change continuously through the thickness of the plate, which can vary according to power law, exponentially or any other formulations in this direction. The fast rate of convergence of the method is demonstrated and comparison studies are carried out to establish its very high accuracy and versatility. Some new results for the natural frequencies of the plate are prepared, which include the effects of elastic coefficients of foundation, boundary conditions, material and geometrical parameters. The new results can be used as benchmark solutions for future researches.[9]

Hiroyuki Matsunaga analyzed Natural frequencies and buckling stresses of plates made of functionally graded materials (FGMs) by taking into account the effects of transverse shear and normal deformations and rotatory inertia. The modulus of elasticity of the plates is assumed to vary according to a power-law distribution in terms of the volume fractions of the constituents. By using the method of power series expansion of displacement components, a set of fundamental dynamic equations of a two-dimensional (2-D) higher-order theory for rectangular functionally graded (FG) plates is derived through Hamilton's principle. Several sets of truncated approximate theories are applied to solve the eigenvalue problems of FG plates with simply supported edges. In order to assure the accuracy of the present theory, convergence properties of the fundamental natural frequency are examined in detail. Critical buckling stresses of FG plates subjected to in-plane stresses are also obtained and a relation between the buckling stress and natural frequency of simply supported FG plates without in-plane stresses is presented. The distributions of modal displacements and modal stresses in the thickness direction are obtained accurately by satisfying the surface boundary conditions of a plate. The modal transverse stresses have been obtained by integrating the three-dimensional equations of motion in the thickness direction starting from the top or bottom surface of a plate. The present numerical results are also verified by satisfying the energy balance of external and internal works are considered to be sufficient with respect to the accuracy of solutions. It is noticed that the present 2-D higher-order approximate theories can predict accurately the natural frequencies and buckling stresses of simply stresses of simply supported FG plates.[10]

Trung-Kien Nguyen, Karam Sab, Guy Bonnet proposed first-order shear deformation plate models for modelling structures made of functionally graded materials. Identification of transverse shear factors is investigated through these models by energy equivalence. The transverse shear stresses are derived from the expression of membrane stresses and equilibrium equations. Using the obtained transverse shear factor, a numerical analysis is performed on the examples of a simply supported square plate and of a cylindrical bending sandwich plate clamped at both ends. The material properties are assumed to be isotropic at each point and vary through the thickness according to a power law distribution. The numerical results of the static analysis are compared to available solutions from previous studies.[11]

Huu-Tai Thai, Dong -Ho Choi represents a simple first-order shear deformation theory for the bending and free vibration analysis of functionally graded plates. Unlike the conventional first-order shear deformation theory, the present first-order shear deformation theory contains only four unknowns and has strong similarities with the classical plate theory in many aspects such as governing equations of motion, boundary conditions, and stress resultant expressions. Equations of motion and boundary conditions are derived from Hamilton's principle. Closed-form solutions of simply supported plates are obtained and the results are compared with the exact 3D and quasi-3D solutions and those predicted by other plate theories. Comparison studies show that the present theory can achieve the same accuracy of the conventional first-order shear deformation theory which has more number of unknowns.[12]

Senthil S. Vel, R.C. Batra present a three-dimensional exact solution for free and forced vibrations of simply supported functionally graded rectangular plates. Suitable displacement functions that identically satisfy boundary conditions are used to reduce equations governing steady state vibrations of a plate to a set of coupled ordinary differential equations, which are then solved by employing the power series method. The exact solution is valid for thick and thin plates, and for arbitrary variation of material properties in the thickness direction. Results are presented for two-constituent metal–ceramic functionally graded rectangular plates that have a power-law through-the-thickness variation of the volume fractions of the constituents. The effective material properties at a point are estimated by either the Mori–Tanaka or the self-consistent schemes. Exact natural frequencies, displacements and stresses are used to assess the accuracy of the classical plate theory, the first order shear deformation theory and a third order shear deformation theory for functionally graded plates. Parametric studies are performed for varying ceramic volume fractions, volume fraction profiles and length-to-thickness ratios. Results are also computed for a functionally graded plate that has a varying microstructure in the thickness direction using a combination of the Mori–Tanaka and the self-consistent methods. Forced vibrations of a plate with a sinusoidal spatial variation of the pressure applied on its top surface are scrutinized.[13]

L.F. Qian, R.C. Batra used a higher-order shear and normal deformable plate theory and a meshless local Petrov–Galerkin method to find the compositional profile of a two-constituent cantilever plate so that either the first or the second natural frequency is maximum. It is found that in each case, the composition varies only in the axial direction. The compositional profile for maximizing the first frequency is different from that for maximizing the second frequency. The forced transient response of each optimal functionally graded plate has been compared with that of the two homogeneous plates. The compositional profile that maximizes the first or the second natural frequency neither results in extreme values of the tip deflection nor in extreme values of the axial stress.[14]

Ashraf M. Zenkour present the static response for a simply supported functionally graded rectangular plate subjected to a transverse uniform load. The generalized shear deformation theory obtained by the author in other recent papers is used. This theory is simplified by enforcing traction-free boundary conditions at the plate faces. No transversal shear correction factors are needed because a correct representation of the transversal shearing strain is given. Material properties of the plate are assumed to be graded in the thickness direction according to a simple power-law distribution in terms of the volume fractions of the constituents. The equilibrium equations of a functionally graded plate are given based on a generalized shear deformation plate theory. The numerical illustrations concern bending response of functionally graded rectangular plates with two constituent materials. The influences played by transversal shear deformation, plate aspect ratio, side-to-thickness ratio, and volume fraction distributions are studied. The results are verified with the known results in the literature.[15]

III. CONCLUSION

FGM provides a relative change in terms of the properties of the materials over the distance and direction. Thus, the FGM has a wide range of engineering applications and it is expected to increase as the cost of material processing and fabrication processes are reduced by improving processing techniques. In the case of functionally graded materials disadvantageous sharp interfaces existing in a composite material are eliminated. These sharp interfaces are replaced with a gradient interface, which guarantees smooth transition from one material to another. The overview presented here shows only a few selected potential applications of FGMs to industrial practice. The proposed solutions can be treated as a contribution to knowledge about graded materials and its dissemination. However, the subject area still requires further advanced research into both characterization of their properties and their behavior under conditions resembling operational conditions.

REFERENCES

[1] V. Kumar, SJ Singh, VH Saran, SP Harsha Exact solution for free vibration analysis of linearly varying thickness FGM plate using Galerkin-Vlasov's method, Materials: Design and Applications, 22 November 2020
[2] Erdurcan, E.F., Cunedio˘glu, Y.: Free vibration analysis of a functionally graded material coated aluminum beam. AIAA J. (2019) https://doi.org/10.2514/1.J059002
[3] Talha Mohammed, B.N. Singh, Static response and free vibration analysis of FGM plates using higher order shear deformation theory, Appl. Math. Model. 34 (2010) 3991–4011.
[4] Omer Civalek, Ali Kemal Baltacioglu, Free vibration analysis of laminated and FGM composite annular sector plates, Elsevier 29 August 2018.
[5] Vyacheslav Burlayenko, Tomasz Sadowski, Meccanica, Free vibrations and static analysis of functionally graded sandwich plates with three-dimensional finite elements 10 (2019).
[6] DeepakS.A, Static and free vibration analysis of functionally graded rectangular plates using ANSYS, Materials Today: Proceedings, Volume 45, Part 1, 2021, Pages 415-419.
[7] M.N.A. Gulshan Taj, Anupam Chakrabarti, Abdul Hamid Sheikh, Analysis of functionally graded plates using higher order shear deformation theory, 37 (2013) 8484–8494
[8] Nam-II Kim, Jaehong Lee, Exact solutions for coupled analysis of thin-walled functionally graded beams with non-symmetric single- and double-cells, doi: 10.1016/j.apm.2018.03.030
[9] P. Malekzadeh, Three-dimensional free vibration analysis of thick functionally graded plates on elastic foundations, Composite Structures 89 (2009) 367–373
[10] Hiroyuki Matsunaga, Free vibration and stability of functionally graded plates according to a 2-D higher-order deformation theory, Composite Structures 82 (2008) 499–512.
[11] Trung-Kien Nguyen, Karam Sab, Guy Bonnet, First-order shear deformation plate models for functionally graded materials, Composite Structures 83 (2008) 25–36.
[12] Huu-Tai Thai, Dong -Ho Choi, A simple first-order shear deformation theory for the bending and free vibration analysis of functionally graded plates, Composite Structures 101 (2013) 332–340.
[13] Vel SS, Batra RC. Three-dimensional exact solution for the vibration of functionally graded rectangular plates. J Sound Vibr 2004;272(3):703–30.
[14] Qian LF, Batra RC. Three-dimensional transient heat conduction in a functionally graded thick plate with a higher-order plate theory and a meshless local Petrov–Galerkin method. Comput Mech 2005;35(3):214–26.
[15] Zenkour AM. Generalized shear deformation theory for bending analysis of functionally graded plates. Appl Math Model 2006;30(1):67–84.

