Review on Vibration Analysis of Functionally Graded Material (FGM) Spherical Shell

Ashish Khinchi[1],Pankaj Sharma[2]

1. *PG Scholar , Department of Mechanical Engineering University Teaching Department Rajasthan Technical University, Kota (Rajasthan), India*
2. *Assistant Professor, Department of Mechanical Engineering University Teaching Department Rajasthan Technical University, Kota (Rajasthan), India*

ABSTRACT-

The main aim of this work is to review the vibration analysis of functionally graded material (FGM) spherical shell with different boundary conditions under thermal effect. This review carried out the vibration behaviour of FG spherical shell with various materials and different solution methods. Effects of various parameters such as radius of curvature, material grading index, thermal gradient and variation of volume fraction are discussed. The objective of this review paper is to find out the reliable and accurate method for vibration analysis of FGM spherical shell.

Keyword*- Vibration analysis, Functionally Graded Material, Thermal effect*

1. INTRODUCTION

The composite materials have properties such as high strength to weight ratio and stiffness to weight ratio. They have widespread use in automobile industry, marine application, aeronautical application and area of civil and safety equipment [1, 2]. But there are some drawback in composite materials such as debonding of layers and stress concentration at the interface of the materials. To avoid these drawbacks, functionally graded materials (FGMs) are introduced [3].

Recently FGMs structures are used in various engineering fields. In recent decade FG spherical shells are used in increasing number of engineering structures to satisfy the special functional requirements [4-6]. The FGMs have smooth grading of components gives better thermal properties, higher fracture toughness, improved residual stress distribution and reduced stress intensity factors.

Spherical shell are used in many applications i.e. circular planform such as the nose of the plane and caps of pressurized cylindrical tanks.The geometrical property of the FG spherical shells is also leads to applications such as various reservoirs, interstages and spherical caps. For example when a shallow spherical shell with a circular planform is used in the nose of a spacecraft, it was exposed to extremely high temperatures while in orbit and especially during the searing 1650 °C heat of atmospheric re-entry[7]. Due to high thermal resistance with low thermal stresses, FGMS are better choice to use in these structures.

2. Geometry of functionally graded spherical shell

A FG spherical shell segment with inner radius R_0, mean radius R, outer radius R_1 and thickness h is considered as shown in Fig.1. Axes , r and θ are co-ordinate system in axial, circumferential and radial directions respectively. Here, u, v, and w are displacement components in radial (r), circumferential (θ) and axial (ø) directions respectively [8, 9].

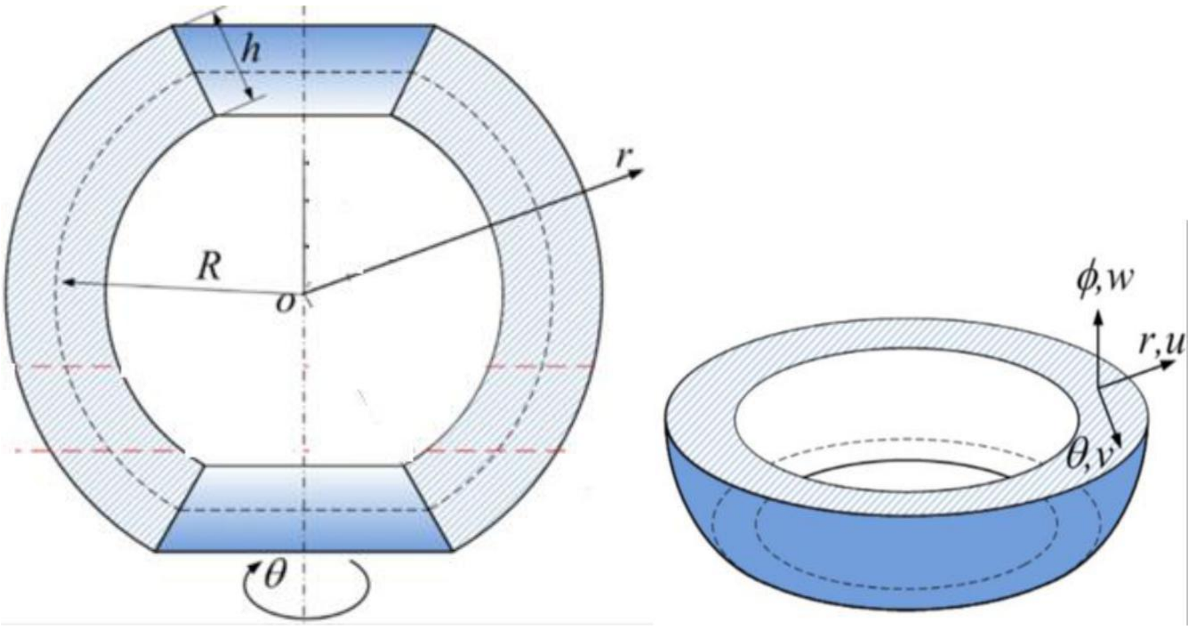

Fig.1. Cross-section of FG spherical shell and co-ordinate system

3. Literature on vibration analysis of FG spherical shell

Biswal and Mohanty [10] dealt with the free vibration and damping characteristics of multilayer sandwich spherical shell panels with viscoelastic material core layers and elastic face layers. In this analysis first order shear deformation theory (FSDT) was adopted by authors. The displacements of the core layers were assumed to vary linearly along the thickness direction. Longitudinal and transverse deformations of the core layers were considered. The equations of motion were derived using Hamilton’s Principle. All sides were considered as simply supported.

Barzegar and Fadaee [11] presented free vibration analysis of a thin functionally graded shallow spherical cap under a thermal load and decoupling technique was adopted to solve the equations of motion.The effects of various parameters such as radius of curvature, material grading index and thermal gradient were discussed. ABAQUS software was used for the frequency analysis. Different boundary conditions were considered such as clamped, simply supported, free end applied at outer edge of shell.

Harmonic modal characteristics of FG-curved panels in rectangular and tilted planforms were investigated by the Badiganti et al. [12]. In their work, power-law based Voigt’s material model was used.A mathematical formulation was done by using third-order shear deformation mid-plane kinematic theory (TOSDT). Frequency analysis of simply supported Functionally Graded shallow shell panels with rectangular

ISBN : 978-93-87793-71-2

and tilted planforms were examined under different thickness, aspect and shallowness ratios. The various boundary conditions were considered such as HHHH, CCCC, CFCF and SFSF and power-law indices.

A semi analytical method was employed by Haichao et al. [13] to analyse free vibration analysis of FG doubly-curved shells of revolution with general boundary conditions.The analytical model was developed on the basis of multi-segment partitioning strategy and first order shear deformation theory (FSDT). Free vibration analysis of FG doubly-curved shells was achieved by Rayleigh–Ritz method.

Duc et al. [14] presented the nonlinear dynamic and vibration of the S-FGM shallow spherical shells with ceramic-metal-ceramic layers (in non-axisymmetric and axisymmetric shells) on elastic foundations with different types of boundary conditions in thermal environment. Material properties are varied in thickness direction according to sigmoid law distribution.

The linear and the nonlinear deformation analysis of FG spherical shell panel under thermo-mechanical load were presented by Kar and panda [15]. In their work, material properties were varied in accordance with Voigt's micromechanical rule and power-law distribution. The nonlinear governing equations of the functionally graded shell panel were derived with the help of variational principle. Different boundary conditions are taken into consideration such as clamped, simply-supported and free.

Fantuzzia et al. [16] presented the free vibration analysis of simply supported functionally graded material (FGM) shells. In this work spherical and cylindrical shell geometries were used with two different materials configuration. First one was one layered FGM structure and second was sandwich structure. The numerical solutions obtained by 2D FE method and advanced generalized 2D Differential Quadrature (GDQ) method. In this investigation, the generalized differential quadrature (GDQ) method compared with exact 3D analysis.

The nonlinear free vibration behaviour of FG-spherical shell panel under nonlinear temperature field was explained by R. Kar et al. [17]. The functionally graded material (FGM) constituents were assumed to be the function of temperature and the thermal conductivity. The effective material properties of the FGM were achieved by using the Voigt micro-mechanical model through power-lawdistribution. The mathematical model of the shell panel was constructed by using Green–Lagrange nonlinear kinematics with the higher order shear deformation theory (HSDT). The governing equations of the functionally graded shell panel under thermal environment were obtained with the help of Hamilton's principle.

R. Ansari et al. [18] presented the modal characteristics of functionally graded carbon nano tube reinforced composite spherical shells resting on elastic foundation using the variational differential quadrature method. For material properties and modelling of shell, rule of mixture and first order shear deformation theory were used respectively. The effects of different parameters such as elastic foundation coefficients, boundary conditions, CNT volume fraction, thickness-to-radius ratio and type of distribution of CNT on the vibrations of FG-CNTRC spherical shells were discussed. The essential boundary conditions were considered at the edges of the spherical shell such as clamped, simply supported etc.

Using Haar Wavelet Differential Quadrature (HWDQ) method, the free vibration analysis of functionally graded (FG) spherical and parabolic shells of revolution with arbitrary boundary conditions was presented by Xie et al. [19]. The first-order shear deformation theory was used. MATLAB program was used to obtain frequencies and corresponding mode shapes.

Tiangui et al. [20] presented the free vibration of laminated FG-spherical shells with general boundary conditions. This analysis was based on the 3D-shell theory of elasticity. The solution was obtained using energy based Rayleigh–Ritz method. It was assumed that the material properties of the laminated FG spherical shells

were varied continuously through the thickness direction according to power law distribution. The effects of boundary conditions (F-F, C-F, and F-C etc.), geometric parameters and material distributions on the natural frequencies of the spherical shells were discussed. Numerical results were described for several laminated FG spherical shells with various boundary conditions and power-law exponents. ANSYS software was used in their analysis.

A unified accurate solution procedure for free vibration analysis of arbitrary FG spherical shell segments with general end restraints was presented by Zhu Su[21]. The material properties of FG spherical shells were assumed to be varied in the thickness direction in accordance with four-parameter power-law distributions. The first-order shear deformation theory was used. The Ritz method was adopted as solution technique. ANSYS software was also used for the analysis.

Tung et al. [22] presented an analytical approach to study the nonlinear stability of clampedfunctionally graded material (FGM) shallow spherical (SS) shells and circular plates resting on elastic foundations, subjected to uniform external pressure and exposed to thermal environments conditions. Material properties were assumed to be temperature dependent, and graded in the thickness direction according to power law distribution in terms of the volume fractions. The effects of material, geometry and foundation parameters, imperfection and temperature dependence of material properties on the nonlinear response of FGM SS shells and circular plates were analysed.

Free vibration behaviour of Levy-type FG spherical shell panel using a new exact closed-form solution was presented by Fadee et al. [23]. Donnell and Sanders theories were used to obtain the exact solution. The shell was opposite edges simply supported (i.e. Levy – Type). The material properties were changed continuously through the thickness of the shell according to a power law distribution. The accuracy and validity of the solution were obtained with the results obtained using finite element analysis.

FE modelling and modal behaviour of functionally graded shell structures under different loading such as thermal and mechanical was presented by Rao et al. [24]. Free vibration behaviour of FG-spherical shell component was also discussed.

Rastgoftar et al. [25] investigated a boundary control of temperature distribution in a spherical shell with spatially varying parameters. Lyapunovs theorem was used to obtain a boundary heat flux which required to obtain a desired steady-state distribution of the temperature. It was assumed that material properties i.e.thermal conductivity, density, and specific heat capacity were varied in radial, polar, and azimuthal directions of the spherical shell.

Huy et al. [26] presented the analytical approach to analyse the non-linear axisymmetric response of functionally graded shallow spherical shells subjected to uniform external pressure. Material properties were assumed to temperature independent and graded in the thickness direction according to a simple power law distribution.

Bich et al. [27] dealt with the non-linear vibration of FG shallow spherical shells. The properties of shell materials were graded in the thickness direction according to the power law distribution (P-FGM). Galerkin method and Runge Kutta approach were used for dynamical analysis of FG spherical shell.

Lee [28] presented the free vibration behaviours of spherical caps for axisymmetric and asymmetric structure. For this analysis chebyshev polynomials and Fourier series were used. Numerical solutions were discussed for different boundary condition such as clamped, hinged and free.

Chiroiu and Munteanu [29] presented the free vibrations behaviourof a piezoceramic hollow sphere with radial polarization.The conical method and a genetic algorithm were used to solve the equations of a radially nonhomogeneous spherically isotropic piezoelectric medium. .

The axisymmetric free flexural vibration and thermal stability analysis of FG spherical caps was investigated by Prakash et al. [30]. They employed three-nodded axisymmetric curved shell element which was based on field consistency approach. For this analysis first-order shear deformation theory was used. Material properties were varied gradually in the thickness direction according to the power-law distribution (P-FGM). Homogenization method was used to evaluate the effective material properties. The effects of shell geometries, power law index of FGMs and base radius-thickness ratio on the vibrations and buckling characteristics of FGspherical shells were discussed.

3D analysis for the free vibrations of a multi-layered spherically isotropichollow sphere using a state-space method was presented by Chen et al. [31]. Taylor's expansion theorem was used to obtain solutions of two state equations and relationships between the state variables at the upper and lower surfaces of each lamina.

Using 3D method, the modal characteristics of a spherically isotropic hollow sphere made of a functionally graded material and filled with a compressible fluid medium was done by Chen et al. [32]. Herein, the material properties were assumed to be varied in radial direction. The effect of material gradient on the natural frequencies were also examined.

4. Conclusion

This paper describes the detailed review on vibration behaviour of FG spherical shell.Effects of boundary condition, material distribution and geometric parameters on free vibration characteristics of FG spherical shell are discussed.

REFERENCES

[1] Yamanouchi M, Koizumi M, Hirai T, Shiota I. FGM-90. InProceedings of the First International Symposium on Functionally Gradient Materials, FGM Forum, Tokyo, Japan 1990.

[2]Koizumi M. The concept of FGM. Ceramic Trans 1993;34:3–10.

[3] Swaminathan K, Sangeetha DM. Thermal analysis of FGM plates–A critical review of various modelling techniques and solution methods. Composite Structures. 2017 Jan 15;160:43-60.

[4] Ganapathi M. Dynamic stability characteristics of functionally graded materials shallow spherical shells. Composite structures. 2007 Jul 1;79(3):338-43.

[5] Qu Y, Meng G. Three-dimensional elasticity solution for vibration analysis of functionally graded hollow and solid bodies of revolution. Part I: Theory. European Journal of Mechanics-A/Solids. 2014 Mar 1;44:222-33.

[6] Tornabene F, Viola E. Free vibrations of four-parameter functionally graded parabolic panels and shells of revolution. European Journal of Mechanics-A/Solids. 2009 Sep 1;28(5):991-1013.

[7] Alibeigloo A, Liew KM. Free vibration analysis of sandwich cylindrical panel with functionally graded core using three-dimensional theory of elasticity. Composite Structures. 2014 Jul 1;113:23-30.

[8] Tornabene F, Viola E. Free vibration analysis of functionally graded panels and shells of revolution. Meccanica. 2009 Jun 1;44(3):255-81.

[9] Brischetto S. Three-dimensional exact free vibration analysis of spherical, cylindrical, and flat one-layered panels. Shock and Vibration. 2014.

[10] Biswal DK, Mohanty SC. Free vibration study of multilayer sandwich spherical shell panels with viscoelastic core and isotropic/laminated face layers. Composites Part B: Engineering. 2019 Feb 15;159:72-85.

[11] Barzegar AR, Fadaee M. Thermal vibration analysis of functionally graded shallow spherical caps by introducing a decoupling analytical approach. Applied Mathematical Modelling. 2018 Jun 1;58:473-86.

[12] Badiganti CM, Koona R. Harmonic frequency analysis of skewed functionally graded flat and spherical shallow shells. Results in Physics. 2018 Sep 1;10:987-92.

[13] Li H, Pang F, Li Y, Gao C. Application of first-order shear deformation theory for the vibration analysis of functionally graded doubly-curved shells of revolution. Composite Structures. 2019 Jan 6.

[14] Duc ND, Quang VD, Anh VT. The nonlinear dynamic and vibration of the S-FGM shallow spherical shells resting on an elastic foundations including temperature effects. International Journal of Mechanical Sciences. 2017 Apr 1;123:54-63.

[15] Kar VR, Panda SK. Geometrical nonlinear free vibration analysis of FGM spherical panel under nonlinear thermal loading with TD and TID properties. Journal of Thermal Stresses. 2016 Aug 2;39(8):942-59.

[16] Fantuzzi N, Brischetto S, Tornabene F, Viola E. 2D and 3D shell models for the free vibration investigation of functionally graded cylindrical and spherical panels. Composite Structures. 2016 Oct 15;154:573-90

[17] Kar VR, Panda SK. Nonlinear flexural vibration of shear deformable functionally graded spherical shell panel. Steel and Composite Structures. 2015;18(3):693-709.

[18] Ansari R, Torabi J, Shojaei MF. Vibrational analysis of functionally graded carbon nanotube-reinforced composite spherical shells resting on elastic foundation using the variational differential quadrature method. European Journal of Mechanics-A/Solids. 2016 Nov 1;60:166-82.

[19] Xie X, Zheng H, Jin G. Free vibration of four-parameter functionally graded spherical and parabolic shells of revolution with arbitrary boundary conditions. Composites Part B: Engineering. 2015 Aug 1;77:59-73.

[20] Ye T, Jin G, Su Z. Three-dimensional vibration analysis of laminated functionally graded spherical shells with general boundary conditions. Composite Structures. 2014 Sep1;116:571-88.

[21] Su Zhu, Jin G, Shi S, Ye T. A unified accurate solution for vibration analysis of arbitrary functionally graded spherical shell segments with general end restraints. Composite Structures. 2014 May 1;111:271-84.

[22] Van Tung H. Nonlinear thermomechanical stability of shear deformable FGM shallow spherical shells resting on elastic foundations with temperature dependent properties. Composite Structures. 2014 Aug 1;114:107-16.

[23] Fadaee M, Atashipour SR, Hosseini-Hashemi S. Free vibration analysis of Lévy-type functionally graded spherical shell panel using a new exact closed-form solution. International Journal of Mechanical Sciences. 2013 Dec 1;77:227-38.

[24] Rao DK, Blessington PJ, Tarapada R. Finite Element Modeling and Analysis of Functionally Graded (FG) Composite Shell Structures. Procedia engineering. 2012 Jan 1;38:3192-9.

[25] Rastgoftar H, Eghtesad M, Khayatian A. Boundary control of temperature distribution in a spherical shell with spatially varying parameters. Journal of Heat Transfer. 2012 Jan 1;134(1):011302.

[26] Bich DH, Van Tung H. Non-linear axisymmetric response of functionally graded shallow spherical shells under uniform external pressure including temperature effects. International Journal of Non-Linear Mechanics. 2011 Nov 1;46(9):1195-204.

[27] Bich DH. Non-linear vibration of functionally graded shallow spherical shells. Vietnam Journal of Mechanics. 2010 Dec 22;32(4):199-210.

[28] Lee J. Free vibration analysis of spherical caps by the pseudospectral method. Journal of Mechanical Science and Technology. 2009 Jan 1;23(1):221-8.

[29] Chiroiu V, Munteanu L. On the free vibrations of a piezoceramic hollow sphere. Mechanics Research Communications. 2007 Mar 1;34(2):123-9

[30] Prakash T, Singh MK, Ganapathi M. Vibrations and thermal stability of functionally graded spherical caps. Structural Engineering and Mechanics. 2006; 24(4):447-61

[31] Chen WQ, Ding HJ. Free vibration of multi-layered spherically isotropic hollow spheres. International Journal of Mechanical Sciences. 2001 Dec 1;43(3):667-80.

[32] Chen WQ, Wang X, Ding HJ. Free vibration of a fluid-filled hollow sphere of a functionally graded material with spherical isotropy. The Journal of the Acoustical Society of America. 1999 Nov;106(5):2588-94.