Research Paper Engineering

Review Paper on Dynamic Analysis of Functionally Graded Material

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ABSTRACT

The improved technological development demands the use of highly efficient materials with improved mechanical properties like improved strength, stiffness etc. The requirement of improved properties demands the use of new hybrid materials like functionally graded materials (FGM) for engineering applications. Understanding of FGM is required before having its implementation. The Finite element method provides a useful tool in modeling the dynamic behavior of FGM to determine its natural frequency which would be used for the designing of mechanical component.

Keywords : Functionally Graded Beams; Free Vibration; Natural Frequency; Dynamic Analysis.

INTRODUCTION

Functionally Graded Material (FGM) belongs to a class of advanced material characterized by variation in properties as the dimension varies. An application may require a material that is hard as well as ductile, there is no such material existing in nature. To solve this problem, combination (in molten state) of one metal with other metals or non-metals is used. This combination of materials in the molten state is termed alloying (recently referred to as conventional alloying) that gives a property that is different from the parent materials.

Composite materials will fail under extreme working conditions through a process called delimitation (separation of fibres from the matrix).This can happen for example, in high temperature application where two metals with different coefficient of expansion are used. To solve this problem, researchers in Japan in the mid 1980s, confronted with this challenge in an hypersonic space plane project requiring a thermal barrier (with outside temperature of 2000K and inside temperature of 1000K across less than 10 mm thickness), came up with a novel material called Functionally Graded Material (FGM). FGM occur in nature as bones, teeth etc.

FGM can be considered second-generation composite materials. These materials are essentially two-phase particulate composites, e.g. ceramic and metallic alloy phases, microscopically engineered to have a smooth spatial variation of material properties in order to improve the overall composition performance.

LITERATURE REVIEW

In this section the research papers related with the present work has been discussed. The FGM is an upcoming technology so not much work has been published. Among the papers published the related articles are highlighted in the subsequent section.

M. Karami Khorramabadi [1] studied free vibration of simply supported functionally graded beams with piezoelectric layers subjected to axial compressive loads. The effect of the constituent volume fractions, the influences of applied voltage and axial compressive loads on the vibration frequency was presented. It was shown that the piezoelectric actuators induce tensile piezoelectric force produced by applying negative voltages that significantly affect the free vibration of the functionally graded beam with piezoelectric actuators. The free vibration frequency increases when the applied voltage is negative. The functionally graded beam with a smaller axial compressive load was more efficient in reduced the chance of resonance.

Gholam Reza Koochaki [2] presented the highly accurate numerical calculation of the natural frequencies for functionally graded beams with simply supported boundary conditions. The Timoshenko first order shear deformation beam theory and the higher order shear deformation beam theory of Reddy have been applied to the functionally graded beams analysis. An exact analytical solution was developed for free vibration of simply supported FG beams based on the first order and third order shear deformation theories. The first order and third order shear deformation theories can be used replace by another one for thin beams with high accuracy, but third order shear deformation theory had higher accuracy for thick beams, therefore it was better to use this theory for thick beams.

S.C. Mohanty [3] investigated the free vibration analysis of a Functionally Graded Ordinary (FGO) pretwisted cantilever Timoshenko beam. Finite element shape functions were established from differential equations of static equilibrium. Expressions for element stiffness and mass matrices were obtained from energy considerations. The material properties along the thickness of the beam are assumed to vary according to power law. Increase in pretwist angle increases first mode frequency and decreases the second mode frequency. The effect of pretwist angle and power law index on the first mode frequency was marginal.

Nuttawit Wattanasakulpong and Variddhi Ungbhakorn [4] applied Differential Transformation Method (DTM) for investigate free vibration of functionally graded beams supported by arbitrary boundary conditions, including various types of elastically end constraints. The DTM also provides all natural frequencies and mode shapes without any frequency missing, Fundamental frequencies as well as their higher frequencies and mode shapes were presented. For their study they selected the $Al2O3/Al$ for the study the free vibration of beam. It was also seen that there were considerable change of frequencies as well as mode shapes when the stiffness of spring becomes larger.

Dr. Luay S. Al-Ansari [5] presented the comparison between the three methods and the convergence for the three methods of study was shown. In this work, three models were used to calculate the natural frequency of cantilever stepping beam compound from two parts. These models were Rayleigh model, modified Rayleigh model and Finite elements model (ANSYS model).The Rayleigh model is modified by calculating the stiffness at each point of the beam. The modified Rayleigh model is much closer to the ANSYS model than the Rayleigh model. The natural frequency of stepping beam was increased with increasing of the width of small and large parts of beam. In addition to, the natural frequency of beam was increased with increasing the length of large width until reach to (0.52 m) and decreasing then when the modified Rayleigh model or ANSYS model are used.

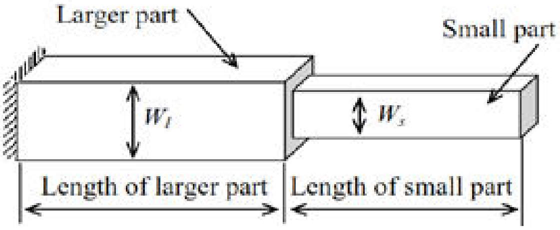

Figure 1: Cantilever Stepping Beam [5]

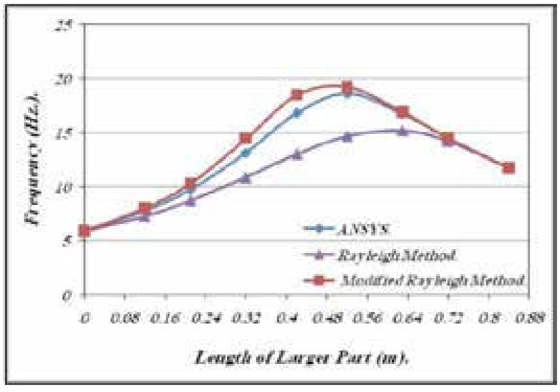

Figure 2: Comparison between the Natural Frequency of the Three Methods with the Length of Larger Part When (WL =0.01m) and (Ws =0.005m) [5].

H. Yaghoobi and A. Feredoon [6] investigated the bending analysis of FG Beams with end condition of simply supported was subjected to a uniformly distributed load. The material properties of the beam vary continuously in the thickness direction according to the power law form. In that article, the position of the natural surface for FG Beam was obtained then influence of neutral surface position on deflection of FG beam under uniformly distribution load was studied.

M. simsek [7] investigated the Static analysis of a functionally graded beam with simply supported end condition subjected to a uniformly distributed load, by using Ritz method within the framework of Timoshenko and the higher order shear deformation beam theories. The material properties of the beam vary continuously in the thickness direction according to the power-law form. Trial functions denoting the transverse, the axial deflections and the rotation of the cross-sections of the beam are expressed in trigonometric functions.

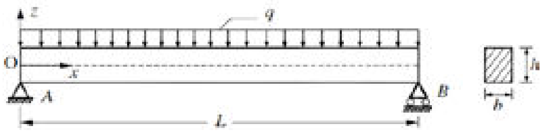

Figure 3: Functionally Graded Beam with simply supported end condition. [7]

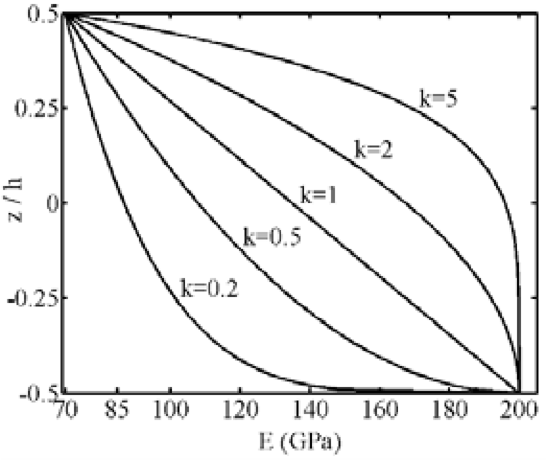

Figure 4: Variation of the modulus of elasticity through the thickness of the FG beam. [7]

Mesut Simsek et al. [8] analyzed the dynamic analysis of an Axially Functionally Graded (AFG) beam with simply-supported edges by using Euler-Bernoulli beam theory. Elasticity modulus and mass density of the beam vary continuously in the axial direction of the beam according to a power-law form. The equation of motion was derived by using Lagrange's equations. They were investigated the influences of material distribution, velocity of the moving load and excitation frequency on the dynamic response of the beam.

M. Rafiee et al. [9] presented to study the nonlinear forced vibration of a beam made of symmetric functionally graded materials based on Euler Bernoulli beam theory and von Karman Geometric nonlinearity. They were discussed that the Effects of material property distribution on the nonlinear dynamic behaviour of FG Beams. The forced vibrations of the system were studied for the first time. The primary resonances of the system by using the MTS method were studied and the frequency response equation of the system was presented and the effects of different parameters on the response of the system were investigated.

Shuang Li et al. [10] analyzed structures by using beam elements was developed with adaptive displacement interpolation functions. Their approach has been presented to solve structural static, vibration, and dynamic problems by beam element. The main feature of the approach was the use of adaptive element displacement interpolation functions, which makes the approach quite suitable to solve the responses of varied cross-section beam and functionally graded beam, such as beams with variable cross-section, variable material properties, many different steps in cross section and/or material properties, and their coupled problems. Finally they conclude that the accuracy and convergence of this approach has been compared satisfactorily with the existing methods and the experimental results with a number of simple static, Eigen value, and dynamic examples. The advantage of their approach was that it was more accurate than conventional finite beam elements in most cases.

S.A. Sina et al. [11] assumed that the beam properties are varying through the thickness following a simple power law distribution in terms of volume fraction of material constituents. It is assumed that the lateral normal stress of the beam is zero and the governing equations of motion are derived using Hamilton's principle. Also, the effects of boundary conditions, volume fraction and shear deformation on natural frequencies and mode shapes are investigated. They concluded that the new beam theories, which have been developed for laminated composite beams, is used for free vibration analysis of shear deformable FG beams. The results show that the new theory is a little different in natural frequency from the traditional first-order shear deformation beam theory and the mode shapes of the two methods are coincidental.

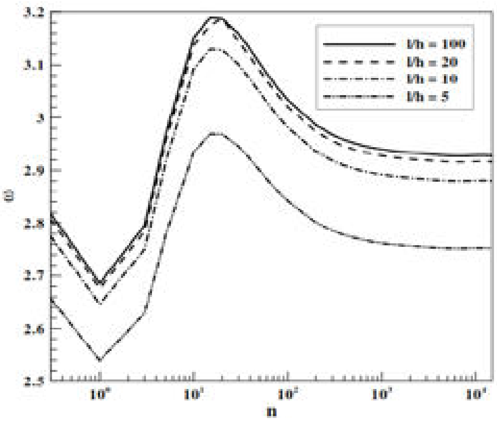

Figure 5: Non-dimensional fundamental frequency of simply supported FG beam for different length-to-height ratios. [11]

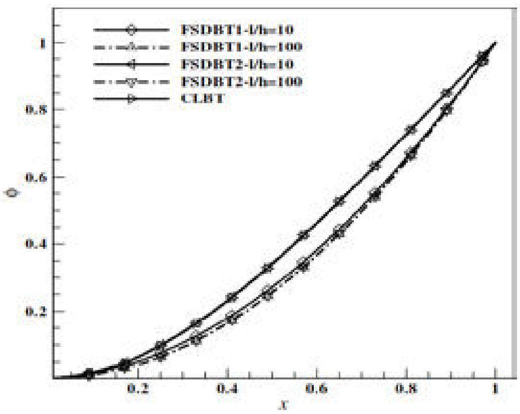

Figure 6: First mode shape of the cantilever FG beam with n = 3. [11]

Carlos A. Almeida et al. [12] analysed the geometric nonlinear formulation of functionally graded beam cross sections by means of a Total Lagrangian formulation. Two Examples were taken that illustrate the main features formulation, in which the behavior of beams of graded cross-sections was compared with homogeneous material beams. The effect of material gradation was incorporated in the formulation considering the beam element effective cross section rigidities associated to axial, shear and fractural deformation kinematics, all obtained in closed form integration of the actual property variation through the thickness. They noticed that in the large displacement analysis the beam of graded material presented a substantial difference in stress distributions as compared to the homogeneous one having the same equivalent cross-section rigidity.

Fernando Cesar Meira Menandro et al. [13] attempted to design and build material specimens whose behavior, under mechanical loading, was similar to that of functionally graded materials, to perform dynamic vibration tests on the produced specimens, and to numerically simulate the vibration tests in order to validate a proposed numerical model for functionally graded material characterization. Finally their results were taken as a validation of the numerical model for dynamic analysis of functionally graded materials. The frequency analysis has shown convergence of the proposed method with the increase in the number of simulation steps.

Mohanty S.C et al. [14] analysed of a Functionally Graded Ordinary (FGO) beam and Functionally Graded Sandwich (FGSW) beam on Winkler's elastic foundation using finite element method. The natural frequency as well as the critical buckling load of FGO beam was founded to be increased with foundation modulus. The result was obtained for both type of property distribution and also for both steel-rich bottom and Al-rich bottom beam. If the properties were assumed to follow power law, the beam with steel-rich bottom becomes stronger. The frequencies of the FGSW beam increase when the Winkler's modulus was increased.

Tahar Hassaine Daouadji et al. [15] presented Theoretical formulation, Naive's solutions of rectangular plates based on a new higher order shear deformation model for the static and dynamic analysis of Functionally Graded Plates (FGPs). The mechanical properties of the plate were assumed to vary continuously in the thickness direction by a simple power-law distribution in terms of the volume fractions of the constituents. They concluded that the proposed theory was accurate and simple to solve the static and dynamic behavior of functionally graded plates. The stresses and displacements were computed for plates with Metal–Ceramic mixture and it was seen that the response was intermediate to that of metal and ceramic. They concluded that thier present model provides better estimates for the deflections and stresses than that of a generalized shear Deformation Theory and very close to the solutions obtained with that of Reddy's higher order model.

Ali Nikkhoo and M. Amankhani [16] studied dynamic behavior of functionally graded beams excited by a random moving load. The beam has been modeled by Euler-Bernoulli beam theory. The equation of motion has been derived and solved by transforming it into state space. The mean square of beams deflection at any arbitrary point has been calculated and expressed as an integral equation. Finally they concluded that an example of a FGM beam traversed by a random moving load has been solved and the effect of the structural damping of the beam on the result has been illustrated through a number of graphs and diagrams.

Shi-Rong Li and Romesh C. Batra [17] derived analytical relations between the critical buckling load of a Functionally Graded Material (FGM) Timoshenko beam and that of the corresponding homogeneous Euler–Bernoulli beam subjected to axial compressive load, for clamped–clamped (C–C), simply supported–simply supported (S–S) and clamped–free (C–F) edges. For the FGM beams Young's modulus, E, and Poisson's ratio, m, are assumed to vary through the thickness. For these end conditions, an algebraic Eigen value problem was derived to determine the critical buckling load of the FGM Timoshenko beam which was similar to that for finding the critical buckling load of a homogeneous Euler–Bernoulli beam with the same end constraints. They predicted from their relations were shown to agree well with the critical buckling loads found by numerically solving the Eigen value problem with the shooting method.

Amal E. Alshorbagy et al. [18] presented the dynamic characteristics of Functionally Graded Beam with material graduation in axially or transversally through the thickness based on the power law. The system of equation of motion is derived by using the principle of virtual work under the assumption of the Euler-Bernoulli beam theory. They conclude that free vibration characteristics and dynamic behavior of a Functionally Graded Beam (FGBs) for different material distributions are analyzed numerically by finite element method. The variation of material distribution along the axial direction means the variation of the beam stiffness along spatial, which effect on the frequencies and mode shape. On the other hand, the beam with stiffness along spatial not changed with the variation of material along the thickness, so the mode shape not varied with this case.

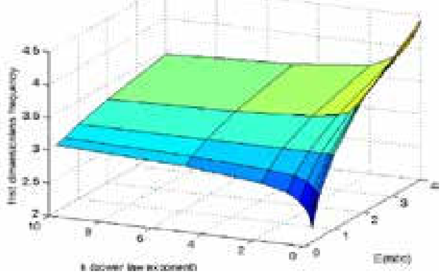

Figure 7: Variation of the first dimensionless frequency with respect to Eratio and k. [18]

Liao-Liang Ke et al. [19] investigated the dynamic stability of micro beams made of Functionally Graded Materials (FGMs) based on the modified couple stress theory and Timoshenko beam theory. The material properties of FGM micro beams are assumed to vary in thickness direction and are estimated through Mori-Tanaka homogenization technique. A simple power law function and Mori-Tanaka technique are employed to model the through the thickness continuous gradual variation of the material properties.

K. Sanjay Anandrao et al. [20] developed the two separate finite element formulations, one based on Euler-Bernoulli beam theory and other based on Timoshenko beam theory. They observed that transverse shear significantly affects the fundamental frequency and mode shape for lower length to thickness ratios of FGM beams. They demonstrated the significance of transverse shear on the frequencies and mode shapes of FGM beams for various boundary conditions and length to thickness ratios. Finally, they concluded that for the real structures with lower length to thickness ratios, transverse shear effects should be included to predict accurate frequencies and mode shapes for homogenous as well as FGM beams.

N. Omidi et al. [21] studied the dynamic stability of functionally graded beams with piezoelectric layers subjected to periodic axial compressive load that is simply supported at both ends lies on a continuous elastic foundation. The Young's modulus of beam is assumed to be graded continuously across the beam thickness. They concluded that the dynamic stability of a functionally graded beam with piezoelectric actuators subjected to periodic axial compressive load that is simply supported at both ends lies on a continuous elastic foundation has been presented. The functionally graded beam with a smaller foundation coefficient is more stable.

CONCLUSIONS

The improved technological development demands the use of highly efficient materials with improved mechanical properties like improved strength, stiffness etc. The requirement of improved properties demands the use of new hybrid materials like Functionally Graded Materials (FGM) for engineering applications. Understanding of FGM is required before having its implementation. The FGM is an upcoming technology so not much work has been published. The newly published papers are considered in this paper. Dynamic Analysis of FGM is recent topic on which the research work is going on, still lots of research work have to find. The research will be further extended for the Frequency Response Function of the FGM beam. The Finite element method provides a useful tool in modeling the dynamic behavior of FGM to determine its natural frequency which would be used for the designing of mechanical component.

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