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Computing of Post-buckling Simulation in Functionally Graded Materials - A Review Paper

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Abstract

A review on the recent development in the non-linear flutter and thermal buckling of an FGM panel under the combined effect of elevated temperature conditions and aerodynamic loading is investigated using a finite element model based on the thin plate theory and von Karman strain-displacement relations to account for moderately large deflection. It is found that the temperature increase has an adverse effect on the FGM panel flutter characteristics through decreasing the critical dynamic pressure. Decreasing the volume fraction enhances flutter characteristics but this is limited by structural integrity aspect. Structural finite element analysis has been employed to determine the FGM panel's adaptive response while under the influence of a uniaxial compressive load in excess of its critical buckling value. With the increase in use of composite materials within aerospace platforms, it is envisaged that the hybrid adaptive FGM panel's configuration will extend the operational performance over conventional materials and structures, particularly when the structure is exposed to an elevated temperature.

Keywords: *functionally graded, FGM, non-linear finite element formulation, thermo-mechanical, post-buckling*

1. Introduction

Functionally graded materials (FGMs) are non-homogeneous composites characterized by a smooth and continuous change of material properties from one surface to the other. This is achieved by gradually varying the volume fraction of the constituent materials. Functionally graded materials are usually composed of two or more materials whose volume fractions are changing smoothly and continuously along desired direction(s). This continuous change in the compositions leads to a smooth change in the mechanical properties, which has many advantages over the laminated composites, where the delamination and cracks are most likely to initiate at the interfaces due to the abrupt variationin the mechanical properties between laminas. One of the advantages of using these materials is that they can survive environments with high temperature gradients, while maintaining structural integrity. Accordingly, one of the most important applications of functionally graded materials is in the skin panels of supersonic and hypersonic flight vehicles, which have to survive the harsh thermal and mechanical loadings [1-3].

Functionally graded materials (FGMs) are a new generation of composite materials wherein the material properties vary continuously to yield a predetermined composition profile. These materials have been introduced to benefit from the ideal performance of its constituents, e.g. high heat/corrosion resistance of ceramics on one side, and large mechanical strength and toughness of metals on the other side. FGMs have no interfaces and are hence advantageous over conventional laminated composites. FGMs also permit tailoring of material composition to optimize a desired characteristic such as minimize the maximum deflection for a given load and boundary conditions, or maximize the first frequency of free vibration, or minimize the maximum principal tensile stress. As a result, FGMs have gained potential applications in a wide variety of engineering components or systems, which include armour plating, heat engine components and human implants. The variation of material properties in an FGM is usually achieved by continuously varying volume fractions of the constituent materials. With the increased use of

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these materials, it is important to understand the nonlinear behaviour of functionally graded plates under pressure load. Approximate solutions of complex engineering problems are usually obtained by a numerical method. In recent years, a new type of numerical method called mesh-free method (MFM) is being developed in the area of computational mechanics [4-8].

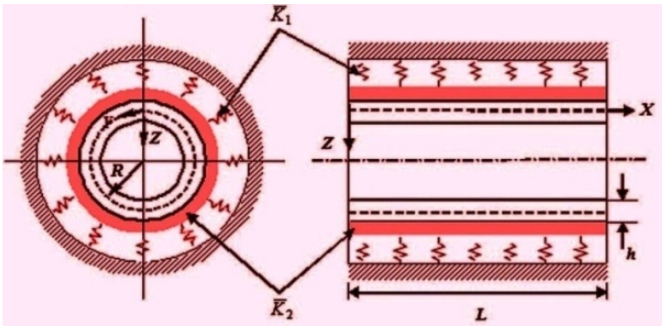

Figure 1. Geometry and coordinate system of a cylindrical shell surrounded by an elastic medium [27]

2. Material and Methods

Conventional aerospace composites have been composed of high-stiffness carbon fibres to maintaindimensional stability under high-performance application. The stiffness property is often associated with a particular susceptibility to impact damage and a corresponding reduction of mechanical properties. However, such structures are expected to only encounter few unintentional impacts. Composite structures for military ground vehicles, on the other hand, are designed to absorb multiple high-energy impacts but have much less dimensional restrictions. Since softer materials tend to dissipate more energy during impact, a low modulus/high strength alternative would be well suited for backing panel composites Effective Material Properties of Functionally Graded Materials Consider an FGM layer that is made from a mixture of ceramics and metals. Assume that the composition is varied from the outer to the inner surface, i.e., the outer surface (Z=-h/2) of the panel is metal rich, whereas the inner surface (Z=+h/2) is ceramic rich, where Z is in the direction of the downward normal to the middle surface, and h is the thickness of the layer. Thermal post-bucklingbehaviour of FGM cylindrical shells surrounded by an elastic medium was presented because of two micromechanical models and multi-scale approach. The surrounding elastic medium is modelled as a Pasternak foundation. The material properties of FGMs are assumed temperature dependent. Numerical results demonstrate that both buckling temperature and thermal post-buckling strength of the FGM shells are increased with increase in foundation stiffness, Figure 2 shows the details [9-15].

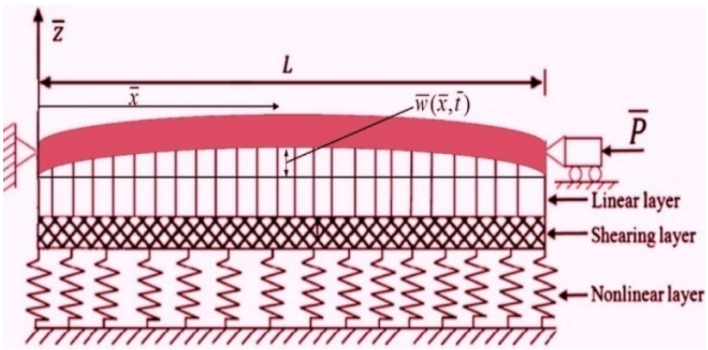

Figure 2. Schematic of the imperfect FG beam with nonlinear foundation [9]

2.1. Voigt and Mori-Tanaka Model

Thermal Post-buckling of Shear Deformable FGM Cylindrical Shells Surrounded by an Elastic Medium presents a study on the thermal post-buckling response of a shear deformable functionally graded cylindrical shell of finite length embedded in a large outer elastic medium by Shen in 2013. The surrounding elastic medium is modelled as a Pasternak foundation. Two kinds of micromechanics models, namely the Voigt model and Mori-Tanaka model, are considered. The governing equations are based on a higher-order shear deformation shell theory that includes shell-foundation interaction. The thermal effects are also included and the material properties of functionally graded materials (FGMs) are assumed temperature dependent. The governing equations are solved by a singular perturbation technique. The numerical results show that in some cases the FGM cylindrical shell with intermediate volume fraction index does not have intermediate buckling temperature and thermal post-buckling strength. The results reveal that Voigt model and Mori-Tanaka model have the same accuracy for predicting the thermal buckling and post-bucklingbehaviour of FGM shells. The results confirm that for the case of heat conduction, the post-buckling equilibrium path for geometrically perfect FGM cylindrical shells with simply supported boundary conditions is no longer of the bifurcation type. Thermal Post buckling of Functionally Graded Materials Shells Consider a circular cylindrical shell, which is made of the combined ceramic and metallic materials with continuously varying mix ratios comprising ceramic and metal. The length, mean radius, and total thickness of the shell are L, R, and h, respectively. The shell is referred to a coordinate system (X, Y, Z) in which X and Y are in the axial and Figure 1 shows the circumferential directions of the shell and Z is in the direction of the inward normal to the middle surface.

2.2. Euler-Bernouli Beam Theory and Von-Karman Geometric Nonlinearity

Yaghoobi and Torabi in 2013 investigated that beams made of functionally graded materials (FGMs) resting on nonlinear elastic foundation subjected to axial force are studied. The material properties of FGMs 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 assumptions of a small strain and moderate deformation are used. Based on Euler–Bernoulli beam theory and von-Karman geometric nonlinearity, the integral partial differential equation of motion is derived. Then this partial differential equation (PDE) problem, which has quadratic and cubic nonlinearities, is simplified into an ordinary differential equation (ODE) problem by using the Galerkin method. Finally, the governing equation is solved analytically using the variational iteration method (VIM) [16-27].

3. Results and Discussion

It is shown that, utilising the considerable control authority generated, even for a small actuator volume fraction, the out-of-plane displacement of the post-buckled FGM panel's can be significantly reduced. Such displacement alleviation allows for load redistribution away from the FGM panel's unloaded edges.

The results show that in some cases the FGM cylindrical shell with intermediate volume fraction index does not necessarily have intermediate buckling temperature and thermal post-buckling strength. The results reveal that the difference of the buckling temperatures between Mori-Tanaka Model and Voigt Model solutions is very small, and the difference of the thermal post-buckling strength between Voigt Model solutions may be negligible. The results confirm that for the case of heat conduction, the post-buckling equilibrium path for geometrically perfect FGM cylindrical shells with simply supported boundary conditions is no longer of the bifurcation type [28].

4. Conclusion

The governing non-linear equations are obtained using the principal of virtual work adopting an approach based on the thermal strain being a cumulative physical quantity to account for temperature dependent material properties. This system of non-linear equations is solved by Newton–Raphson numerical technique.

It is found that the temperature rise has an opposite outcome on the FGM panel flutter features through diminishing the critical dynamic pressure. Reducing the volume fraction improves flutter aspects but this is controlled by systemic integrity characteristic. Structural finite-element analysis has been carried out to determine the FGM panel's adaptive reaction while under the impact of a uniaxial compressive load in excess of its critical buckling value to comply the specifications.

The presence of aerodynamic flow results in postponing the buckling temperature and in suppressing the post-buckling deflection while the temperature increase gives way for higher limit cycle amplitude.

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