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Review on Thermal Buckling of Symmetric Cross-Ply Laminated Plate

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ABSTRACT

In the present work thermal buckling of symmetric cross-ply composite laminates is investigated. In this study, a square plate element is employed for the thermal buckling analysis of composite laminated plates. The maximum buckling temperature of symmetric cross-ply laminates under various sides to thickness ratios, aspect ratios, stacking sequence and boundary condition are studied in detail. The maximum buckling temperature analysis of square composite eight and four layered plates under uniform temperature rise is investigated using the classical laminated plate theory & first order shear deformation theory and material properties (Stiffnesses, Poisson's ratio and Coefficient of thermal expansion) are considered to be temperature dependent. The classical laminated plate theory and first order shear deformation theory in conjunction with the Rayleigh-Ritz method is used for the evaluation of the thermal buckling parameters of structures made out of graphite fibers with an epoxy matrix. The post-buckling response of symmetrically cross-ply laminated composite plates subjected to a combination of uniform temperature distribution through the thickness and in-plane compressive edge loading is presented. The maximum buckling temperature is obtained from the solution. The computing is done by using MATLAB.

Keywords : Thermal Buckling of Symmetric Cross-Ply Laminated Plate

I. INTRODUCTION

COMPOSITE MATERIALS

Composite means the composition of two or more different materials (or different phases of the same materials) with the resultant properties being better than that of the component materials. The main part of the composite is known as the matrix. The matrix holds the reinforcing phases [1].

Composite materials have long history of usage. Their beginning is often unknown but all recorded history contains references same forms of composite materials, for example straw was used by Israelites to strengthen mud bricks. Plywood was used by ancient Egyptian when they realized that wood would be rearranged to achieve superior strength and resistance to thermal expansion as well as to swelling owing to the presence of moisture.

The advantages of composites are that they usually exhibit the best qualities of their constituents and often same qualities that neither constituent possesses. The properties that can be improved by forming a composite material include strength, stiffness, corrosion resistance, wear resistance, attractiveness, weight, fatigue life, temperature dependent behavior, thermal insulation, thermal conductivity, acoustical insulation. The word composite signified that two or more materials are combined on a microscopic scale or macroscopic scale to form a useful material. Composites materials i.e. composites, are considered as combination of material or element which differs in composition to form on a macroscopic scale with respect to each other, the individual fibrous constitute elements can be manmade are generally insoluble, retain their identities within the composite & may be continuous and discontinuous.

The advent of new stiff, strong and lightweight composites consisting of high performance fibers offers aerospace engineers a lucrative choice in designing composite structures which have high potential in replacing metallic structures for most of the structural applications. The analysis of composite laminates is a complex task because composites are generally anisotropic and are characterized by bending extension coupling. Structures such as beams, plates, shells, and so on are often subjected to severe thermal environments during launching and re-entry, so their stability study under thermal loads is important for aerospace engineers. Aircraft and space vehicles are examples of applications that are weight-sensitive. As a result, thermal-buckling analysis of composite laminates is very important, especially in thin-walled members such as submarine structures, space structures, automobiles, sport equipment and electronic circuit boards. Since these structural components are usually subjected to uniform and non-uniform temperature distribution due to aerodynamic, nuclear radiation heating and solar radiation heating [2].

1.2 Classification of Composite Materials

(1) Fiber reinforced Composites: Fiber Reinforced Composites are composed of fibers embedded in matrix material. These fibers must be supported to keep individual fibers from bending and buckling.

(2) Laminar composites: Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

(3) Particulate composites: Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category [1].

Reinforcement

Figure 1.3 illustrates three common types of reinforcements used. Reinforcements for metal matrix composite have a manifold demand profile, which is determined by production, processing and the matrix system of the composite material. The following demands are generally applicable:

- Low density
- Mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix)
- Chemical compatibility
- Thermal stability
- High Young's modulus
- High compression and tensile strength
- Good process-ability
- Economic efficiency

These demands can be achieved only by using non-metal inorganic reinforcement components. For metal reinforcement ceramic particles, rather fibers or carbon fibers are often used. Due to the high density and the affinity to reaction with the matrix alloy, the use of metallic fiber usually fails. The constituent, finally used, depends on the selected matrix and on the demand profile of the intended application.

Mechanical behavior of composite materials

Composite materials have much mechanical behavior characteristic that are different from those of more conventional engineering materials. Some characteristics are merely modifications of conventional behavior; others are totally new analytical and experimental procedures.

Homogeneous Body has uniform properties throughout, i.e., the properties are independent of position in the body.

Isotropic Body has material properties that are the same in every direction at a point in the body i.e. the properties are independent of orientation at a point in the body.

Inhomogeneous Body has non uniform properties over the body, i.e., the properties depend on position in the body.

Orthotropic Body has material properties that are different in three mutually perpendicular directions at a point in the body and further has three mutually perpendicular planes of material property symmetry. Thus, the properties depend on orientation at a point in the body.

Anisotropic Body has material properties that are different in all directions at a point. No planes of material property symmetry exist. Again, the properties depend on orientation at a point in the body [3].

Buckling

Buckling models characterized by a sudden failure in a structural member subjected to high compressive stresses. This characteristic appears to be when the actual compressive stresses at the point of failure are less than the ultimate compressive stresses. This mode of failure is known as failure due to elastic instability.

A plate buckles when, the compressive load reach to larger than the designed flat equilibrium state is no longer stable and the plate deflects into a wavy configuration. The load at which the departure from the flat state takes place is called the buckling load. The flat equilibrium state has only in-plane forces and undergoes only extension, compression and shear.

In buckling of plate, the deformation transverse to the plane of the plate has a two dimensional wavy nature which has multiple sine waves in load direction. As the load is increased, the plate is shortened in the load direction. The plate can support increased load over the buckling load at decreased stiffness.

II. CLASSIFICATION OF BUCKLING

Buckling can be categorized into following types:

1. Lateral-torsional buckling

When a simple beam is loaded in flexure, the top side remains in compression and the bottom side remain in tension. If the beam is not supported in the lateral direction (i.e., perpendicular to the plane of bending) and the flexural load increases to a maximum limit, the beam will fail due to lateral buckling of the compression flange. In wide-flange sections, if the compression flange buckles laterally, the cross section will also twist in torsion, resulting in a failure mode known as lateral-torsional buckling.

2. Plastic buckling

Buckling will generally occur slightly before the theoretical buckling strength of a structure due to plasticity of the material. When the compressive load is near buckling, the structure will bend significantly and approach yield. The stress-strain behavior of materials is not strictly linear even below yield and the modulus of elasticity decreases as stress increases with more rapid change near yield. This lower rigidity reduces the buckling strength of the structure and causes premature buckling. This is the opposite effect of the plastic bending in beams, which causes late failure relative to the Euler-Bernoulli beam equation.

3. Dynamic buckling

If the load on the column is applied suddenly and then released, the column can sustain a load much higher than its static (slowly applied) buckling load. This can happen in a long unsupported column (rod) used as a drop hammer. The duration of compression at the impact end is the time required for a stress wave to travel up the rod to the free end and back down as a relief wave. Maximum buckling occurs near the impact end at a wavelength much shorter than the length of the rod.

4. Thermal buckling

Thermal buckling causes due to thermal effects on structure, which are of two types:

1. Due to change of material properties under elevated or lowered temperature as many material properties are temperature dependent.

2. Due to thermal stresses induced by temperature gradients in an unrestrained body as well as by uniform or non-uniform temperature changes in restrained bodies.

Thermal stress with or without mechanical stresses can be high enough to cause failure. Compressive thermal stresses are high enough to cause thermal buckling of structural members if restrained to thermal expansion exists.

III. LITERATURE REVIEW

Alessandro Mannini (1997) [4] had given the thermal buckling behaviour of a cross-ply laminated beam using first order shear deformation theory. He considered the both symmetric & non symmetric lay-up sequences and different boundary conditions. He concluded that buckling parameter reduces when the slenderness ratio decreases and increasing the transverse shear modules would provide a higher thermal buckling.

Kapania and Raciti (1989) [5] had presented the analysis of laminated beams and plates such as shear effects, buckling, post buckling, de-lamination buckling and growth, linear vibration of symmetrical plates, analysis of unsymmetrically laminated plates, linear and non-linear vibration of plates and wave propagation and transient response analysis.

Chen and Chen (1987) [6] had investigated the thermal buckling of laminated cylindrical shells. They solved the governing differential equations with the help of Galerkin method to compute the maximum temperature under clamped and simply supported end conditions.

MetinAydogdu (2007) [7] had presented the thermal buckling analysis of cross-ply laminated composite beams subjected to different boundary conditions on the basis of a unified three-degree-of-freedom shear deformable beam theory. He found that by the use of the shape functions incorporated into that theory it is possible to full the material and geometrical constraints, such as the requirement of continuity conditions among the layers and/or stress-free conditions of top and bottom surfaces of the beam.

Tauchert (1987) [8] had investigated the buckling behaviour of moderately thick antisymmetric angle ply laminates that are simply supported and subjected to a uniform temperature rise using first order shear deformation plate theory.

Singha et al. (2001) [9]had investigated thermal buckling and post buckling analyses of graphite/epoxy rectangular laminated plates with temperature dependent material properties using the finite element method. Their analysis revealed that the entire equilibrium path of symmetrically laminated plates under uniform temperature rise consists of three parts: the pre-buckling path, symmetric post-buckling path (after buckling) and the post-buckling path (after secondary instability).They concluded that after the secondary instability, the position of maximum displacement moves from center towards one corner of the plate.

Meyers and Hyer (1991) [10] had investigated thermal buckling and post buckling responses of symmetrically laminated composite plates using the Rayleigh-Ritz method. They observed that for some geometrical parameters, the buckling mode associated with higher Eigen temperatures influence the post buckling response, which was termed as model interaction. The displacement contour becomes more oval shaped and the regions of maximum displacement move from the center towards the edges.

IV. DISCUSSION

For Four Layer Symmetric Cross Ply Laminated Plate

The maximum buckling temperature obtained from the CLPT for symmetric cross ply laminates (0°/90°/90°/0°) for graphite epoxy material has been compared with the maximum buckling temperature obtained from FSDT. The maximum buckling temperature delta T for the plate AR<1 at side to thickness ratio 100 with uniform thermal loading is 78.76 °C and that of for the plate AR=1 at same side to thickness ratio with same loading is same and that is also same for the plate AR>1 at same condition for CLPT.The reason of this similarity is that the transverse displacement is independent of the transverse (or thickness) coordinate and the transverse normal strainε_n, which is equal to zero. But delta T is varied with aspect ratio according to FSDT.This is because FSDT requires shear correction factors which depend on the lamination, geometric parameters, loading and boundary conditions. The maximum buckling temperature delta T for the plate AR<1 at side to thickness ratio 100 with uniform thermal loading is 84.66 °C and that of for the plate AR=1 at same side to thickness ratio with same loading is 100.9 °C and 350.35°C for the plate AR>1 at same condition for FSDT as given in Table 4.2 & 4.4. These obtained results have been compared with the results obtained byJavaheri and Eslami[29]. The maximum buckling temperature delta T for the plate AR=1 obtained with their analysis was 24.1982 °C for side to thickness ratio 100.The reason of this difference is that they had analyzed the results by using ceramic composite plate. More over these obtained results also have been compared with the previous research of Ganapathi and Touratier [16].In their study they found that the maximum buckling temperature delta T was 62.09 °C for the plate AR=1 at side to thickness ratio 100 with uniform thermal loading and 114.16 °C for the plate AR>1 at side to thickness ratio 100 with uniform thermal loading. The reason of this difference is that they had analyzed the results by usinganisotropic composite plates. But according to M.Shariyat [13] the maximum buckling temperature was 58.7 °C for the plate AR=1 at side to thickness ratio 100.The reason of this difference is that they had analyzed the results by usinganisotropic composite plates with layerwise theory.

V. CONCLUSION

In the present work maximum buckling temperature for square, simply supported, symmetric cross-ply laminated plates are obtained. The CLPT & FSDT theories are implemented for obtaining the maximum buckling temperature. Then, the maximum buckling temperature analysis of symmetric cross-ply laminates is presented according to side to thickness ratio, aspect ratio and stacking sequence. The present study leads to the following conclusions:-

1. The maximum buckling temperature for the symmetric cross-ply laminates is increased by decreasing the side to thickness ratio.

2 The maximum buckling temperature for the symmetric cross-ply laminates remain same for CLPT, while that is increased for FSDT by increasing the aspect ratio.

3. The maximum buckling temperature for the symmetric cross-ply laminates is decreased for CLPT and increased for FSDT by increasing the stacking sequence.

4. For thesymmetric cross-ply laminates, the maximum buckling temperature is obtained with fibers orientated at **(0°/90°/90°/0°/0°/90°/90°/0°)** at aspect ratio greater than unity according to FSDT.

5. The maximum buckling temperature for thesymmetric cross-ply laminates is mainly dependent on the E1/E2 ratio, ${}^{\alpha_2}/_{\alpha_1}$ ratio, fibers orientation and aspect ratio of the plate.

6. The E1/E2 and ${}^{\alpha_2}/_{\alpha_1}$ratios of the symmetric cross-ply laminates produce higher thermal buckling along the fiber direction and higher in-plane compressive

force in a direction perpendicular to the fiber direction. Therefore, the higher buckling temperature is obtained.

VI. FUTURE SCOPE OF THE PRESENT WORK

In the present study the maximum buckling temperature of symmetric cross-ply laminates was determined. The effect of side to thickness ratio, aspect ratio and stacking sequence on maximum buckling temperature was studied. The future scope of the present investigation can be expressed as follows:

a) The maximum buckling temperature of symmetric cross-ply laminates depends on the linear elastic behavior of the fiber reinforced composite in the present study. For better understanding, non-linear behavior is required.

b) The symmetric cross-ply laminates is of transverse orthotropic type and unidirectionally orientated. Hence, further research is required for higher order materials.

c) The maximum buckling temperature of antisymmetric cross-ply, antisymmetric angle-ply and symmetric angle-ply laminated composite plates can be determined by classical and higher order theories.

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