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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. The classical laminated plate theory & 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 critical buckling temperature is obtained from the solution. The computing is done by using MATLAB. The present approach is evaluated by comparing the results with both theories. Finally, a parametric study for several types of laminates is given for different boundary conditions and changing the values of various parameters such as lay-up sequences, aspect ratios and side to thickness ratio .***

Keywords: Rayleigh-Ritz method, MATLAB, buckling, matrix, FEM, ESL.

1. Introduction

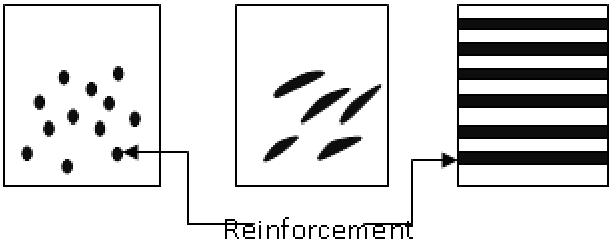
The advent of new stiff, strong and lightweight composites consisting of high performance fibers offers aerospace engineers a lucrative choice in designing composite structures which have high potential in replacing metallic structures for most of the structural applications. The analysis of composite 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, since structural components of these high-speed machines are usually subjected to non-uniform temperature distribution due to aerodynamic and solar radiation heating.

2. 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. 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.

A. Classification of Composite Materials

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



B. Reinforcement

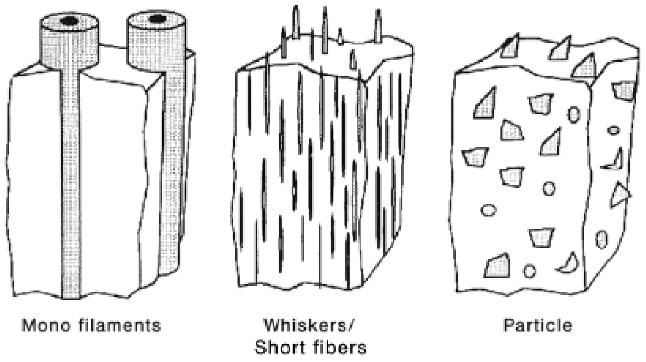
Reinforcements for metal matrix composite have a manifold demand profile, which is determined by production, processing and the matrix system of the composite material.

- 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

C. Metal Matrix Composites

By the mid-eighties, it was established that metallic materials when reinforced with brittle fibers, whiskers or particulates, offer the potential for significant improvements in strength, stiffness, elevated temperature strength retention, wear resistance, creep resistance etc.



2.1 Title and authors

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3. Literature Review

Alessandro Mannini (1997)[1] 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)[2] 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)[3] had investigated the thermal buckling of laminated cylindrical shells. They solved the governing differential equations with the help of Galerkin method to compute the critical temperature under clamped and simply supported end conditions.

Metin Aydogdu (2007)[4] 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.

M. Shariyat (2007)[10] had investigated thermal buckling analysis of rectangular composite multilayered plates under uniform temperature rise using a layerwise plate theory. Von Karman strain–displacement equations were employed to account for large deflections occurrence. It is already proven that the layerwise theory results are compatible with the three-dimensional theory of elasticity results. The final governing equations were not simplified or linearized. Material properties were assumed to vary with temperature. Hermitian finite element formulation was used to ensure continuity for the lateral deflections. No semi-analytic solution was employed to reduce the problem to an eigenvalue one. Layer wise formulations are usually displacement-based. Therefore, force or moment boundary conditions (e.g. simply supported boundary condition), were approximately satisfied. A FEM algorithm was presented to exactly incorporate the boundary conditions. A proposed numerical scheme and a modified Budiansky instability criterion presented by the author were used to determine the buckling He concluded that the accuracy of the present results was increased by substituting each layer by many virtual sub-layers.

3.1 Equivalent Single-Layer Laminate Theories:

The equivalent single-layer laminate theories are those in which a heterogeneous laminated plate is treated as a statically equivalent single layer having a complex constitutive behaviour, reducing the 3-D continuum problem to a 2-D problem. The ESL theories are developed by assuming the form of the displacement field or stress field as a linear combination of unknown functions and the thickness coordinate:

$$\varphi_i(x,y,z,t) = \sum_{j=0}^{N} (z)^j \varphi_i^j(x, y,z,t)$$

3.2 Shear Deformation theory (SDT):

The next theory in the hierarchy of ESL laminates theories is the first order shear deformation theory (or SDT), which is also based on the displacement field:

$$u(x,y,z,t) = u\_0\,(x,y,t) + z\phi x\,(x,y,t)$$
$$v(x,y,z,t) = v_0(x,y,t) + z\phi_y(x,y,t)$$
$$w(x,y,z,t) = w_0(x,y,t)$$

3.3 Stiffness's, Compliances and Engineering Constants For Orthotropic Materials

Engineering constants are generalized Young's moduli, Poisson's ratios and shear moduli as well as some other behavioral constants. These constants are measured in simple tests such as uniaxial tension or pure shear tests. Most simple material characterization tests are performed with a known load or stress. The resulting displacement or strain is then measured. The engineering constants are generally the slope of a stress-strain curve.

3.4 Stress-strain Relations for a Lamina of Arbitrary Orientation

The stresses and strains were defined in the principal material coordinates for an orthotropic material. However, the principal directions of orthotropy often do not coincide with coordinate directions that are geometrically natural to the solution of the problem. For example laminated plates with different lamina at different orientations. Thus, a relation is needed between the stresses and strains in the principal material coordinates and those in the body coordinates. Then, a method of transforming stress-strain relations from one coordinate system to another is also needed.

4. Results

Numerical results are obtained for four layered symmetric cross ply (0°/90°/90°/0°) and eight-layered symmetric cross ply (0°/90°/90°/0°/0°/90°/90°/0°) laminated plates.

- Material property
- Maximum buckling temperature in simply supported (SS) symmetric cross-ply with orientation (0°/90°/90°/0°) laminates subjected to thermal load by using LPT.
- Maximum buckling temperature in simply supported (SS) symmetric cross-ply with orientation (0°/90°/90°/0°/0°/90°/90°/0°) laminates subjected to thermal load by using LPT.
- Maximum buckling temperature in simply supported (SS) symmetric cross-ply with orientation (0°/90°/90°/0°) laminates subjected to thermal load by using SDT.
- Maximum buckling temperature in simply supported (SS) symmetric cross-ply with orientation (0°/90°/90°/0°/0°/90°/90°/0°) laminates subjected to thermal load by using SDT.

5. Discussion

5.1 For Four Layers Symmetric Cross Ply Laminated Plate:

The critical buckling temperature obtained from the LPT for symmetric cross ply laminates (0°/90°/90°/0°) for graphite epoxy material has been compared with that of obtained from FSDT. The critical buckling temperature delta T of the plate AR<1 at side to thickness ratio 100 with uniaxial thermal loading is 78.76˚C and that of 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 LPT. But delta T is varied with aspect ratio according to FSDT. The critical buckling temperature delta T of the plate AR<1 at side to thickness ratio 100 with uniaxial thermal loading is 84.66˚C and that of the plate AR=1 at same side to thickness ratio with same loading is 100.9˚C and that is 350.35˚C for the plate AR>1 at same condition for SDT.

5.2 For Eight Layers Symmetric Cross Ply Laminated Plate:

The critical buckling temperature for symmetric cross ply laminates (0°/90°/90°/0°/0°/90°/90°/0°) for graphite epoxy material by LPT for the plate AR<1 at side to thickness ratio 100 with uniaxial thermal loading is 54.94˚C and that of 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. But delta T is also varied with aspect ratio according to FSDT. The critical buckling temperature delta T of the plate AR<1 at side to thickness ratio 100 with uniaxial thermal loading is 65.71˚C and that of the plate AR=1 at same side to thickness ratio with same loading is 100.9˚C and that is 703.38˚C for the plate AR>1 at same condition for SDT. Moreover, the results obtained by CLPT are not in good agreement because this theory neglecting both transverse shear and transverse normal. In case of FSDT, the shear correction factor is necessary, so it gives better result over FSDT.

6. Conclusion

This study considers the buckling temperature of laminated rectangular plates with simply supported boundary conditions. The laminated composite plates have varying side to thickness ratio, aspect ratio, cross-ply orientation and stacking sequence. From the present analytical study, the following conclusions can be made:

1) It was noted that different side to thickness ratio affects the critical buckling temperature. The critical buckling temperature increases as the side to thickness ratio decreases. The rate of increasing of buckling temperature is uniform with the rate of decreasing of the side to thickness ratio .
2) As the aspect ratio increases, the critical buckling temperature of the plate increases. When the aspect ratio changed from 0.5 to 1.5, the variation in buckling temperature remain same in CLPT, while increases in FSDT.
3) It was seen that the different stacking sequence affected the critical buckling temperature. When the stacking sequence increases, the critical buckling temperature increases in CLPT While that decreases in FSDT for AR≤1 and increases for AR>1. The plate with (0°/90°/90°/0°) layup has the highest buckling temperature and the plate with (0°/90°/90°/0°/0°/90°/90°/0°) layup has the lowest buckling temperature.

7. Future Scope of the Work

In the present study the critical buckling temperature of the laminated plate was determined. The effect of side to thickness ratio, aspect ratio and stacking sequence on critical buckling temperature was studied. The future scope of the present investigation can be expressed as follows:

a) The critical buckling temperature of delaminated industry driven woven composite plates with and without cutouts.
b) The critical buckling temperature of laminated composite plates can be determined by numerical approach for different boundary conditions & loading condition.
c) The critical buckling temperature of dynamic laminated composite plate can be determined with different types of loading and stacking sequence.
d) The critical buckling temperature of laminated composite plates can be determined by higher order theories.

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