STABILITY OF LAMINATED COMPOSITE PLATES

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The present study deals with the parametric effects of geometry and lamination parameters on buckling analysis of industry driven woven fiber glass/epoxy composite plates subjected to uniform temperature and moisture experimentally and comparing them with the predictions using finite element method. Rectangular woven glass fiber: epoxy composite specimens were fabricated using weight fraction of 55:45 by hand layup method. The specimens were hygrothermally conditioned in a humidity cabinet where the conditions were maintained at a temperature of 323K and relative humidity (RH) ranging from 0-1% for moisture concentrations. All specimens were loaded up to buckling. The load, which is the initial part of the curve deviated linearity, is taken as the critical buckling load. The buckling results shows that there is a good agreement between experimental and numerical results within prescribed FEM formulation. It is observed that the increase in temperature and moisture concentration there is a decrease in critical buckling loads due to reduction of stiffness and strength.

Keywords: *Buckling, woven fiber, composite plates*

1 Introduction

Fiber reinforced composites are being increasingly used in the aerospace industry because of their properties, namely high specific strength, high specific stiffness and low specific density which reduce the overall operational cost. They are subjected to environmental conditions during their service life. In contrast to transverse loads, they often lose stability at fairly low stress level, when subjected to in-plane forces. So, the buckling behavior of laminated composite plates subjected to hygrothermal environments are of tremendous technical importance for understanding the behavior of laminated composite plates subjected to plane loads.

Plenty of studies are available on buckling behavior of composite plates under ambient temperature and moisture conditions. Tauchert [1] reviewed the previous works on buckling and post buckling characteristics associated with elevated temperatures of thin and moderately thick plates having various plan forms and support conditions through 1991. Whitney and Ashton [2] studied the thermal buckling of symmetrically laminated plates with simply supported edges using a generalized Duhamel-Newmann form of Hooke's law. Sai Ram and Sinha [3] investigated the effects of moisture and temperature on the buckling of laminated composite plates using finite element method. Noor and Burton [4] presented analytically the three-dimensional solutions for the free vibrations and buckling of thermally stressed multilayered angle-ply composite plates. Babu and Kant [5] proposed with a refined higher order finite element models for thermal buckling of laminated composite and sandwich plates. Shen [6] examined the influence of hygrothermal effects on the postbuckling of shear deformable laminated plates subjected to uniaxial compression using a micro-to-macro-mechanical analytical model of a laminate. Patel *et al*. [7] studied the static and dynamic characteristics of thick composite laminates exposed to hygrothermal environment using a higher-order finite element method. Jones [8] studied the thermal buckling of uniformly heated unidirectional and symmetric cross-ply laminated fiber-reinforced composites uniaxial in-plane restrained simply supported rectangular plates. Matsunaga [9] studied the free vibration and stability problems of angle-ply laminated composite and sandwich plates subjected to thermal loading using the method of power series expansion.

Most of the above studies deal with the buckling analysis of unidirectional composite plates in hygrothermal environments showing the subject is of current interest. Dash *et al.* [10] presented an experimental study on the effects of corrosion on elastic buckling and post buckling response of unidirectional E-glass/epoxy composite rectangular plates subjected to compressive load and liquid environment exposure. To the best of author's knowledge, no experimental work is reported on buckling analysis of woven fiber composite plates subjected to hygrothermal environments. The present study deals with the effects of aspect ratios, side to thickness ratios, geometry and lamination parameters on buckling analysis of industry driven woven fiber glass/epoxy composite plates subjected to uniform temperature and moisture experimentally and comparing them using finite element method.

2 Mathematical formulation

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An eight nodded isoparametric element is used for static stability analysis of woven fiber composite plates subjected to hygrothermal environment. Five degrees of freedom *u*, *v*, *w*, θ_x and θ_y are considered at each node. The stiffness matrix, geometric stiffness matrix due to residual stresses, geometric stiffness matrix due to applied in-plane loads and nodal load vector of the element are derived using the principle of minimum potential energy. The stiffness matrix, the initial stress stiffness matrix due to hygrothermal load, the geometric stiffness matrix and the load vectors of the element, are evaluated first by expressing the integrals in local natural co-ordinates and then performing numerical integration using Gaussian quadrature. Then the element matrices are assembled to obtain the respective global matrices. The solution involves determination of buckling loads from the eigenvaluesolutions of the equation of motion.

$$[K] + [K^r{}_G] - \lambda[K_G] = 0 \qquad (1)$$

where [K] , [K_G] and [$K^r{}_G$] are elastic stiffness, geometric stiffness due to applied in plane load and geometric stiffness due to hygrothermal conditions respectively. Λ is the buckling load obtained by eigenvalue solution of above equation.

3 Experimental Programme

Rectangular glass fiber: epoxy composite specimens were fabricated using weight fraction of 55:45 by hand layup method. Woven roving E-Glass fibers were used for testing. A plastic sheet i.e. a mould releasing sheet was kept on the plywood platform and a thin film of polyvinyl alcohol was applied as a releasing agent. Layers of reinforcement were placed on the mould at top of the gel coat and gel coat was applied again by brush. Any air which may be entrapped was removed using serrated steel rollers to minimize void contents in the samples. The process of hand lay-up was the continuation of the above process before the gel coat had fully hardened. The laminates were cured at normal temperature (25^{0}C and 55 % Relative Humidity) under a pressure of 0.2 Mpa for 3 days. After proper curing of laminates, the release film was detached. The specimens were cut for buckling testing by brick cutting machine into 235mm×235mm. The thickness of 16 layer laminate was measured as 6.0 mm. The specimens were hygrothermally conditioned in a humidity cabinet where the conditions were maintained at a temperature of 323K and relative humidity (RH) ranging from 0-1% for moisture concentrations. The humidity cabinet had an inbuilt thermometer for temperature and hygrometer for relative humidity measurements. The temperature variation was maintained between 300K-425K whereas the RH was 0 in temperature bath. The composite laminates were placed on perforated trays. The hygrothermal conditioning was carried out for every six hours in a total period of thirty six hours. The specimen was clamped at two sides and kept free at two other sides. The specimen was loaded in axial compression by using an INSTRON Universal testing machine. All specimens were loaded up to buckling. Clamped boundary conditions were simulated along top and bottom edges, restraining 2.5cm length. For axial loading, the test specimens were placed between the two extremely stiff machine heads, of which the lower one was fixed during the test; whereas the upper head was moved downwards by servo hydraulic cylinder. All plates were loaded at constant cross-head speed of 0.5mm/min. The load verses end shortening curve was plotted. The displacement is plotted along x-axis and the load was plotted on the y-axis. The load, which is the initial part of the curve deviated linearity, is taken as the critical buckling load in KN.

4 Results and discussion

The convergence study is carried out for non-dimensional critical load at a temperature of 325K and 0.1% moisture concentration for different mesh divisions and the details are omitted here for sake of brevity. As observed, a mesh of 10 ×10 shows good convergence of the numerical solution for the buckling analysis of woven fiber composite plates in hygrothermal environment and this mesh is employed throughout for buckling analysis of woven fiber composite plates in hygrothermal environment.

The present formulation is validated for buckling analysis of composite plates subjected to hygrothermal loadings and are compared with the numerical predictions by Sairam and Sinha [3] and Patel *et al.*[7]. As shown in table 1, there exist good comparison between the present analysis and the previous studies. Then the experimental results for critical buckling loads of laminated composite plates clamped-free-clamped-free (CFCF) boundary conditions are determined to study the effects of ply orientation, number of layers, aspect ratios and side to thickness ratios. The geometrical and non-mechanical properties are:

a=b=235mm, t= 6mm, Thermal coefficient α_1=-0.3 X $10^{-6}/^{O}$K, α_2 =28.1 X $10^{-6}/^{O}$K,

Moisture coefficient β_1=0, β_2=0.44

The results for buckling loads in KN of both the numerical analysis and experimental values with increase in temperature from 300K to 425K in every 25K rise in temperature and 0 to 1% in every 0.25% rise in moisture concentration of sixteen layered woven roving glass fiber/epoxy composites plates are presented for clamped-free-clamped-free boundary conditions.

Table 1. Comparison of buckling load of composite plates under hygrothermal loads with previous studies

References	Non-dimensional critical load λ	
	At 325K	At 0.1%
Sairam & Sinha[2]	0.4488	0.669
Patel, Ganapathi & Makhecha[5]	0.4466	0.6084
Present FEM	0.4481	0.6095

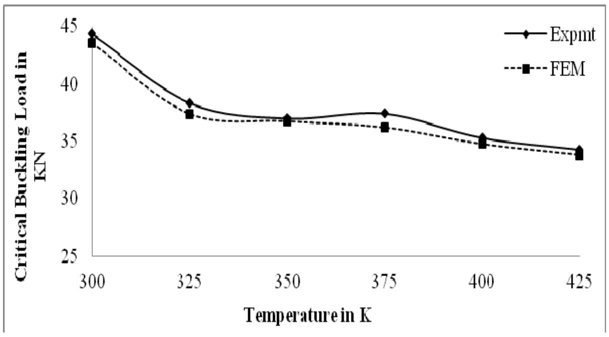

Fig.1 Variation of buckling load in KN with temperature of 16 layers $[0/90]_{4S}$ woven fiber composite plates (C-F-C-F).

Lamina material properties at elevated moisture concentrations and temperatures are used in the present analysis. The variation of buckling load with temperature is determined experimentally and using the present formulation and is shown in Figure 1. The results shows that there is a good agreement between experimental and numerical results within prescribed FEM formulation. It is observed that the increase in temperature there is decrease in critical buckling loads due to reduction of stiffness and strength. The effect of temperature generally causes a softening of the fibers and the effect of moisture causes plasticization due to absorbed moisture. The critical buckling load decreased severely with increase in temperature upto 425K and moisture concentration beyond 1%, in which hygrothermal buckling appears. In thermal buckling, the composite plate does not remain perfectly flat and suddenly develops a large deformation due to critical temperature stress. The variation of buckling load of woven fiber composite plates with moisture is shown in figure 2. This is due to the lowered glass transition temperature at increased moisture concentration. It is also seen that the hygroscopic condition on the stability of the plate becomes more significant in presence of the thermal loading.

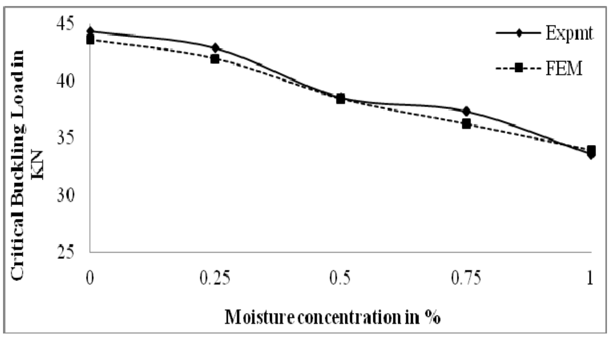

Fig.2. Variation of buckling load in KN with moisture concentration of 16 layers $[0/90]_{4S}$ woven fiber composite plates (C-F-C-F).

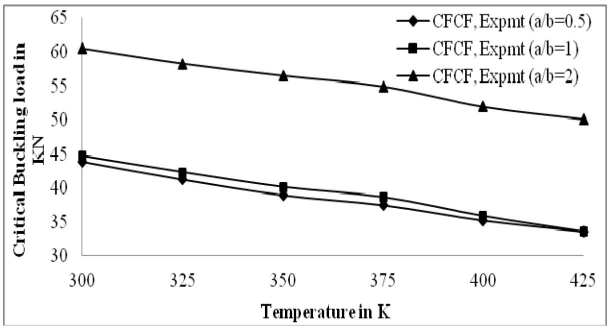

Fig.3. Variation of critical buckling load in KN with temperature of 16 layers $[0/90]_{4S}$ woven fiber laminated composite plates (C-F-C-F) boundary condition

The experimental results of critical buckling loads for different aspect ratios a/b=0.5, a/b=1 and a/b=2 for b/t=40, sixteen layered cross-ply symmetric woven fiber laminated composite plates for clamped-free-clamped-free boundary conditions are subjected to uniform distribution of temperature from 300Kto 425K in every rise in temperature of 25K and moisture concentration 0 to 1% in every rise of 0.25% moisture are presented in figure 3 and 4 respectively. From the results it is clear that the critical buckling loads are increase with increase in aspect ratios in hygrothermal environment. The reduction of critical buckling loads with increase in temperature and moisture concentration is linear. The reduction in critical buckling loads from increase in temperature from 300K to 425K, the experimental results for CFCF boundary conditions with aspect ratio for a/b=0.5 is 8.81%, a/b=1 is 11.04 and a/b=2 is 11.04% respectively. Similarly The reduction in critical buckling loads from increase in moisture from 0 to 1%, the experimental results for CFCF boundary conditions with aspect ratios for a/b=0.5 is 15.28%. a/b=1 is 19.7% and a/b=2 is 22.92% respectively. The reduction in critical buckling loads for higher aspect ratio is more than lower one in severe hygrothermal environment.

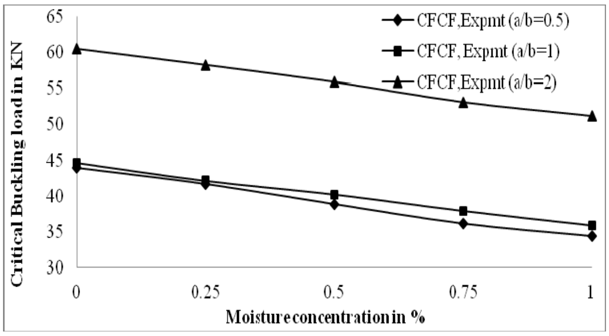

Fig.4. Variation of critical buckling load in KN with moisture concentration 16 layers $[0/90]_{4S}$ of woven fiber laminated composite plates (C-F-C-F) boundary condition

5 Conclusion

- A general buckling theory is formulated for industry driven woven fiber composite plates which accounts for hygrothermal effects due to moisture diffusion, temperature and mechanical loads in addition to transverse shear, deformation and bending-stretching coupling. There is good agreement between the experimental and numerical results for buckling of laminated composite plates at different temperature and moisture concentration. The critical buckling loads decreases with increase in temperature and moisture concentration due to reduction of stiffness and strength of laminated plates. The critical buckling loads reduce significantly depending upon the temperature, moisture concentration, lamination sequence, and aspect ratios. From the present studies, it is concluded that the buckling behavior of woven fiber laminated composite plates is greatly influenced by the geometry and lamination parameter. Such a property can be utilized to tailor the design of woven fiber composite plates in hygrothermal environment.

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6 References

[1] Tauchert, T. R , Thermally induced flexure, buckling, and vibration of plates. *ASME Appl. Mechanics Review,* Vol. 44, p. 347, 1991.

[2] Whitney , J. M. and Ashton, J. E, Effect of environment on the elastic response of layered composite plates, *AIAA Journal*, Vol. 9, p. 1708, 1971.

[3] Sai Ram, K.S. and Sinha, P.K. Hygrothermal effects on the buckling of laminated composite plates. *Computers Structures*, Vol. 21, p. 233, 1992.

[4] Noor, A. K., and Burton, W.S., Three-dimensional solutions for the free vibrations and buckling of thermally stressed multilayered angle-ply composite plates. *J. of Applied Mechanics,* Vol. 59 p. 868,1992.

[5] Babu C.S. and Kant, T. Refined higher order finite element models for thermal buckling of laminated Composite and sandwich plates. *J. of Thermal Stresses,* Vol. 23, p. 111, 2000.

[6] Shen-H-S, Hygrothermal effects on the postbuckling of shear deformable laminated plates, *International Journal of Mechanical Science*, Vol. 43, p. 1259, 2001.

[7] Patel, B.P. Ganapathi M. and Makhecha, D. P., Hygrothermal effects on the structural behavior of thick Composites using higher-order theory *Composite Structures,* Vol. 56, p. 25, 2002.

[8] Jones, R. M. Thermal buckling of uniformly heated unidirectional and symmetric cross-ply laminated fiber-reinforced composite uniaxial in-plane restrained simply supported rectangular plates, *Composites Part A*, Vol. 36, p. 1355, 2005.

[9] Matsunaga, H. Free vibration and stability of angle-ply laminated composite and sandwich plates under thermal Loading, *Composite Structures*, Vol. 77, p. 249, 2007.

[10] Dash, P.K., Sathisbabu, R. and Ganesan, C. , Effect of corrosive environment on elasto-buckling strength of GFRC Plate, *Asian. J of Material Science*, Vol. 3, p. 1, 2011.