Abstract

A finite element formulation based on layerwise plate theory using B-spline basis functions is used to study stability of delaminated composite plates subjected to static (mechanical and thermal) and dynamic (periodic and pulse) in-plane compressive loading. In the layerwise plate theory, the out-of-plane variation of in-plane displacement components are interpolated by linear Lagrange interpolation function and the in-plane variation of in-plane and out-of-plane displacement fields are interpolated by B-spline functions. Delamination between layers of composite plate is modeled by jump discontinuities in displacement fields using Heaviside functions. In the delaminated region, virtual springs are added to prevent interpenetration of lower and upper sublaminates. The nonlinear response of the plate is computed considering von Karman geometric nonlinearity. A rectangular delamination at different layer interfaces is considered in the present work.

The dynamic instability regions are computed by Bolotin's method. The influence of single and multiple delaminations and their positions at various layer interfaces on the buckling loads, mode shapes and dynamic instability regions of the composite plates with various plate boundary conditions are examined. Both uniform and non-uniform periodic edge loading in the form of concentrated and partial edge loading are considered. When the loading is non-uniform, prebuckling stresses are not known a priori and are evaluated by solving the plane elasticity/thermo-elasticity problem. Subsequently, using these stress distributions, the governing equations of the problem are written. The local buckling of thinner sublaminate is observed when delamination is placed near the top/bottom interface. The present numerical model can capture successfully global, local and combined global-local buckling mode shapes. Furthermore, the effect of Rayleigh damping on the dynamic instability regions of delaminated composite plate is explored. The nature of unstable and stable regions are studied by plotting displacement responses. From the linear and nonlinear responses in the stable and unstable regions, various response characteristics such as beats, its dependence on forcing frequency and damping are observed.

The proposed model is used to investigate the stability and first-ply failure of composite plates with single and multiple embedded delaminations at various layer interfaces and subjected to non-uniform/localized thermal heating over the plate surface with uniform temperature rise through its thickness. Four different types of temperature distributions (Full heating, partial rectangular heating, tent shape temperature distribution and dome shaped temperature distribution) are considered here. Buckling of plate due to both symmetric and unsymmetric locations of partial heating regions are studied. The localized thermal load at which the first-ply failure of the lamina occurs has been detected by Tsai-Wu quadratic interaction criterion. The effects of the area of heating region, delamination size and its position in the thickness direction and plate boundary condition on the composite plate critical buckling temperature and on first-ply failure load are reported.

The nonlinear dynamic pulse buckling of imperfect composite plate with embedded delamination is investigated numerically in the present work. The dynamic pulse buckling load is computed using Tsai-Wu quadratic interaction criterion. The effect of type of pulse loading i.e., sinusoidal, exponential and rectangular and plate boundary condition on the shock spectrum is explored. Response of delaminated plates is also computed for various delamination percentages at different layer interfaces. Sublaminates open up at the zone of delamination around peak displacement. Moreover, the same percentage of delamination at outer interface results in higher relative displacement of sublaminates compared to the delamination at inner interfaces. Dynamic load factor (DLF) is reported for different percentages of plate delaminations.

Finally, discrete cohesive zone model is implemented within the framework of B-spline layerwise finite element model to capture the propagation of delamination. At the delaminated interface discrete spring elements are considered in between the upper and lower sublaminates. The spring elements follow bilinear cohesive law. The accuracy and efficacy of the present model is tested on three standard test cases for mode I (Double cantilever beam test), mode II (End notch fracture test) and mixed mode I/II (Mixed mode bending test) delamination propagation. Subsequently, the evolution of delamination is studied in the postbuckling region for a laminated composite plate with through-the-width single and multiple delaminations and subjected to in-plane compressive loading.

Keywords: *B-spline, Layerwise finite element model, Delamination, Dynamic instability, Thermal stability, Pulse buckling, Discrete cohesive zone model*