

ABSTRACT

The aerospace industry is intensively involved in the development of advanced composites for aircraft structures to reduce weight and cost and to increase the lifetime and operational performance. The knowledge of the behaviour of the composite structures under static and dynamic loads along with environmental effects is vital for the design. In particular, laminated composite structures have extensively been used where the in-plane properties are more important. However, the laminated composites have relatively poor mechanical properties in the transverse direction and are prone to interlaminar delamination. In the aircraft wing skin-spar joint (T-joint), where the load transfer is out of plane, the web/skin interface is the critical zone for failure due to high transverse normal and shear stresses. Also the hygrothermal effects due to large transverse expansion coefficients may make the integrity of composite structures more critical and therefore need detailed studies.

The present investigation is aimed at developing the three-dimensional finite element analysis procedures using twenty noded isoparametric solid elements to study the static and dynamic response of thick laminated and multidirectional composites in hygrothermal environments. For handling of multilayered laminated composite problems in a three-dimensional domain, an efficient and economic three-dimensional super elements scheme formulated based on the theory of elasticity is implemented. A multidirectional composite element is developed to study the effect of fibre orientation on the static and dynamic behaviour of multidirectional composites. The three-dimensional super element concept along with the multidirectional composite model is further employed to analyse composite wing T-joints for studying the linear and geometrically nonlinear bending behaviour under combined mechanical (tension load) and hygrothermal loadings.

The finite element codes are accordingly developed in C language. The analysis accounts for the reduced material properties at elevated temperature and moisture concentration. For stitched laminates, the lamina properties are computed using the unit cell concept. The impregnated carbon fibres (T300/9310) have been used as stitch thread and the strength of a stitch is calculated based on the statistical bundle strength. Several failure criteria are applicable to composites, but in the present investigation the three-dimensional Tsai-Wu failure criterion, Quadratic Delamination Criterion (QDC),

interlaminar peel index (IPI) and interlaminar shear index (ISI) are used to identify the initiation of failure and mode of failure.

The linear and nonlinear bending problems are solved using Gaussian elimination and modified Newton-Raphson methods, respectively. The free and forced vibration equations are solved using inverse iteration and Newmark's constant average acceleration algorithm, respectively. The modified Hertzian contact law is used to compute the contact force between the target and impactor, when the structure is under impact.

Numerical results on the static and dynamic response of laminated composite plates subjected to uniform temperature and moisture concentration are generated for different structural parameters like aspect ratio, lamina orientation, number of layers, lamina sequence, support conditions, etc. Both linear and nonlinear finite element analysis procedures are employed to study the bending behaviour of laminated composites subjected to uniform temperature and moisture concentration. The results are also presented for the fundamental frequencies, transient response solutions and impact response of stitched and unstitched laminated composite plates in hygrothermal environments.

The bending, free vibration, forced vibration and impact response results are presented for different multidirectional composite models subjected to uniform temperature and moisture concentration. An attempt is made to compute critical indentation and critical impact velocity numerically for multidirectional composites using Tsai-Wu three-dimensional failure criterion and Quadratic Delamination Criterion (QDC).

Experimental and finite element analysis results are presented for the laminated composite wing T-joints under bone dry and hygrothermal conditions. A special climatic chamber is fabricated and instrumented to maintain hygrothermal conditions during testing. The test results are presented for the bending response and ultimate failure loads. The test results are compared with the linear and nonlinear finite element analysis results. Also the loads at the initiation of failure and the modes of failure for transversely stitched and unstitched joints are presented. Based on the critical discussion of analysis and experimental results, a set of conclusions are drawn and the scope for future research in this area is also identified.