ABSTRACT

This Thesis deals with three-dimensional non-linear Finite Element Analyses (FEA) of adhesion failure and delamination damages in four different types of adhesively bonded joints of laminated FRP composites. They are: Single Lap Joint (SLJ), Lap Shear Joint (LSJ), Double Lap Joint (DLJ) and Spar Wingskin Joint (SWJ). Different concepts of SWJ along with varying aspect ratios (ratio of spar base to height) with improved performance for integral structural construction of aircraft wings under out-of-plane loads have been studied. Comprehensive and relevant geometric and material parameters appropriate for damage analyses of different types of bonded joints have been considered in the present research. Layered solid and brick finite elements have been used for 3D modelling of the laminated FRP composite adherends and the epoxy adhesive layer, respectively, with appropriate orthotropic material characteristics. Sublaminate modelling techniques have been adopted for modelling of delaminations which have been presumed either to pre-exist or get evolved due to the coupled stress failure criteria in the laminated FRP composite adherends. Multi-point constraints have been used along the adhesion failure and the delamination damage fronts for maintaining the interface continuity. By sequential release of these constraints, self similar delamination progression has been realized. 3D Contact elements have been used inside the damaged region for preventing the interpenetration of damaged surfaces. The three individual components of Strain Energy Release Rate (SERR), G_I, G_{II} and G_{III} have been used as the defining parameters for assessing the adhesion failure and the delamination damage propagation behaviours. Modified Crack Closure Techniques (MCCI) based on the concepts of Linear Elastic Fracture Mechanics (LEFM) have been employed for computation of the SERR components.

Pertinent three-dimensional issues relating to stress states and damage onset and propagations have been dealt with in details. The distributions of out-of-plane stresses in the adhesive layer and the interfacial surfaces, the interlaminar stress distributions along the adhesion failure and the delamination damage fronts, and the SERR corresponding to the three individual modes have been evaluated for the SLJ, LSJ, DLJ and SWJ with laminated FRP composite adherends. Coupled stress failure criteria have been used to determine the locations of onset of the adhesion failure and the delamination induced damages. The critical locations for onset of the adhesion failure are found to be from the edges of stress singularity points in case of SLJ and DLJ. Delamination induced damages are found to occur near the overlap ends beneath the ply adjacent to the overlap region, and at the transition points where the spar changes its orientation from horizontal to inclined for LSJ and SWJ, respectively. The variations of the interlaminar stresses and the SERRs along the delamination fronts are found to be significantly different at the two ends of any such delamination indicating dissimilar rate of propagation of the delamination fronts. For a DLJ, it is seen that there is a significant difference in SERR values along the adhesion failure front and the delamination front. The trend of damage front propagation indicates, in general, that the straight delamination front may tend to propagate in non-self similar manner towards a curved delamination front. Suitable modified elliptical load coupler profiles have been developed from the stress and damage analyses of SWJ for improved performance. Associated recommendations have been made for arresting the delamination damages emanating from the toe ends of the spar of the SWJ.

Keywords: Adhesively bonded joints, Adhesion failure, Delamination damage, FRP composites, Interlaminar stresses, Sublaminate modelling, SERR, SWJ.