ABSTRACT

This Thesis deals with three-dimensional Finite Element (FE) based adhesion failure and delamination damage analyses of bonded Tubular Single Lap Joints (TSLJ) and Socket Joints (TSJ) made with laminated FRP composites and Functionally Graded Materials (FGMs). Layered solid finite elements have been used for 3D modelling of the laminated FRP composite adherends/sockets, whereas the FGM adherends/socket and the isotropic adhesive layer have been modelled using solid brick elements of ANSYS 10.0. Suitable APDL codes have been developed to assign Power law variations of the FGM material properties of the adherends/socket. Failure indices at different critical interfaces have been determined using Quadratic Failure Criterion (QFC) within the adhesive and Tsai-Wü coupled stress criterion for the adherend-adhesive and socket-adhesive interfaces. Strain Energy Release Rate (SERR) components, G_I, G_{II} and G_{III}, calculated using Modified Crack Closure Integral (MCCI) vis-à-vis Virtual Crack Closure Technique (VCCT) have been used as the characterizing parameters for assessing the growth of adhesion/delamination failures.

The (inner) adherend-adhesive interfaces of the bonded TSLJ and TSJ are found to be prone to initiation of adhesion failures which propagate in self-similar manner mainly in in-plane shearing mode. Fibre orientation of the plies of the laminated FRP composites is recommended to be along the direction of applied load to offer better resistance to the growth of adhesion failures. Boron-Epoxy laminated FRP composite is found to be the best as compared to Glass/Carbon/Graphite-Epoxy composites for lowest rate of growth of adhesion failures in the bonded TSLJ and TSJ under uniaxial tension.

Outer adherend of the bonded TSLJ has been seen to be more prone to delamination initiation as compared to the inner adherend. Delamination propagating from the outer adherend of the bonded TSLJ causes adhesion failure and delamination damages in the inner adherend-adhesive interface and first-ply interface of the inner adherend, respectively and vice versa. When both the adherends are delaminated, the adhesion failure and delamination damages are seen to initiate from the outer-adherend adhesive interface and the second ply-interface of the outer adherend, respectively. Both the delaminations propagate in self-similar manner and get accelerated in presence of each other. However, delamination in the outer adherend propagates at a faster rate as compared to the delamination in the inner adherend.

Both the adherends of the bonded TSJ are equally prone to delamination at the first ply-interface from the free edges. As the delaminations propagate, they cause adhesion failures and delamination at the adherend-adhesive interfaces and second ply-interface of both the adherends of the bonded TSJ, respectively. Both the delamination will propagate in self-similar manner mostly in the in-plane shearing mode with small and almost no influence of opening and tearing modes of failures.

Stress concentrations at the joint edges of the bonded functionally graded TSLJ/TSJ are increased/decreased, respectively with the increase in compositional gradient exponent (n) of the Power law variation description of the FGM. Hence, Power law gradation of material properties of the adherends/socket of bonded TSLJ/TSJ is recommended with lowest/highest possible values of "n", respectively for better performance of the joint structure. FGM adherends and socket are capable of providing improved resistance against adhesion failures as compared to the laminated FRP composites and hence, are recommended for the bonded TSLJ and TSJ.

Keywords: Adhesion failure, Delamination Damage, FRP composites, FGM, MCCI, QFC, SERR, TSJ, TSLJ, VCCT**.**