Damage tolerance criteria for composite laminates under tension and compression load

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Any composite aircraft structure exposed to impact has to be designed accounting for damage tolerance (DT). Impact damage has to be endured throughout the structure's service life. The damage tolerant design has to guarantee a load-sustaining capability above the limit load at any time. An exceptional challenge to the damage tolerant design of composites is the "multiplicity of failure modes" in a composite laminate [1]. Considerable effort is necessary to characterize the damage behavior and the respective residual properties through physical experiments or numerical high-fidelity methods. The common proceeding during the preliminary design phase is a fixed strain allowable that may not be exceeded.

To relax the existing single allowable and to open the design space allowing composite structures with arbitrary laminates, specific allowables for each laminate have to be determined. The methods presented in this work shall enable this specific calculation for the preliminary phase of the aircraft design. In this phase, efficient DT criteria building on elementary material parameters are required. To derive suitable calculation methods, the driving failure mechanisms of the damage evolution are identified for cyclic tension and compression loading, separately.

Under tensile loading, the mechanism driving the damage propagation results from an interaction of delamination and fiber fracture (cf. Fig. 1(a)). The corresponding mode II energy release rate (ERR) G_{IIx} at the delamination crack tip can be calculated through an elementary energy balance approach and the principle of maximum energy release. Under compression load, fiber kinking and delamination growth characterize the damage evolution of an impact damage. A sublaminate buckling criterion combined with a virtual crack extension method permits one to calculate the ERRs G_{Ix} and G_{Iy} in each propagation direction [2, 3] (cf. Fig. 1(b)). The results are validated through the data of cyclic tension after impact and compression after impact tests.

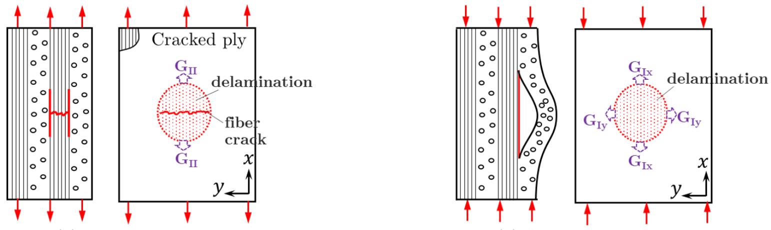

Fig. 1: Mechanisms driving the delamination evolution under tension (a) and compression (b).

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