Micromechanical vs lamina based failure theories

J. Anders Holmberg, Peter Lundmark, and David Mattsson

SICOMP AB, Box 271, SE-941 26 Piteå, Sweden

KEYWORDS: failure criteria, environmental load, thermal load, micro-scale.

ABSTRACT

Current design practice for composite structures relies on rather simple analysis procedures and failure criteria that are supplemented by extensive testing. To deduce material and design allowables testing is performed at the expected extremes of the service environment both at coupon and higher structural levels. Design guidelines that limit lay-up patterns and geometrical features are also employed to ensure that failure modes become fibre dominated and hence also possible to predict with reasonable accuracy.

To reduce the amount of testing and enabling more optimised designs than currently permitted, it is necessary to make use both of analysis procedures that accurately predict the actual material state at relevant micro structural scales and of a failure criteria that is using such information. Consider for instance thermal residual stresses. These develop at a lamina level (meso-scale) as a consequence of the mis-match in thermal expansion between the plies in a laminate. Thermal residual stresses do however also develop at the fibre-resin level (micro-scale) due to the mis-match in thermal expansion between the constituents. All failure theories in common use are applied on the lamina or laminate level and hence all of them also neglect the influence from micro-scale residual stresses. Accounting for the micro-scale residual stresses appears however to be important when failure is to be predicted for a wide variety of loads and environments based on a limited set of experimental data.

The rather newly developed failure theory, Strain Invariant Failure Theory (SIFT), is a fully 3D approach which includes a set of micromechanics based criteria that include the thermal residual strains also at the micro-scale. The critical effective properties of a lamina that control damage initiation are the effective volumetric and equivalent strains of the constituents, fibre and resin. The volumetric strain is the first invariant of the strain whereas the equivalent (or von Mises) strain is a function of the second invariant of the strain deviator tensor.

Within this work, SIFT is compared to the Tsai-Hill criterion, a traditional lamina based failure criteria. Failure envelopes for laminas and laminates with and without including the effect of thermal residual stresses are created and compared. Comparisons are also made with experimental data from selected cases of the World Wide Failure Exercise. Based on these results conclusions are made regarding the feasibility for using lamina and micro-scale based failure criteria for laminates subjected to environmental loads.