Failure of Notched Laminates under Out-of-Plane Bending

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ABSTRACT

The use of model predictions for composite materials in aircraft structures is important for potentially lowering development costs and increasing the design space. Of key interest is the ability to predict the onset and propagation of damaging modes. Current commercial finite element simulation software typically utilizes a fiber and matrix "apparent fracture" model for the tension and compression damage modes. It is known that existing damage models, while computationally advantageous, may not depict the actual material science. Further, it is of interest to determine if the use of linear elastic fracture mechanics in these damage models is always valid. Consequently, the determination and validation of an effective model for the damage modes based on the material science is imperative. A key element to this task is the existence of a test specimen that enables understanding of the material science and generation of model input properties. The work presented here focuses on identifying effective damage models for matrix compression and fiber tension, measuring the associated material properties where applicable, and determining the effects of using the new models versus the current models. Very little published research exists dealing with matrix compression damage. Daniels, Rawlings, and Parmigiani have presented a matrix-compression test specimen however it has been shown that it is only applicable when the ratio of matrix compressive-to-tensile strength is less than two. Experimental compact compression specimens exceeding two can exhibit matrix tension damage before the onset of matrix compression damage. To alleviate premature tensile failures, both finite element simulation and experimental testing of multiple varying through-thickness compact compression specimens was conducted. Evaluated geometries comprised of 90° plies and included either a machined taper along the through thickness and a step-wise layered profile. Use of these techniques produced preferentially stronger matrix tension features, thereby enabling the onset and propagation of matrix compression damage. Displacement controlled compression testing of the machined compact compression specimens produced damage initiation and propagation but machining of the taper generated substantial variability. Testing the layered specimens also resulted in damage initiation in a constant thickness region, followed by fairly stable propagation through this area, and finally some growth into the specimen's tapered thickness. Damage progression was slowed upon encountering a thickness change but continued until the specimen catastrophically failed when the matrix tensile limit was reached. Use of the varying through-thickness compact compression specimen was successful in permitting matrix compression damage to initiate and indicated the existence of a residual load carrying capabilities not commonly present in damage models. In addition to the matrix compression damage, fiber tension damage was also investigated. Unlike matrix compression damage, a significant amount of existing literature exists for fiber tension damage. This literature indicates that fracture mechanics testing can be applied to characterize the initiation and propagation of reinforcing fibers in composite materials. However, difficulties faced by early researchers in conducting unidirectional fiber tension tests led to the ensuing prevalence of [90/0] cross-ply layups for fiber tension fracture testing. Investigators accounted for the 90° interlaminar tensile failure energy by either considering it to be negligible or by making use of additional testing to determine its energetic contribution to the overall cross-ply fracture energy and subsequently subtract this value to arrive at a pure 0° fiber tensile fracture toughness. As such, it has been shown that fracture mechanics can be effectively employed to model fiber tension damage. Thus overall current "apparent fracture" damage models can be utilized well for fiber tension damage but require further modifications to represent the actual

material science occurring in matrix compression. Further efforts to include a residual load carry capability after matrix damage will aid in enhancing overall composite model predictions.