DAMAGE AS A PRESAGE TO COMPOSITE FAILURE

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Summary It is shown that the rate of damage accumulation in composite structures is a presage to ultimate failure. Damage is modeled using the mesoscale composite damage theory and an interfacial damage model. Damage accumulation in structural components and the interfaces between components is demonstrated for finite width, angle-ply coupons under tensile loading, and a stiffened composite panel under tension, compression, shear, internal pressure, thermal and combinations of these loads.

A fundamental question for the use of composite materials for primary structural components of new and emerging modern structures, such as the Boeing 787 and the Airbus 380 airplanes, is: what are the conditions that presage catastrophic failure? An efficient, cost-effective design can be accomplished only with the aid of a proven model that presages (i.e. gives a warning) ultimate failure. Without such a model, safety dictates that the structure be overdesigned. This paper presents a methodology for presaging ultimate failure of composite structures; the methodology is based upon the rate of accumulation of damage in, or between, individual components of the structure.

It is well known that fibrous composite materials, such as carbon/epoxy and glass/epoxy, accumulate damage in the form of local failures such as matrix cracking, fiber breakage, fiber kinking, fiber/matrix debonding and delamination prior to ultimate failure The proposed methodology analyzes the accumulation of local damage in individual components of the composite structure as predicted by the mesoscale composite damage model of Ladevèze [1], and the accumulation of interfacial damage between components as predicted by the interfacial damage model of Allix and Ladevèze [2]. Ultimate failure of the structure is then presaged through consideration of the rate of damage accumulation in individual structural components and interfaces between components [3].

For the mesoscale and interfacial damage models, the primary damage modes of interest are d_2, d_{12} *and* d corresponding to transverse tensile stress cracking, shear stress cracking, and delamination, respectively. These damage parameters are then incorporated into damage accumulation functions, $D_{x,C}$, defined for each damage mode, $x = d_i$, in each component, C. For N_C finite elements in a component, the accumulation function is:

$$D_{x,C} = \frac{1}{N_C} \sum_{j=1}^{N_C} d_x^j \qquad (1)$$

This theory was incorporated into an ABAQUS finite program for modeling composite structures. The approach is demonstrated through application to two types of structures: 1) finite width tensile coupons of angle-ply laminates, and 2) a stiffened composite panel. The stiffened composite panel was evaluated under a variety of loading conditions, including tension, compression, shear, thermal, internal pressure and combinations of the above. For the finite width coupons, it is shown that there is excellent correlation between the predictions of the model and experimental results. For the stiffened panel it is shown that the model predicts the expected behavior.

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Failure of finite width tensile coupons of angle-ply laminates is known to be a function of the fiber orientation and stacking sequence. In some cases failure is the result of interlaminar shear stresses and delamination near the free edge. Figure 1 shows the interfacial damage accumulation functions for several angle-ply laminates, and the development of this function along the edges of a $[\pm 10]_S$ laminate.

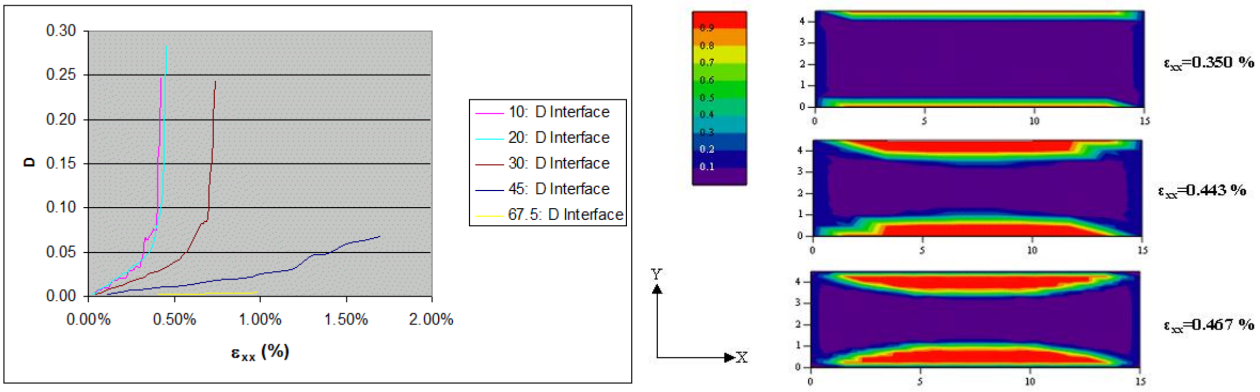

Figure 1 Interfacial Damage Accumulation in Angle-ply Laminates

Figure 2 shows a comparison between interfacial damage accumulations at the stiffener/flange interface for a stiffened composite panel. Clearly, tensile loading results in delamination at a much lower strain level and correspondingly lower strength.

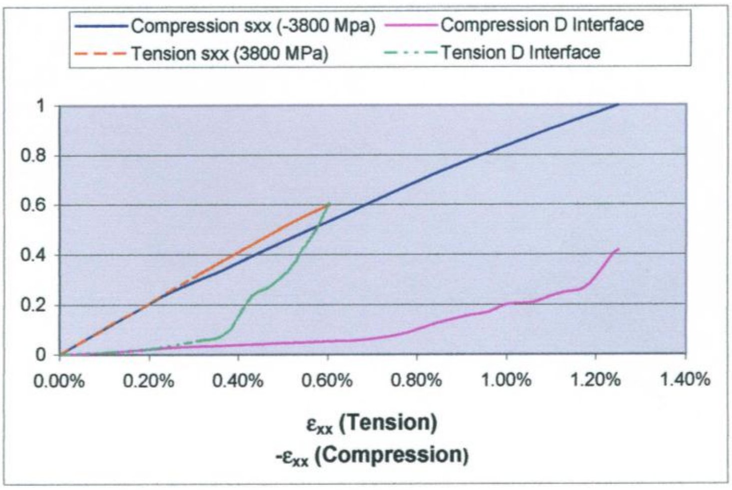

Figure 2 Comparison for Stiffened Panel in Tension and Compression

References

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