A MICROMECHANICAL SUB-MODELLING TECHNIQUE FOR IMPLEMENTING ONSET THEORY

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Summary. A multi-scale modeling approach is investigated for implementation of the onset theory proposed by Gosse, Christensen and Hart-Smith. Micromechanical submodels derived from a laminate shell or layered solid finite element model enable direct de-homogenized strain fields to be investigated without the need of strain enhancement factors. These strain fields allow for a prediction and visualization of the onset of damage within both fiber and matrix phases as well as type of deformation (dilatational or distortional).

1 INTRODUCTION

Recently, Gosse and Christensen [1] and Hart-Smith [2] have proposed a micromechanics failure theory for composites, called Strain Invariant Failure Theory (SIFT), or more recently the Onset Theory [3]. This failure theory is based on the use of critical strain invariants to predict the onset of damage. The onset theory is considered to be rigorous and have unique advantages over traditional failure theories in that it is suitable for all possible laminate lay-ups, geometric configurations, loading and boundary conditions. Implementation of the theory involves determining microscopic strains in the resin, in the fiber and at the fiber/resin interface of composite laminates.

Using the continuum models to obtain the critical values requires strain enhancement factors to determine strains in the resin and fibers which take time and effort. To overcome this issue a new micromechanics submodeling approach within the shell or layered solid continuum model has been proposed. The fiber and resin are modeled in a three-dimension sub-model. The boundaries of the model are subject to deflections recovered from a three-dimensional laminate analysis of the structure. Strains are obtained directly to implement the onset theory without needing to apply amplification factors.

2 METHODS

In the approach proposed by Pipes and Gosse [3] strains from a continuum model of the laminate are enhanced by micro-mechanical strain amplification factors to determine strains in the resin including thermal residual stresses from the cure. These amplification factors are determined from unit cell finite element models that assume an arrangement of fiber and resin. The square and hexagonal arrangements have been shown to give the greatest magnification factors and are assumed to exist somewhere in the random distribution of fibers in the laminate. The correct volume fraction for fiber and resin is preserved in the unit cell models. Strains determined for the laminate in a finite element analysis are first scaled by the magnification factors before the strain invariants are calculated and compared to the critical values to predict failure.

A new micromechanical submodeling approach is presented in this paper. Finite element analysis of composites at the micro level is implemented including fiber and resin. In the simplest approach sparse models with only a few fibers embedded in resin are used in the submodel to
mitigate meshing issues and the CPU runtime. In an extended approach the sub-model fiber diameters are reduced while the fiber volume fraction is maintained to achieve more fibers in the resin. This allows investigating the effects of varying the model fiber diameter with respect to the dilatational and distortional invariants. The diameters of the fiber are calculated such that the volume fraction of fibers is always maintained at 60% as indicated in the manufacture data sheet for the prepreg material for the specimens used in this study.

3 RESULTS AND DISCUSSION

In this paper this new sub-modeling approach will be compared to analysis using the continuum approach proposed by Pipes and Gosse [3] and the full micromechanical modeling approach proposed in [4]. These procedures will be applied to predict the invariants for a number of uni-directional off-axis specimens as shown in Fig. 1 as well as a complex 0/90/90/0 test specimen described in the WWFE [5] as shown in Fig. 2. The advantages of the micromechanical submodelling approach are that it allows direct dehomogenization of strain fields for implementing the onset theory with less computational effort. The capability of direct visualization of the dehomogenized strain fields to significantly enhance understanding is another advantage of the micromechanical submodelling approach in this paper. In addition a degradation algorithm has been applied to map damage progression. For the 0/90/90/0 specimen the algorithm will be used to identify the sequence of cracking in the specimen and final fiber failure in the 0 degree fibers.

Fig. 1. Critical modes of the onset theory from a set of off-axis specimens

Fig. 2. Micromechanical submodelling approach from a laminate shell global model

REFERENCES


