A COMPUTATIONAL TECHNIQUE FOR PREDICTING DELAMINATION GROWTH IN SOLIDS WITH VISCOELASTIC INTERFACES

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ABSTRACT
Debonding of ply interfaces in composites is modeled herein with a micromechanically based viscoelastic cohesive zone model that is embedded in an implicit nonlinear finite element code. The cohesive zone model can be characterized from simple debonding experiments for a variety of viscoelastic media. The finite element code is briefly described, especially the algorithm for integrating the cohesive zone model in time. Example problems are solved herein demonstrating both the numerical robustness and accuracy of the numerical technique, as well as its usefulness for a wide range of current applications.

1 INTRODUCTION
Layered media such as laminated composites often fail due to fracture or debonding of the interfacial region between the layers. Therefore, designing components that are failure resistant requires that accurate interface failure models be developed and included in the design algorithm. In many cases the fracture phenomenon demonstrates significant rate and history dependence, significantly complicating the construction of the fracture model. The author has over the last several years developed a computational technique for modeling the evolution of multiple delaminations in such media. This model utilizes a micromechanically constructed viscoelastic cohesive zone model that is incorporated into a finite element algorithm wherever interfaces occur in the medium, so that multiple delaminations can be modeled. A significant feature of the cohesive zone model is that, due to the fact that it is constructed from a micromechanics description, the viscoelastic properties of the fracture model may be obtained quite simply from laboratory experiments.

The cohesive zone model has been implemented into an in-house finite element code and this code has been used to model the response of a variety of heterogeneous viscoelastic media, including tank armor [Gazonas and Allen, 2003], geologic salt [Helms et al., 1999], plastic ballistic explosives [Seidel et al., 2004], and asphaltic pavement [Soares et al., 2003; DeSouza et al., 2004]. Briefly, the finite element code is a standard implicit algorithm that utilizes a time marching scheme, to capture the nonlinearity associated with debonding and/or crack propagation. The code is named SADISTIC (Structural Analysis of Damage Induced Stresses in Thermo-Inelastic Composites) [Allen et al., 1994]. The model and the resulting algorithm are described briefly in the next section.

2 MODEL DESCRIPTION
The model is constructed by considering a small representative volume element in the damaged zone ahead of a crack in a ductile viscoelastic medium. The solution of this microscale boundary value problem, and the subsequent homogenization results in the following traction-displacement relationship:

\[
T_i(t) = \frac{u_i(t)}{\delta_i} \left( 1 - \alpha(t) \right) \frac{\lambda(t)}{\lambda(t)} \left[ \int_0^t \tau_c(\tau) \frac{\partial \lambda}{\partial \tau} d\tau \right], \quad \text{(no sum over i)} \tag{1}
\]

where the subscript i denotes the component of the uniaxial volume averaged traction in the normal and two mutually perpendicular tangential directions allowing for fracture mode-mixity, and where

\[
\alpha(t) \equiv \frac{A - \sum_{k=1}^{n} A^k(t)}{A} \tag{2}
\]
and

\[
\lambda = \sqrt{\left(\frac{u_n}{\delta_n}\right)^2 + \left(\frac{u_t}{\delta_t}\right)^2 + \left(\frac{u_x}{\delta_x}\right)^2}.
\]  

(3)

The damage parameter, \(\alpha\), corresponds to the time-varying area fraction of the growing voids with respect to the cross-sectional area of the representative volume. Other parameters in the above description are as described in [Allen and Yoon, 1998; Yoon and Allen, 1999; Allen and Searcy, 2000; Allen and Searcy, 2001a; Allen and Searcy, 2001b].

The above model has been implemented to the nonlinear finite element code SADISTIC [Allen et al., 1994], and has been utilized to solve several problems involving viscoelastic crack growth. Details regarding this code can be found in [Foulk et al., 2000].

3 EXAMPLE PROBLEM

The results for a double cantilever beam with a single delamination growing between two plies in a viscoelastic medium is shown in Fig. 1. The beam has an initial delamination that is 2 in. in length, and is subjected to monotonically increasing tip load. As shown in Fig. 1, the methodology produces mesh insensitive crack growth. Fig. 2 shows the evolution of normal traction in the cohesive zone ahead of the crack tip, demonstrating that the crack growth is not self-similar.

Figure 1.: Predicted Crack Tip Advancement in a Double Cantilever Beam with Three Different Meshes
4 CONCLUSION

A model has been briefly described for predicting crack growth in a variety of viscoelastic media. This model has now been implemented to a finite element code, and several problems have been solved with it. The interested reader is referred to the references for further information regarding this computational model.

5 REFERENCES


