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 (**S**tructural **A**nalysis of **D**amage **I**nduced **S**tresses in **T**hermo-**I**nelastic **C**omposites) [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:

$$T_i(t) = \frac{u_i(t)}{\delta_i} \cdot \frac{\left(1-\alpha(t)\right)}{\lambda(t)} \cdot \left[\int_{t_0}^{t} E^c(t-\tau)\frac{\partial \lambda}{\partial \tau}d\tau\right], \text{(no sum over i)} \qquad (1)$$

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

$$\alpha(t) \equiv \frac{A - \sum_{k=1}^{n} A^k(t)}{A} \qquad (2)$$

and

$$\lambda = \sqrt{\left(\frac{u_n}{\delta_n}\right)^2 + \left(\frac{u_t}{\delta_t}\right)^2 + \left(\frac{u_s}{\delta_s}\right)^2} \, . \tag{3}$$

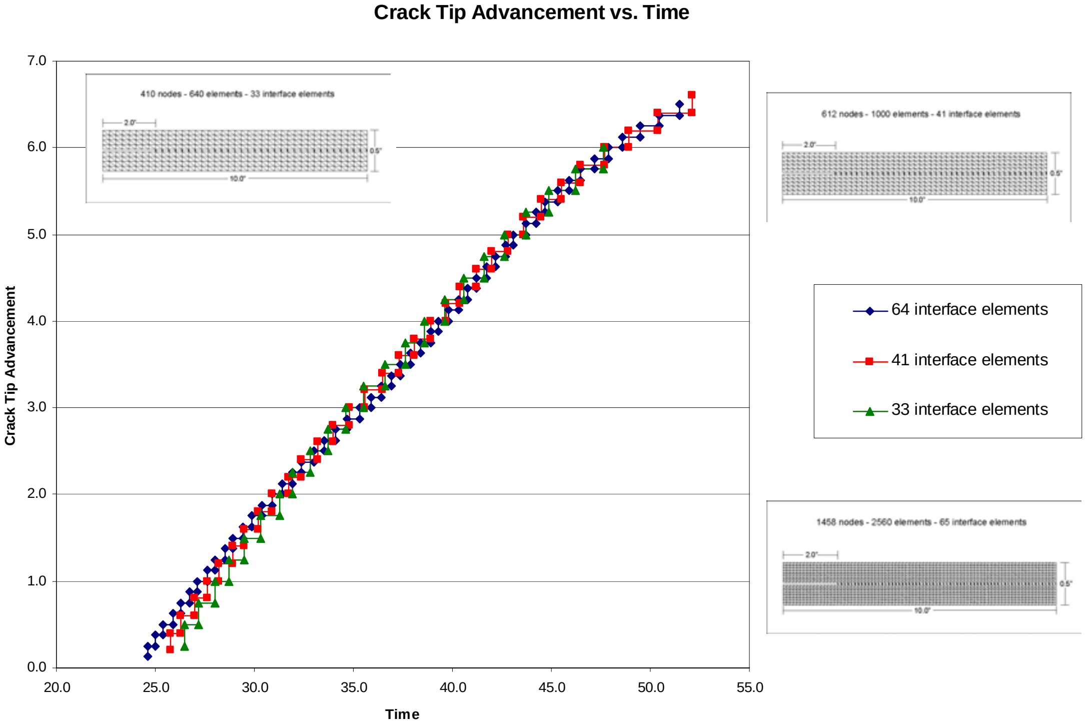
The damage parameter, α, corresponds to the time-varying area fraction of the growing voids with respect to the cross-sectional area of the representative volume. Other parameters in the above description are as described in [Allen and Yoon, 1998; Yoon and Allen, 1999; Allen and Searcy, 2000; Allen and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



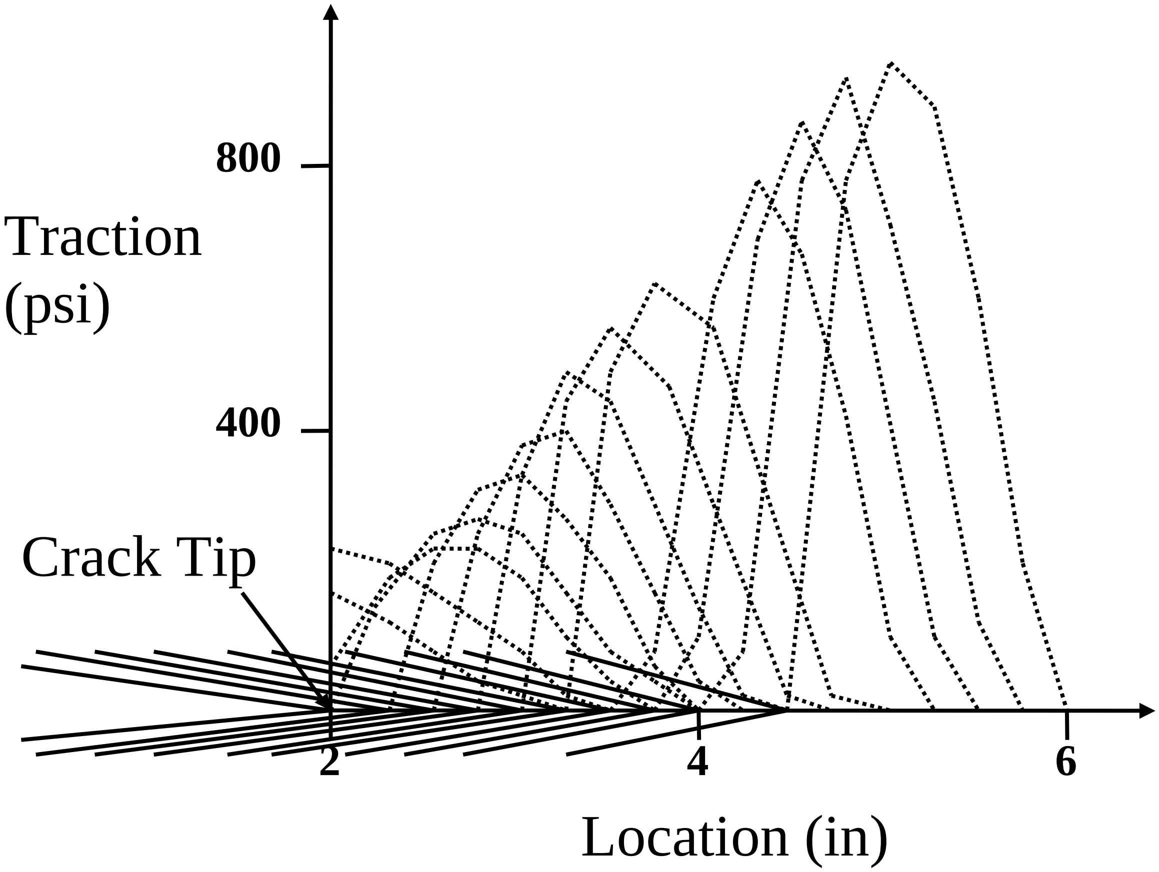


Figure 2.: Normal Tractions in Cohesive Zone Ahead of Advancing Crack Tip

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

Allen, D.H., Jones, R.H., and Boyd, J.G., "Micromechanical Analysis of a Continuous Fiber Metal Matrix Composite Including the Effects of Matrix Viscoplasticity and Evolving Damage," ***Journal of the Mechanics and Physics of Solids,*** Vol. 42, No. 3, pp. 505-529, 1994.

Allen, D.H., and Yoon, C., "Homogenization Techniques for Thermoviscoelastic Solids Containing Cracks," ***International Journal of Solids and Structures***, Vol. 35, pp. 4035-4054, 1998.

Allen, D.H., and Searcy, C.R., "Numerical Aspects of a Micromechanical Model of a Cohesive Zone," ***Journal of Reinforced Plastics and Composites,*** Vol. 19, No. 3, pp. 240-248, 2000.

Allen, D.H. and Searcy, C.R., "A Micromechanical Model for a Viscoelastic Cohesive Zone," ***International Journal of Fracture***, Vol. 107, pp. 159-176, 2001.

Allen, D.H.and Searcy, C.R., "A Micromechanically Based Model for Predicting Dynamic Damage Evolution in Ductile Polymers," ***Mechanics of Materials,*** Vol. 33, pp. 177-184, 2001.

De Souza, F.V., Soares, J.B., Allen, D.H., and Evangelista, F., "A Model for Predicting Damage Evolution in Heterogeneous Viscoelastic Asphaltic Mixtures," to appear in the ***Journal of the Transportation Research Board,*** 2004.

Foulk, J.W., Allen, D.H., and Helms, K.L.E., "Formulation of a Three Dimensional Cohesive Zone Model for Application to a Finite Element Algorithm," ***Computational Methods in Applied Mechanics and Engineering***, Vol. 183, pp. 51-66, 2000.

Gazonas, G.A. and Allen, D.H., "Stress Waves and Cohesive Failure in a Finite Strip Subjected to Transient Loading," Proc. 9th International Conference on Materials, Geneva, May, 2003.

Helms, K.L.E., Allen, D.H., and Hurtado, L.D., "A Model for Predicting Grain Boundary Cracking in Polycrystalline Viscoplastic Materials Including Scale Effects," ***International Journal of Fracture,*** Vol. 95, pp. 175-194, 1999.

Soares, J.B., Freitas, F.A.C., and Allen, D.H., "Considering Material Heterogeneity in Crack Modeling of Asphaltic Mixtures," ***Journal of the Transportation Research Board,*** No. 1832, Bituminous Paving Mixtures 2003, pp. 113-120, 2003.

Seidel, G.D., Allen, D.H., Groves, S.E. and Helms, K.L.E., "A Model for Predicting the Evolution of Damage in Viscoelastic Particle Reinforced Composites," to appear in ***Mechanics of Materials,*** 2004.

Yoon, C. and Allen, D.H., "Damage Dependent Constitutive Behavior and Energy Release Rate for a Cohesive Zone in a Thermoviscoelastic Solid" ***International Journal of Fracture***, Vol. 96, pp. 56-74, 1999.