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Linear Viscoelastic Fracture Mechanics: energetic theory, FE simulations and experiments

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Delayed fracture represents a crucial aspect in the design of components made of viscoelastic materials. In such materials, a crack may appear stable under a given load and start propagating only after a finite time, commonly referred to as the 'delay time'. This time is not an intrinsic material property, but depends on the entire loading history, the viscoelastic response, and the energy available at the crack tip. Its quantitative prediction is therefore essential for assessing the safety and reliability of polymers, elastomers, gels, and polymer-based composite materials.

In this work, we propose an energy-based theory for Mode I crack initiation in linear viscoelastic solids. The model, derived from the principle of virtual work, leads to a generalized Griffith criterion. In particular, the fracture energy release rate depends on the convolution between the time history of the stress intensity factor KI(t) and the creep function of the material. Crack initiation is therefore not determined by an instantaneous critical value of KI, but by the attainment of a time- and history-dependent energy threshold.

The formulation allows the direct prediction of the delay time for different loading conditions, including step loading, loading ramps, and power-law loading histories. In all cases, the theory captures the reduction of the delay time with increasing applied load and describes the influence of the loading rate on fracture initiation.

The theoretical predictions are verified through finite element simulations, in which viscoelastic fracture is modeled using a cohesive zone modeling (CZM) approach. The numerical results confirm the proposed criterion and show that the delay time is accurately predicted when the process zone, where cohesive mechanisms are concentrated, remains small compared with the characteristic lengths of the problem.

Finally, the theory is validated against experiments performed on pre-notched PTFE specimens. The viscoelastic response of the material is reconstructed from DMA measurements and incorporated into the theory through a Prony-series representation. The comparison shows that the theory accurately reproduces the experimentally measured delay times while maintaining predictive capability over a loading-time interval spanning approximately two orders of magnitude.

The results therefore demonstrate that the delay time can be quantitatively predicted exclusively from the viscoelastic characterization of the material and the applied loading history. In particular, unlike many approaches based on cohesive zone models or phenomenological energetic formulations, the present framework does not require the introduction of a characteristic process-zone length calibrated as a fitting parameter. This aspect represents a significant advancement with respect to traditional approaches in viscoelastic fracture mechanics.

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