
Unsteady crack propagation in viscoelastic solids

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Abstract

Crack propagation in rubbery-like materials is a fundamental topic in several engineering applications: rubber wear, pressure sensitive adhesives, windscreen wipers, tire friction, peeling of tapes, just to mention some examples. Significant scientific interest in this field is driven by the experimental observation that linear elastic fracture mechanics falls short in tackling the observed phenomena. Indeed, the fracture behavior of rubbery-like materials is governed by their intrinsic viscoelastic response, which entails a certain amount of energy dissipation occurring during crack propagation. As a result, given a remotely enforced loading condition (e.g., a certain applied stress or strain) a certain crack propagation speed is recovered once that the transient effects have faded out and steady-state conditions are reached. The steady crack velocity can be predicted by enforcing the overall energy equilibrium: the energy release rate must equate the variation of surface energy plus the internal dissipation occurring within the bulk per unit free surface created, as shown by de Gennes (1) and Persson (2). Many other existing studies are based on cohesive zone models, exploiting a detailed description of the failure zone, where local force equilibrium is enforced (3). However, most of the existing studies focus on the steady-state regime, and viscoelastic crack propagation in unsteady conditions is still poorly understood. Notably, if the steady-state assumption is relaxed, the calculation of the energy release rate might be much more complex, as recently shown in (4). Nonetheless, experimental observation clearly suggests that the viscoelastic response of rubbery-like materials might result in complex phenomena before steady-state conditions are reached. E.g., when a viscoelastic specimen, initially unloaded, is instantaneously subjected to a constant force, the fracture behavior is governed by the material's creep response involving its entire volume. Indeed, since the amount of elastic energy stored within the solid monotonically increases over time, crack propagation might occur after a certain delay time, once a sufficient amount of elastic energy is available. This phenomenon, usually referred to as delayed fracture, has been experimentally observed in fracture tests performed on viscoelastic materials (5,6). In this study, we perform a comprehensive analysis of crack propagation in linear viscoelastic materials under general unsteady conditions by exploiting a novel energy formulation. The proposed approach relies on the virtual work formalism: the variation of surface energy caused by virtual variations of the crack tip position must be balanced by the virtual work of internal stresses. This allows for correctly tackling the non-conservative nature of viscoelastic materials. Moving from the assumption of infinitely short-range adhesive forces and exploiting the Green's function approach, the overall time-history of crack propagation is predicted under general loading conditions. The proposed approach can predict the delayed fracture of viscoelastic materials and, specifically, provides a closed form relation between the delay time and the applied stress, which clearly indicates that this phenomenon is triggered by the creep response of the material. The overall time-history of the crack propagation is predicted and analyzed in

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detail, from the transient stage to the steady-state regime. Results are in solid agreement with experimental observations and previous studies.

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