Rate-dependency influence on limiting crack-tip speeds in dynamic phase-field

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Rate-dependent materials such as viscoelastic polymers are abundantly relevant in engineering and real-life applications. This rate (time) dependency is expected to affect their overall behaviour. Specifically, there's a relevant need for exploring their failure behaviour. Moreover, the phase-field approach to fracture has proven to be a powerful tool for the prediction of crack phenomena.

Within this context, this contribution explores three thermodynamically consistent phase-field formulation for rate-dependent fracture in viscoelastic materials. By means of a numerical study on a Uniform Displacement Strip Benchmark, the formulations and modelling assumptions are compared, and the corresponding limiting crack-tip speeds are discussed.

The first formulation [1] is characterised by the addition to the pseudo-energy functional of the phase-field problem (free energy and fracture dissipation) a contribution which is related to viscous dissipation. The viscous dissipation is assumed to promote fracture. It is based on experimental evidence that shows how the resistance to fracture of many rate-dependent materials decreases as the temperature increases - knowing that viscoelastic dissipation leads to a raise in the temperature of the material. In this formulation, we observe viscoelastic hardening in the wake of the crack.

The second model [2] is characterised by the introduction of a strain-rate dependent toughness g_c. It is based on experimental evidence that indicate a strong relationship between the rate of strains and the material's resistance against fracture. This results in a higher strength for faster loading, which directly translates to a higher toughness g_c. In this formulation, quasi-viscous stresses appear in the damaged region around the crack, and we observe viscoelastic-like hardening at the crack-tip.

Alternatively, in the same spirit, we suggest a damage-rate dependent toughness formulation. Naturally, the toughness g_c would be limited by means of the limited damage-rate (damage-delay-like effect) inherent to the phase-field model. Moreover, no hardening at the crack-tip should be observed.

The numerical study lead on a Uniform Displacement Strip Benchmark shows that the three formulations are indeed able to suppress fracture branching in dynamic fracture. The limiting crack-tip speeds are observed to slightly increase as the branching is suppressed. However, for stronger rate-dependent effects (increased viscosity or rate-dependency of the toughness), the mechanical energy dissipation increases; hence, the available energy to advance the crack decreases, which in its turn, suppresses the branching, but also slowers the crack-tip advancement.

Depending on the specific choice of parameters, our simulations show crack propagations at speeds that exceed the shear-wave speeds. Indeed, these high speeds are attributed to the viscoelastic and viscoelastic-like (strain-rate dependent g_c) stiffening at the crack-tip. This translates to faster running surface waves and enables supersonic wave-speeds; a never-seen-before result in phase-field simulations [3].

References

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