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## Rate-dependent toughness in soft materials via microscopic scratch testing

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### ABSTRACT

Although fracture processes are rate-sensitive in a wide variety of biological and engineering systems, such as protein materials and bulk metallic glasses, the exact contribution of the prescribed mechanical loading rate to the measured fracture resistance is not fully understood. In this study, we formulate a novel energy-based framework for crack propagation in nonlinear viscous solids, using microscopic scratch tests. The scratch test consists in pushing a tool across the surface of a weaker material at a given penetration depth, and is relevant to several fields of science and engineering ranging from quality control of thin films and coatings to fracture characterization of cementitious materials. A hybrid experimental and theoretical study on amorphous and semicrystalline polymers shows that the apparent fracture toughness increases with the prescribed scratching speed up to an asymptotic value that is independent on the prescribed loading rate. Nonlinear viscoelastic fracture mechanics reveals that, because of the bulk viscous dissipation, the crack propagation processes can be inhibited or delayed, resulting in a coupling between the intrinsic fracture energy and the material viscoelastic properties. Moreover, by combining indentation and scratch tests to decouple creep and fracture, it becomes possible to represent with a single master curve the evolution of the apparent fracture toughness for three loading rates, 0, 45, and 90 N/min, and for scratching speeds ranging from 0 to 20 mm/min. Overall, by considering a dual dissipation mode, viscous and fracture dissipation, we can capture the scaling of the scratch forces over a wide range of loading rates and scratching speeds in order to assess the intrinsic rate-independent and geometry independent fracture toughness of the tested material. Given the scalability of scratch tests, this new development opens new venues for the characterization of the fracture toughness of soft materials at the microscopic scale.