Statistical mechanics of fracture phenomena and brittle-to-ductile transitions

Andrea Cannizzo[1,2], Giuseppe Florio[3,4], Giuseppe Puglisi[3], Stefano Giordano[1]

[1] Univ. Lille, CNRS, Centrale Lille, Univ. Polytechnique Hauts-de-France, UMR 8520 - IEMN - Institut d'Electronique de Microelectronique et de Nanotechnologie, F-59000 Lille, France
[2] Politecnico di Bari, (DMMM) Dipartimento di Meccanica, Matematica e Management, Via Re David 200, I-70125 Bari, Italy
[3] Politecnico di Bari, (DICATECh) Dipartimento di Ing. Civile, Ambientale, del Territorio, Edile e di Chimica, Via Re David 200, I-70126 Bari, Italy
[4] INFN, Sezione di Bari, I-70126, Italy
`andrea.cannizzo@iemn.fr`

The fracture behavior of brittle and ductile materials can be strongly influenced by thermal fluctuations, especially in micro- and nano-devices as well as in rubberlike and biological materials. However, temperature effects, in particular on the brittle thermo-activated fracture and on the brittle-to-ductile transition, still require a deeper theoretical investigation. As a step in this direction we propose a theory, based on equilibrium statistical mechanics, able to describe the temperature dependent brittle fracture and brittle-to-ductile transition in prototypical discrete systems consisting in a lattice with breakable non-linear elements. Concerning the brittle behavior, we obtain closed form expressions for the temperature-dependent fracture stress and strain, representing a generalized Griffith criterion [1], ultimately describing the fracture as a genuine phase transition. With regard to the brittle-to-ductile transition [2,3,4], we obtain a complex critical *scenario* characterized by a threshold temperature between the two fracture regimes, an upper and a lower yield strength, and a critical temperature corresponding to the complete breakdown. The proposed fracture models are implemented by means of the spin variable approach, useful to deal with arbitrarily non-convex potential energies [5]. This method has been largely applied to several situations including the physics of muscles [6], the folding of macromolecules [7,8,9], the adhesion or peeling processes [10,11], and the phase transformations in solids [12]. In the context of fracture, it allows to distinguish between the intact, softened and broken states of the discrete elements and therefore to directly follow the propagation of cracks in given materials and structures.

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