Fracture in microstructured materials: continuum and discrete approach

A. Piccolroaz[1]

[1]Institute of Mathematical and Physical Sciences, Aberystwyth University, Wales, U.K.

In view of the discontinuous nature of many engineering materials, it is well known that the classical theory of elasticity is not adequate to accurately describe the stress and displacement fields at small scales (Morozov, 1984). The discrepancy between the classical theoretical predictions and experimental results is found more pronounced for materials with a coarse-grain structure (Fleck et al., 1994). The mechanical behaviour of most materials with microstructure, like composites, cellular materials, foams, masonry, bone tissues, glassy and semicrystalline polymers, is strongly influenced by the microstructural characteristic lengths, especially in the presence of large stress (or strain) gradients (Lakes, 1986; Lakes, 1995). These findings stimulated the development of generalized theories of continuum mechanics such as micropolar elasticity (Cosserat, 1909), indeterminate couple stress elasticity (Koiter, 1964) and more recently strain gradient theories (Fleck & Hutchinson, 2001; Aifantis, 2011).

Because of the characteristic lengths coming into play, the generalized theories predict dispersive wave propagation in microstructured media (Nowacki, 1985). Also the generalized theories predict different asymptotic behaviour for some components of the deformation and stress fields near singular points, compared to the classical elasticity theory (Morozov, 1984). However, as already pointed out by Zhang et al. (1998) and Radi (2008) for the static case, a simple asymptotic characterization of the crack tip fields is not sufficient to analyse the fracture behaviour of materials with microstructure. This is due to the fact that the asymptotic solution is valid in a region close to the crack tip which is smaller than the characteristic lengths of the material, and thus it is of scarce physical relevance. A full field analysis is then required in order to grasp the qualitative and quantitative behaviour of the solution in a larger region and to be able to judge on the stress level supported by the material.

We analyse the steady-state propagation of an antiplane crack in couple stress elastic materials with finite characteristic lengths in bending and torsion. The static analysis is extended to the case of steady-state propagation in order to study the effects of inertia and crack-tip speed on the stress and deformation fields, as well as the variation of the fracture toughness due to the presence of microstructure. The stability of antiplane crack propagation is also discussed by using the fracture criterion based on the maximum shear stress hypothesis (Radi, 2008; Piccolroaz et al. 2012).

On the other hand, at scale even smaller than the microstructural size the continuum approach fails to describe the mechanism of dissipation associated with the fracture propagation, and in particular the properties of waves generated by the crack (Slepyan, 2000). These phenomena can be described by a discrete approach and linked to lattice models of structured media.